Taneeka Hansen

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To: House Health and Social Services
Subject: HB328 Opposing Documents-Clear Stream Air Project 09-01-2012
Attachments: HB304 Opposing Documents-Clear Stream Air Project 09-01-2012.pdf; ATT00001.txt

My name is Angela Carroll and I live in Wasilla. I represent Alaskas chapter of the Smoke Free Alternative Trade Association.

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Statement from specialists in nicotine science and public health policy

Dr Margaret Chan
Director General
World Health Organisation
Geneva

CC: FCTC Secretariat, Parties to the FCTC, WHO Regional Offices

26 May 2014

Dear Dr Chan

Reducing the toll of death and disease from tobacco – tobacco harm reduction and the Framework Convention on Tobacco Control (FCTC)

We are writing in advance of important negotiations on tobacco policy later in the year at the FCTC Sixth Conference of the Parties. The work of WHO and the FCTC remains vital in reducing the intolerable toll of cancer, cardiovascular disease and respiratory illnesses caused by tobacco use. As WHO has stated, up to one billion preventable tobacco-related premature deaths are possible in the 21st Century. Such a toll of death, disease and misery demands that we are relentless in our search for all possible practical, ethical and lawful ways to reduce this burden.

It is with concern therefore that a critical strategy appears to have been overlooked or even purposefully marginalised in preparations for FCTC COP-6. We refer to 'tobacco harm reduction' - the idea that the 1.3 billion people who currently smoke could do much less harm to their health if they consumed nicotine in low-risk, non-combustible form.

We have known for years that people 'smoke for the nicotine, but die from the smoke': the vast majority of the death and disease attributable to tobacco arises from inhalation of tar particles and toxic gases drawn into the lungs. There are now rapid developments in nicotine-based products that can effectively substitute for cigarettes but with very low risks. These include for example, e-cigarettes and other vapour products, low-nitrosamine smokeless tobacco such as snus, and other low-risk non-combustible nicotine or tobacco products that may become viable alternatives to smoking in the future. Taken together, these tobacco harm reduction products could play a significant role in meeting the 2025 UN non-communicable disease (NCD) objectives by driving down smoking prevalence and cigarette consumption. Indeed, it is hard to imagine major reductions in tobacco-related NCDs without the contribution of tobacco harm reduction. Even though most of us would prefer people to quit smoking and using nicotine altogether, experience suggests that many smokers cannot or choose not to give up nicotine and will continue to smoke if there is no safer alternative available that is acceptable to them.

We respectfully suggest that the following principles should underpin the public health approach to tobacco harm reduction, with global leadership from WHO:

1. *Tobacco harm reduction is part of the solution, not part of the problem.* It could make a significant contribution to reducing the global burden of non-communicable diseases caused by smoking, and do so much faster than conventional strategies. If regulators treat low-risk nicotine products as traditional tobacco products and seek to reduce their use without recognising their potential as low-risk alternatives to smoking, they are improperly defining them as part of the problem.

2. *Tobacco harm reduction policies should be evidence-based and proportionate to risk, and give due weight to the significant reductions in risk that are achieved when a smoker switches to a low risk nicotine product*. Regulation should be proportionate and balanced to exploit the considerable health opportunities, while managing residual risks. The architecture of the FCTC is not currently well suited to this purpose.

3. *On a precautionary basis, regulators should avoid support for measures that could have the perverse effect of prolonging cigarette consumption.* Policies that are excessively restrictive or burdensome on lower risk products can have the unintended consequence of protecting cigarettes from competition from less hazardous alternatives, and cause harm as a result. Every policy related to low risk, non-combustible nicotine products should be assessed for this risk.

4. *Targets and indicators for reduction of tobacco consumption should be aligned with the ultimate goal of reducing disease and premature death, not nicotine use* per se*, and therefore focus primarily on reducing smoking*. In designing targets for the non-communicable disease (NCD) framework or emerging Sustainable Development Goals it would be counterproductive and potentially harmful to include reduction of low-risk nicotine products, such as e-cigarettes, *within these targets*: instead these products should have an important role in *meeting the targets*.

5. *Tobacco harm reduction is strongly consistent with good public health policy and practice and it would be unethical and harmful to inhibit the option to switch to tobacco harm reduction products*. As the WHO's Ottawa Charter states: "*Health promotion is the process of enabling people to increase control over, and to improve, their health"*. Tobacco harm reduction allows people to control the risk associated with taking nicotine and to reduce it down to very low or negligible levels.

6. *It is counterproductive to ban the advertising of e-cigarettes and other low risk alternatives to smoking*. The case for banning tobacco advertising rests on the great harm that smoking causes, but no such argument applies to e-cigarettes, for example, which are far more likely to reduce harm by reducing smoking. Controls on advertising to non-smokers, and particularly to young people are certainly justified, but a total ban would have many negative effects, including protection of the cigarette market and implicit support for tobacco companies. It is possible to target advertising at existing smokers where the benefits are potentially huge and the risks minimal. It is inappropriate to apply Article 13 of the FCTC (Tobacco advertising, promotion and sponsorship) to these products.

7. *It is inappropriate to apply legislation designed to protect bystanders or workers from tobacco smoke to vapour products.* There is no evidence at present of material risk to health from vapour emitted from e-cigarettes. Decisions on whether it is permitted or banned in a particular space should rest with the owners or operators of public spaces, who can take a wide range of factors into account. Article 8 of the FCTC (Protection from exposure to tobacco smoke) should not be applied to these products at this time.
8. *The tax regime for nicotine products should reflect risk and be organised to create incentives for users to switch from smoking to low risk harm reduction products.* Excessive taxation of low risk products relative to combustible tobacco deters smokers from switching and will cause more smoking and harm than there otherwise would be.
9. *WHO and national governments should take a dispassionate view of scientific arguments, and not accept or promote flawed media or activist misinterpretations of data*. For example, much has been made of 'gateway effects', in which use of low-risk products would, it is claimed, lead to use of high-risk smoked products. We are unaware of any credible evidence that supports this conjecture. Indeed, similar arguments have been made about the use of smokeless tobacco in Scandinavia but the evidence is now clear that this product has made a significant contribution to reducing both smoking rates and tobacco-related disease, particularly among males.
10. *WHO and parties to the FCTC need credible objective scientific and policy assessments with an international perspective.* The WHO Study Group on Tobacco Product Regulation (TobReg) produced a series of high quality expert reports between 2005 and 2010. This committee should be constituted with world-class experts and tasked to provide further high-grade independent advice to the WHO and Parties on the issues raised above.

The potential for tobacco harm reduction products to reduce the burden of smoking related disease is very large, and these products could be among the most significant health innovations of the 21st Century – perhaps saving hundreds of millions of lives. The urge to control and suppress them as tobacco products should be resisted and instead regulation that is fit for purpose and designed to realise the potential should be championed by WHO. We are deeply concerned that the classification of these products as tobacco and their inclusion in the FCTC will do more harm than good, and obstruct efforts to meet the targets to reduce non-communicable disease we are all committed to. We hope that under your leadership, the WHO and FCTC will be in the vanguard of science-based, effective and ethical tobacco policy, embracing tobacco harm reduction.

We would be grateful for your considered reaction to these proposals, and we would like to request a meeting with you and relevant staff and a small delegation of signatories to this letter. This statement and any related information will be available on the Nicotine Science and Policy web site (http://nicotinepolicy.net) from 29 May 2014.

Yours sincerely,

Signatories this statement at 26 May 2014

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Public Health England

Protecting and improving the nation's health

E-cigarettes: a new foundation for evidence-based policy and practice

Introduction

Smoking rates in England are in long-term decline. However, tobacco use remains one of the country's major public health challenges with the harm increasingly concentrated in more disadvantaged communities. Over recent years, e-cigarettes have risen in popularity to become the number one quitting aid used by smokers.[1] This consumer-led phenomenon has attracted considerable controversy within public health and beyond, with the unfortunate consequence of confusion among the general public about the relative risks of nicotine, e-cigarettes and smoked tobacco.

Public Health England (PHE) has a key role in mobilising the evidence base to protect public health and reduce inequalities. Our response to the uncertainty and controversy associated with e-cigarettes has been to establish a sound evidence base. In our first year we commissioned independent evidence reviews from leading UK researchers Professor John Britton[2] and Professor Linda Bauld.[3] These were published in May 2014 to coincide with our national symposium on e-cigarettes and tobacco harm reduction.

Together with Cancer Research UK we have set up the UK Electronic Cigarette Research Forum to discuss new and emerging research, develop knowledge and understanding, enhance collaboration among researchers interested in this topic, and inform policy and practice.

This latest comprehensive review of the up-to-date evidence on e-cigarettes, commissioned from Professor Ann McNeill and Professor Peter Hajek, synthesises what is now a substantial international peer-reviewed evidence base on e-cigarettes. It provides a firm foundation for policy development and public health practice in the context of new regulations for e-cigarettes to be introduced in the UK from May 2016 under the revised EU Tobacco Products Directive (currently under consultation).

Main findings of the evidence review

The report details the steady increase in the use of e-cigarettes in England over recent years (fig 1). This increase has taken place in the context of continued long-term declines in smoking prevalence among adults (fig 2) and youth (fig 3).

Figure 1

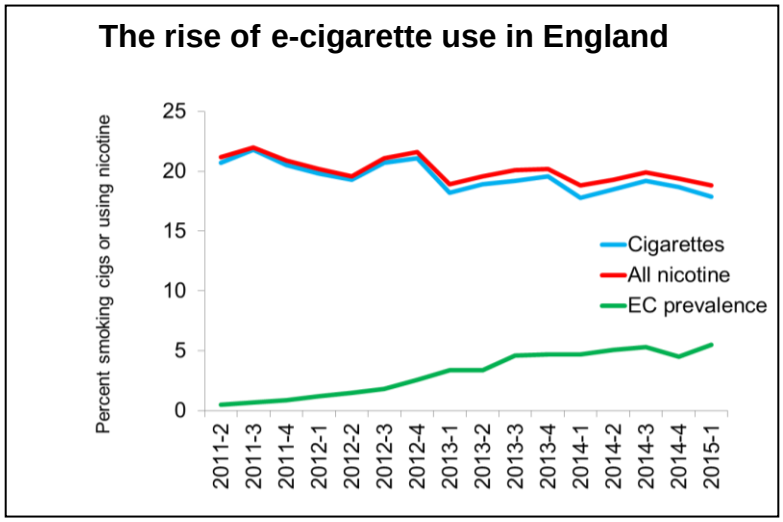


Figure 2

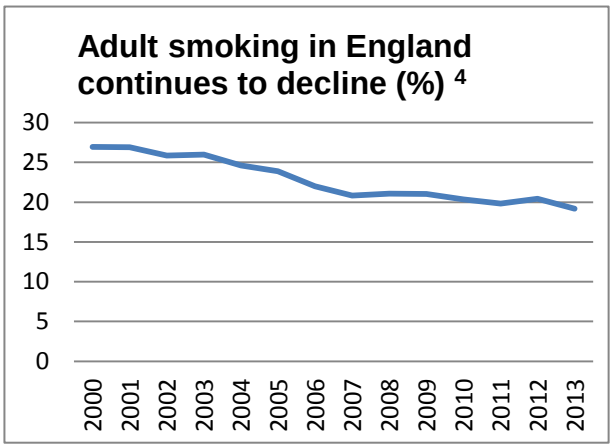
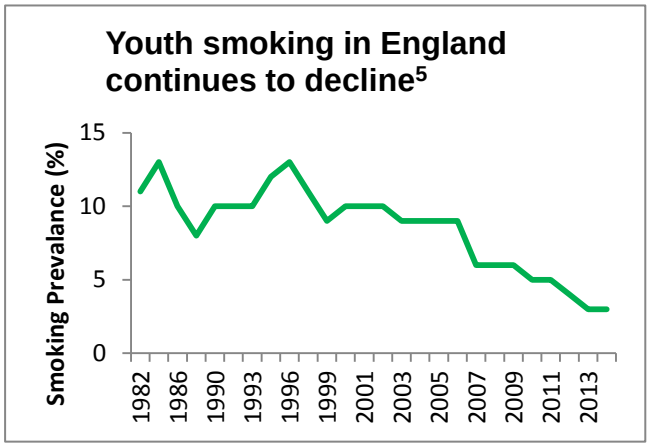


Figure 3



The authors find that among adults and youth, regular use of e-cigarettes is found almost exclusively among those who have already smoked. The highest rates of e-cigarette use are found among adult smokers. E-cigarettes have rapidly become the most widely used quitting aid in England (fig 4).

Figure 4

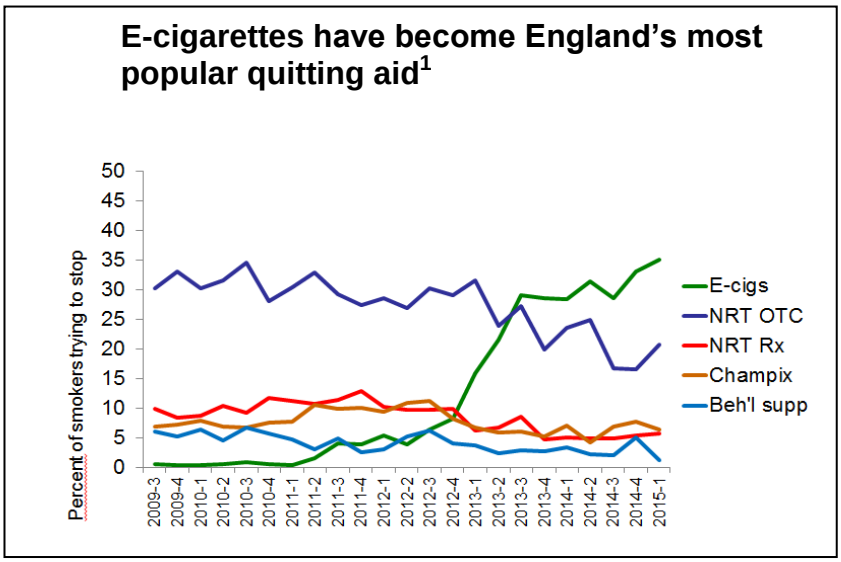
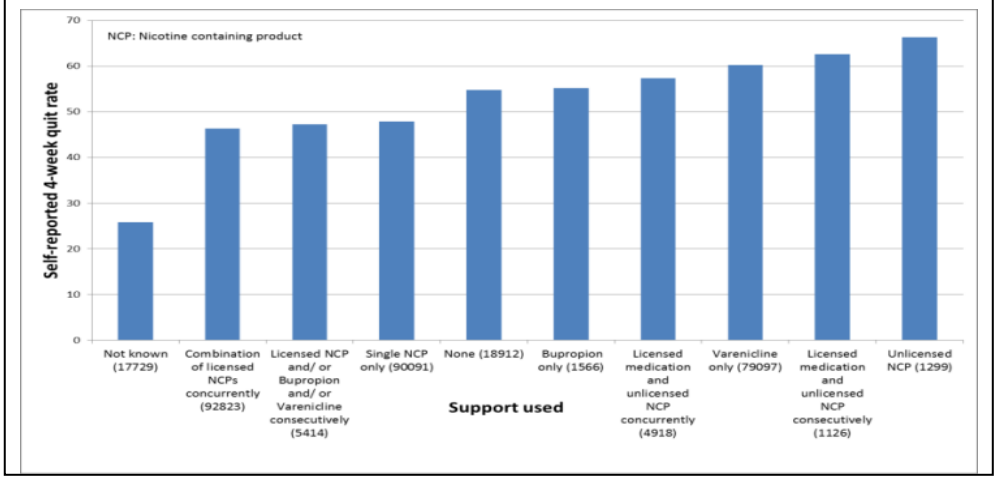


Figure 5

Smokers using EC with expert support to quit enjoy high levels of success[6]

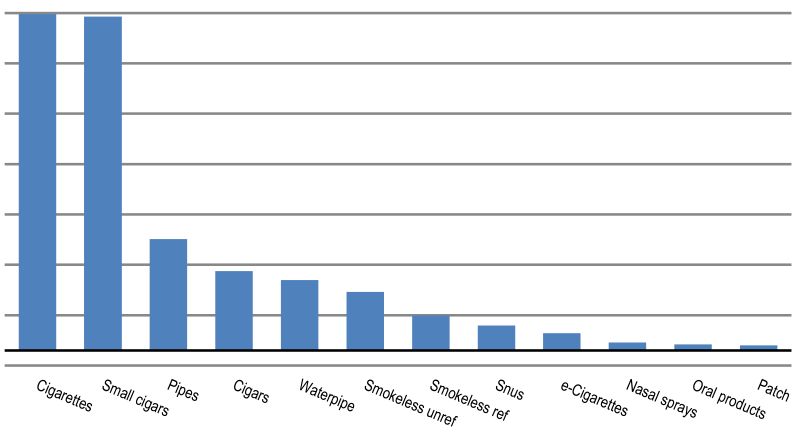


Recent studies support the Cochrane Review[7] findings that e-cigarettes can be effective in helping people to quit smoking. In local stop smoking services across England the relatively small number of smokers who have combined e-cigarettes with expert support have had high rates of success (fig 5).

Under the current regulatory system individual e-cigarette products vary considerably in quality and specification. We also do not yet have data on their long-term safety. However, the current best estimate by experts is that e-cigarette use represents only a fraction of the risk of smoking (fig 6).

Figure 6

Experts estimate e-cigarettes carry a fraction of the risk of smoking[7]



Safety and the perception of risks

It is important that the public be provided with balanced information on the risks of e-cigarettes, so that smokers understand the potential benefits of switching and so non-smokers understand the risks that taking up e-cigarettes might entail:

- when used as intended, e-cigarettes pose no risk of nicotine poisoning to users, but e-liquids should be in 'childproof' packaging. The accuracy of nicotine content labelling currently raises no major concerns
- the conclusion of Professor John Britton's 2014 review for PHE, that while vaping may not be 100% safe, most of the chemicals causing smoking-related disease are absent and the chemicals present pose limited danger, remains valid. The current best estimate is that e-cigarette use is around 95% less harmful to health than smoking
- e-cigarettes release negligible levels of nicotine into ambient air with no identified health risks to bystanders
- over the last year, there has been an overall shift among adults and youth towards the inaccurate perception of e-cigarettes as at least as harmful as cigarettes

Implications of the evidence for policy and practice

Based on the findings of the evidence review PHE also advises that:

- e-cigarettes have the potential to help smokers quit smoking, and the evidence indicates they carry a fraction of the risk of smoking cigarettes but are not risk free
- e-cigarettes potentially offer a wide reach, low-cost intervention to reduce smoking in more deprived groups in society where smoking is elevated, and we want to see this potential fully realised
- there is an opportunity for e-cigarettes to help tackle the high smoking rates among people with mental health problems, particularly in the context of creating smokefree mental health units
- the potential of e-cigarettes to help improve public health depends on the extent to which they can act as a route out of smoking for the country's eight million tobacco users, without providing a route into smoking for children and non-smokers. Appropriate and proportionate regulation is essential if this goal is to be achieved

- local stop smoking services provide smokers with the best chance of quitting successfully and we want to see them engaging actively with smokers who want to quit with the help of e-cigarettes
- we want to see all health and social care professionals providing accurate advice on the relative risks of smoking and e-cigarette use, and providing effective referral routes into stop smoking services
- the best thing smokers can do for their health is to quit smoking completely and to quit for good. PHE is committed to ensure that smokers have a range of evidence-based, effective tools to help them to quit. We encourage smokers who want to use e-cigarettes as an aid to quit smoking to seek the support of local stop smoking services
- given the potential benefits as quitting aids, PHE looks forward to the arrival on the market of a choice of medicinally regulated products that can be made available to smokers by the NHS on prescription. This will provide assurance on the safety, quality and effectiveness to consumers who want to use these products as quitting aids
- the latest evidence will be considered in the development of the next Tobacco Control Plan for England with a view to maximising the potential of e-cigarettes as a route out of smoking and minimising the risk of their acting as a route into smoking

Next steps for PHE

PHE's ambition is to secure a tobacco-free generation by 2025. Based on the evidence, we believe e-cigarettes have the potential to make a significant contribution to the endgame for tobacco. With opportunity comes risk, and a successful approach will be one that retains vigilance and manages these risks, while enabling a flourishing and innovative market with a range of safe and effective products that smokers want to use to help them quit.

From October this year, new regulations prohibiting the sale of e-cigarettes to under-18s and purchase by adults on behalf of under-18s will provide additional protection for young people.The government is consulting on a comprehensive array of regulations for e-cigarettes under the revised EU Tobacco Products Directive, for introduction from May 2016.

As part of our ongoing work to build an evidence-based consensus to support policy and practice on e-cigarettes, PHE will:

- continue to monitor the evidence on uptake of e-cigarettes, health impact at individual and population levels, and effectiveness for smoking cessation as products and technologies develop

- hold a second national symposium on e-cigarettes and harm reduction in spring 2016 to present the latest evidence and discuss its implications for policy and practice
- provide the public with clear and accurate information on the relative harm of nicotine, e-cigarettes and smoked tobacco. Nearly half the population don't realise e-cigarettes are safer than smoking, and studies have shown that some smokers have avoided switching in the belief that e-cigarettes are too dangerous
- publish framework advice to support organisations in developing evidence-based policies on use of e-cigarettes in enclosed public places and workplaces. This follows an engagement exercise conducted with public health partners and the wider stakeholder community to discuss the evidence and invite their input on its implications
- commission the National Centre for Smoking Cessation and Training to provide training and support to stop smoking practitioners to improve their skills and confidence in advising clients on the use of e-cigarettes
- monitor tobacco industry involvement in the evolving e-cigarettes market and exercise continuing vigilance to ensure we meet our obligations under Article 5.3 of the Framework Convention on Tobacco Control to protect public health policy from commercial and other vested interests of the tobacco industry

[1] Smoking Toolkit Study www.smokinginengland.info

[2] www.gov.uk/government/uploads/system/uploads/attachment_data/file/311887/Ecigarettes_report.pdf

[3] www.gov.uk/government/uploads/system/uploads/attachment_data/file/311491/Ecigarette_uptake_and_marketing.pdf

[4] Statistics on Smoking, England 2015 HSCIC www.hscic.gov.uk/catalogue/PUB17526/stat-smok-eng-2015-rep.pdf

[5] Smoking drinking and drug use among young people in England 2014, HSCIC, www.hscic.gov.uk/pubs/sdd14

[6] Stop Smoking Service Quarterly Returns 2014-5, HSCIC, www.hscic.gov.uk/stopsmoking

[7] McRobbie H, Bullen C, Hartmann-Boyce J, Hajek P. Electronic cigarettes for smoking cessation and reduction. Cochrane Database of Systematic Reviews 2014, Issue 12. Art. No.: CD010216. DOI: 10.1002/14651858.CD010216.pub2

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Comparison of select analytes in aerosol from e-cigarettes with smoke from conventional cigarettes and with ambient air

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ABSTRACT

Leading commercial electronic cigarettes were tested to determine bulk composition. The e-cigarettes and conventional cigarettes were evaluated using machine-puffing to compare nicotine delivery and relative yields of chemical constituents. The e-liquids tested were found to contain humectants, glycerin and/or propylene glycol, (⩾75% content); water (<20%); nicotine (approximately 2%); and flavor (<10%). The aerosol collected mass (ACM) of the e-cigarette samples was similar in composition to the e-liquids. Aerosol nicotine for the e-cigarette samples was 85% lower than nicotine yield for the conventional cigarettes. Analysis of the smoke from conventional cigarettes showed that the mainstream cigarette smoke delivered approximately 1500 times more harmful and potentially harmful constituents (HPHCs) tested when compared to e-cigarette aerosol or to puffing room air. The deliveries of HPHCs tested for these e-cigarette products were similar to the study air blanks rather than to deliveries from conventional cigarettes; no significant contribution of cigarette smoke HPHCs from any of the compound classes tested was found for the e-cigarettes. Thus, the results of this study support previous researchers' discussion of e-cigarette products' potential for reduced exposure compared to cigarette smoke.

1. Introduction

Electronic cigarettes (e-cigarettes) are a relatively new consumer product. Unlike conventional cigarettes, e-cigarettes do not burn tobacco to deliver flavor. Instead, they contain a liquid-based flavorant (typically referred to as e-liquid or e-juice) that is thermally vaporized by an electric element. This liquid typically consists of a mixture of water, glycerin, and/or propylene glycol. The liquid also contains nicotine and flavor, although nicotine-free products are available.

While there are decades of characterization studies and numerous standardized analytical procedures for conventional cigarettes, relatively little published analytical data exists for commercial e-cigarette products. Furthermore, no standardized test methods or reference products exist for e-cigarettes.

Electronic cigarettes are generally purported to provide reduced exposure to conventional cigarettes' chemical constituents because they deliver flavors and nicotine through vaporization rather than by burning tobacco. Goniewicz et al. (2014) reported low levels of select chemical constituents in select e-cigarette brands commercially available in Poland. A recent review of analyses from diverse e-cigarettes shows comparatively simple chemical composition relative to conventional cigarette smoke (Burstyn, 2014). However, limited published results exist for commercial products that represent a significant presence in the marketplace (Cheng, 2014).

The purpose of this study was to evaluate e-cigarette products with a significant presence in the marketplace for bulk composition, including nicotine, and for select constituents for comparison with conventional cigarette products. Three blu eCigs products (approximately 50% of the US market) and two SKYCIG products (approximately 30% of the UK market) were chosen for evaluation. Marlboro Gold Box (US), and Lambert & Butler Original and Menthol products (UK), with significant market share in their respective geographical areas, were included in the study for conventional cigarette comparisons.

Abbreviations: ACM, aerosol collected mass; HPHC, harmful and potentially harmful constituents; CO, carbon monoxide; TSNA, tobacco-specific nitrosamines; PAA, polyaromatic amines; PAH, polyaromatic hydrocarbons; LOQ, limit of quantitation; LOD, limit of detection; CAN, Health Canada Test Method T-115; blu CTD, Classic Tobacco Disposable; blu MMD, Magnificent Menthol Disposable; blu CCH, Cherry Crush, Premium, High Strength; SKYCIG CTB, Classic Tobacco Bold; SKYCIG CMB, Crown Menthol Bold; MGB, Marlboro Gold Box; L&B O, Lambert & Butler Original; L&B M, Lambert & Butler Menthol; TPM, total particulate matter; PG, propylene glycol.

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The products used in the study were evaluated for content and delivery of major ingredients (glycerin, propylene glycol, water, and nicotine) and for select constituents (carbon monoxide (CO), carbonyls, phenolics, volatile organic compounds (volatiles), metals, tobacco-specific nitrosamines (TSNAs), polyaromatic amines (PAAs), and polyaromatic hydrocarbons (PAHs)). Many of these constituents are included in cigarette industry guidance issued by the FDA that includes reporting obligations for harmful and potentially harmful constituents (HPHCs) in cigarette filler and smoke under section 904(a)(3) of the 2009 Family Smoking Prevention and Tobacco Control Act (FDA, 2012). For delivery studies, the conventional cigarettes were smoked under an intense puffing regime published by Health Canada (1999). The e-cigarettes were tested using minimal modifications to this smoking regime. Ninety-nine puffs were used to collect approximately the same aerosol mass as obtained from conventional cigarette testing. Ambient 'air' samples, empty port collections, were included as a negative control of aerosol testing for cigarette constituents (i.e. HPHC).

2. Materials and methods

2.1. Test products

Two disposable e-cigarette products and three rechargeable e-cigarette products were obtained from the manufacturers. Three conventional cigarette products were purchased through wholesale or retail sources for testing. Information for each of the products is listed in Table 1.

2.2. Methods overview

ISO 17025 accredited analytical methods were used to evaluate the cigarette samples for select HPHCs in mainstream smoke. Official methods are cited and other, internally validated, methods are briefly described for general understanding. Furthermore, because no standardized methods exist for e-cigarette analysis, the methods used to evaluate the conventional cigarettes were adapted to evaluate the e-cigarette products and the study blanks (room air). In an effort to maximize signal and lower methods' limits of quantitation, aerosol collection amounts were maximized (but maintained below breakthrough) and extraction solvent volumes were minimized. In some cases, alternative instrumentation was employed to improve detection. For example, mainstream smoke TSNAs were analyzed by GC–TEA while aerosol and air blank samples were analyzed by LC–MS/MS. Accuracy, precision, and method limits of quantitation and detection (LOQ and LOD) were verified for each method. On average, accuracy and method variability for the analytes tested were determined to be 98% and 3%, respectively. Analyte LOD and LOQ information is listed in Supplemental Appendix A Tables 1 and 2. Method resolution for low levels of analytes was influenced by background levels of select analytes in air control samples. These background levels are attributed to instrument or smoking machine carry-over as evidenced in solvent or air blanks. In addition, the high concentration of glycerin and water in e-cigarette aerosol present challenges for volatile-based measurement systems (i.e. GC). Additional method refinements and dedicated e-cigarette puffing machines are two areas for consideration to improve e-cigarette aerosol method sensitivities. Method development and verification details for e-cigarette liquids and aerosols are the subject of a future publication.

2.3. Smoke and aerosol collection

Cigarette preparation and machine smoking for conventional cigarettes are described in Health Canada Test Method T-115 (CAN) (1999). Two to three cigarettes were smoked per replicate for conventional cigarettes and 99 puffs were taken from single e-cigarettes for no more than approximately 200 mg of particulates collected per pad. Three to five replicates were tested for each measurement. Prior to analysis, filter pads from cigarette smoke collection were visually inspected for overloading of particulates, as evidenced by brown spotting on the back of the filter pad. To ensure no overloading of particulates for aerosol collection, e-cigarette units were weighed before and after collection to verify that product weight change and filter pad weight change were comparable. Air blanks were prepared by puffing room air (99 puffs) through an empty smoking machine port to the indicated trapping media for an analysis method. These air blank samples were prepared and analyzed in the same manner and at the same time as the e-cigarette aerosol samples. Smoke and aerosol collection sections were conducted separately. Smoke and aerosol particulate was collected onto 44 mm glass fiber filter pads with >99% particulate trapping efficiency for each replicate analysis. For carbonyls, smoke/aerosol was collected directly by two impingers, in series. For smoke metals analysis, electrostatic precipitation was used. For volatiles and PAH determinations, single chilled impingers were placed in-line with the filter pads. e-Liquid glycerin and nicotine were quantitated using GC–FID and/or GC–MS using a method equivalent to ISO 10315 (ISO, 2000a). e-Liquid water was quantitated using Karl Fischer analysis. A reference e-liquid was developed and used as a testing monitor for ingredient determinations in the e-liquid samples. The reference e-liquid is composed primarily of glycerin, propylene glycol, and water with low levels of nicotine, menthol, and Tween 80. The Tween 80 is added to improve solubility of menthol in the solution. The reference is not meant to directly mimic an e-liquid used for consumption but merely used for analytical control charts. Three replicates were tested for each sample and the reference.

2.4. Analytical assays

Carbon monoxide was determined concurrently with aerosol and smoke collection for nicotine and water and analyzed by NDIR using ISO method 8454:2007 (ISO, 2007). Carbonyls were trapped using 2,4-dinitrophenylhydrazine as a derivatizing agent with

Table 1
List of cigarette and e-cigarette products tested.

Product	Manufacturer	Product type	Nicotine information provided on packaging
Classic Tobacco Disposable (blu CTD)	blu eCigs	Disposable e-cigarette	Content: 24 mg/unit
Magnificent Menthol Disposable (blu MMD)	blu eCigs	Disposable e-cigarette	Content: 24 mg/unit
Cherry Crush, Premium, High Strength (blu CCH)	blu eCigs	Rechargeable e-cigarette	Content: 16 mg/unit
Classic Tobacco Bold (SKYCIG CTB)	SKYCIG	Rechargeable e-cigarette	Content: 18 mg/unit
Crown Menthol Bold (SKYCIG CMB)	SKYCIG	Rechargeable e-cigarette	Content: 18 mg/unit
Marlboro Gold Box (MGB)	Philip Morris USA	Conventional cigarette	–
Lambert & Butler Original (L&B O)	Imperial Tobacco	Conventional cigarette	Yield: 0.9 mg/cig (ISO)
Lambert & Butler Menthol (L&B M)	Imperial Tobacco	Conventional cigarette	Yield: 0.5 mg/cig (ISO)

subsequent analysis by UPLC–UV using CORESTA method 74 (CORESTA, 2013). For phenolics determination, filter pads were extracted with 20 mL of 1% acetic acid/2.5% methanol (MEOH) in water using 30 min of agitation. Extracts were analyzed by UPLC-fluorescence detection using a C18 column for separation. For volatiles analysis, filter pads and impinger solutions (20 mL MEOH) were combined. Extracts were analyzed by GC–MS in SIM mode using a WAX capillary column. For metals analysis, cigarette smoke was collected using an electrostatic precipitator while e-cigarette aerosol was collected on glass fiber filter pads. After smoking, the cigarette smoke condensate was rinsed from the electrostatic precipitation tube using methanol. The dried condensates were digested using hydrochloric (10% v/v), nitric acids (80% v/v), and heat and were diluted prior to analysis by ICP-MS. For aerosol samples, filter pads were extracted using 20 mL of a mixture of nitric (2% v/v) and hydrochloric acids (0.5% v/v) using wrist action shaker (20 min). Resultant extracts were analyzed by ICP-MS equipped with an octapole reaction cell.

For TSNA analysis of smoke, samples were extracted in nonpolar solvent, treated to an SPE clean-up, concentrated and analyzed by GC–TEA following CORESTA method 63 (CORESTA, 2005). For TSNA analysis of aerosol samples, filter pads were extracted with 20 mL of 5 mM aqueous ammonium with 15 min of shaking. Extracts were analyzed by LC–MS/MS with a C18 column. For PAA determinations, filter pads were extracted using 25 mL of 5% HCl (aq) and shaking (30 min) followed by solvent exchange and derivatization with pentafluoropropionic acid anhydride and trimethylamine. After an SPE clean-up step (Florisil® SEP-PAK), samples were analyzed by GC–MS in SIM mode using negative chemical ionization. PAH analysis was conducted by extraction in MEOH followed by SPE clean-up and analysis by GC–MS in SIM mode (Tarrant et al., 2009).

The results obtained from these analyses were tabulated as mean ± one standard deviation for levels of selected compounds in Supplementary Appendix A. In cases where quantifiable amounts of analyte were present in an e-cigarette aerosol sample above that of the associated air blanks, an Analysis of Variance (ANOVA) was used to compare the means for the cigarette smoke data with respective aerosol data. Statistical analyses were performed using JMP 10.0.0 (SAS Institute, Inc. Cary, NC, USA). The significance level was established as $p < 0.05$ for all comparisons.

3. Results and discussion

3.1. Collection of aerosol

Machine smoking of cigarettes under standardized regimes is for comparative purposes and is not intended to represent the range of consumer smoking behaviors. Thus, standardized equipment, cigarette reference products, and methodology have been established to allow comparison of different products under a common set of controlled conditions. ISO 3308:2000E and Health Canada (CAN) methods are frequently used for standardized smoking of conventional cigarettes for the purposes of laboratory comparisons among products (ISO, 2000b; Health Canada, 1999). Following each of these methods, conventional cigarettes are smoked to a specified butt length using a fixed and specified puffing volume, duration, and interval.

Regarding e-cigarette experimentation, there is no generally accepted standard e-cigarette puffing regime at this time. Topography studies are limited but anecdotal information indicates e-cigarette usage depends greatly on the individual consumer and product design and capabilities. For the purposes of this study, our objective was to collect sufficient aerosol to be able to detect, if present, select HPHCs. A wide range of parameters would be adequate to accomplish this. Given the objectives of this study, use of collection parameters which are compatible with conventional and electronic cigarettes was essential for facilitating comparisons between cigarette smoke and e-cigarette aerosol. The more intense of the standard regimes used with cigarettes, CAN, which requires 55 mL puffs taken twice a minute, was adapted for this investigation. The key difference required for testing e-cigarettes with the CAN method is that a fixed puff count (rather than 'butt length') is necessary for aerosol collection. A standard of 99 puffs was adopted for all e-cigarette and air blank analyses. This puff count provides similar total particulate collection per pad between the e-cigarette samples and the conventional cigarette testing. This also represents approximately 11 times more puffs than are typically observed for a conventional cigarette. Marlboro Gold Box, L&B O, and L&B M averaged 9.1, 8.2, and 7.2 puffs per cigarette, respectively, when machine-smoked to the standard butt length. If more aggressive puffing parameters had been chosen for the study, the puff count specification would have been lowered to maintain the target level of ACM collected. Note that the range of puffs collected in-use may vary widely depending on product design, battery strength, and user puffing preferences. Thus, the 99 puffs collection in this study is not intended to represent a life time use yield for any of the analytes tested.

3.2. Aerosol and smoke characterization – reference information

Traditional cigarette testing incorporates the use of monitor or reference cigarettes that serve as positive controls and provide quality metrics for standardized analytical methods. Key examples are Kentucky Reference cigarettes and CORESTA monitor cigarettes (CORESTA, 2009; ISO, 2003; University of Kentucky, 2014). Each of

Table 2
Percent composition of e-liquid and aerosol.

	Glycerin (%)	Propylene glycol (%)	Water (%)	Nicotine (%)	Flavor[a] (%)
e-Liquid composition					
blu Classic Tobacco Disposable	82	–	9	2	7
blu Magnificent Menthol Disposable	75	–	18	2	5
blu Cherry Crush High Premium	77	–	14	2	7
SKYCIG Classic Tobacco Bold	24	67	6	2	1
SKYCIG Crown Menthol Bold	21	66	7	2	4
e-Cigarette aerosol composition[b]					
blu Classic Tobacco Disposable	73	–	15	1	11
blu Magnificent Menthol Disposable	80	–	18	2	–
blu Cherry Crush High Premium	70	–	19	1	10
SKYCIG Classic Tobacco Bold	24	61	10.4	1.4	3
SKYCIG Crown Menthol Bold	21	59	12	2	6

[a] Flavor content is estimated by difference.
[b] Aerosol % composition calculated based on the ACM delivery as analyte yield (mg)/ACM (mg) × 100.

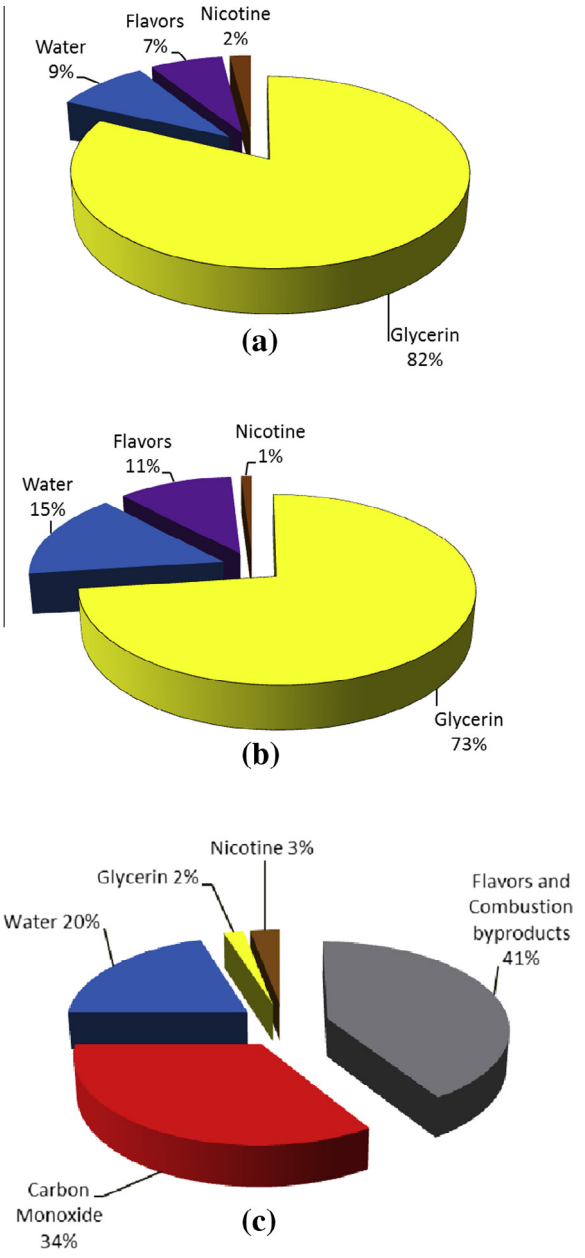

Fig. 1. Percent composition comparison for e-liquid, e-cigarette aerosol, and cigarette smoke: (a) Classic Tobacco Disposable e-liquid Composition. (b) Classic Tobacco Disposable Aerosol Composition (99 puffs, CAN). (c) Marlboro Gold Box Smoke Composition (9 puffs, CAN).

these reference cigarettes can serve as a single positive control and an indicator of method variability within and among laboratories for all analytes of interest. The manufacture, design, and function of these reference products are similar to those of commercial cigarettes. Currently reference products are not available for e-cigarette testing. Given the range of e-cigarette designs, development of a consensus strategy to produce positive controls or monitors for e-cigarette testing is needed.

In the absence of standardized e-cigarette references, measures were taken to ensure experimental robustness. For example, aerosol collected mass (ACM) results for the e-cigarette samples were compared across methods as an indicator of puffing consistency for a given product among the machine-puffing sessions required to conduct the battery of tests. Thus, if a sample set yielded ACM outside of a specified ranged deemed typical for a given product, the sample set was repeated. This range was determined for each product based on collection of 20 or more replicates across the product lot using CAN parameters.

Also, because results from initial analyses indicated low or no measurable levels of many of the analytes, blank samples were included to verify any contribution of analyte from the laboratory environment, sample preparation, and/or analyses for each HPHC test method. The air blank results are listed with the samples' results in Tables 4 and 5. There were instances for which solvent blank and air blank samples had measurable levels of an analyte. This is due to the ubiquitous nature of some of the analytes, such as formaldehyde, or to carry-over. Laugesen reported similar findings (2009). These observations serve as a cautionary note regarding the measurement of extremely low levels of constituents with highly sensitive instrumentation.

3.3. Main ingredients

e-Liquid expressed from the individual products was tested for reported e-cigarette ingredients to compare the percent compositions of the e-liquids and the aerosols. Percent composition calculations of the ingredients are shown in Table 2 for each sample and in Fig. 1 for blu CTD, as this product's comparative results were exemplary of the samples. The primary ingredients in the e-cigarette samples were glycerin and/or propylene glycol ($\geqslant$75%). Water ($\leqslant$18%) and nicotine ($\sim$2%) were also present. Based on a mass balance, other ingredients, presumed to be flavorants, were present at less than 7%. Note that this calculation would also include method uncertainty and any possible HPHCs, if present. The composition of the aerosol was calculated based on the ACM delivery as analyte yield (mg)/ACM (mg) $\times$ 100. The bulk composition of the delivered aerosol was similar to the bulk composition of the e-liquid.

By comparison, the total particulate matter (TPM) of the conventional cigarettes tested is 30% water and <5% nicotine. The essential difference between the ACM composition of the e-cigarettes tested and the TPM of the conventional cigarettes is that the remaining 65% of the TPM of the conventional cigarette is predominantly combustion byproducts. There was no detectable carbon monoxide in the emitted aerosol of the e-cigarette samples. The conventional cigarettes, on the other hand, delivered more than 20 mg/cig of CO. Smoke composition for Marlboro Gold Box, exemplary of the conventional cigarettes tested, is shown in Fig. 1 in contrast to the e-liquid and aerosol results for blu CTD.

While the percent composition of the nicotine in the ACM and TPM are relatively similar, it should be noted that the actual deliveries of nicotine are markedly lower for the e-cigarettes tested than the conventional cigarettes. The nicotine yields ranged from 8 μg/puff to 33 μg/puff for the e-cigarette samples which was 85% lower than the 194–232 μg/puff for the conventional cigarettes. These results are presented in Table 3.

3.4. Aerosol and smoke HPHC testing

For cigarette smoke analysis, the conventional cigarettes were machine smoked by established cigarette smoking procedures. Approximately 7–9 puffs per cigarette were collected. For the e-cigarette samples and air blanks, 99 puffs were collected. Results were compared on an 'as tested' basis; i.e. yields for a single cigarette of 7–9 puffs compared to yields from 99 puffs of an e-cigarette as displayed in Table 4. Additionally, in order to simplify making comparisons between the cigarette and e-cigarette samples, all values were converted to yield per puff. These results are summarized by class in Table 5. Results for individual analytes are tabulated as mean ± one standard deviation in Supplemental Appendix A Tables 1 and 2.

Table 3
Nicotine content and yield comparison between e-cigarettes and conventional cigarettes (mean ± standard deviation).

	Nicotine content (μg/unit)	Nicotine yield (μg/puff)
blu Classic Tobacco Disposable	20,600 ± 1500	33 ± 12
blu Magnificent Menthol Disposable	20,000 ± 300	25 ± 4
blu Cherry Crush High Premium	11,700 ± 300	8 ± 3
SKYCIG Classic Tobacco Bold	12,750 ± 295	29 ± 4
SKYCIG Crown Menthol Bold	13,027 ± 280	33 ± 6
Marlboro Gold Box	11,431 ± 80	226 ± 2
L&B Original	12,941 ± 26	232 ± 5
L&B Menthol	12,131 ± 24	194 ± 10

Number of replicates = 3–5.

Table 4
Analytical characterization of commercial e-cigarettes and conventional cigarettes collected using CAN parameters – select cigarette HPHC methodology (mg/total puffs collected) summary by analyte classes.

	CO	Carbonyls[a]	Phenolics[b]	Volatiles[c]	Metals[d]	TSNAs[e]	PAA[f]	PAH[g]	Sum
Marlboro Gold Box (mg/cig)	27	1.92	0.204	1.430	<0.00020	0.000550	0.000024	0.00222	<30.6 mg
L&B Original (mg/cig)	22	1.89	0.26	1.02	<0.0002	0.000238	0.000019	0.00219	<25.2
L&B Menthol (mg/cig)	20	1.81	0.17	0.94	<0.0003	0.000185	0.000017	0.00153	<22.9
blu CTD (mg/99 puffs)	<0.1	<0.07	<0.001	<0.001	<0.00004	<0.00002	<0.000004	<0.00016	<0.17
blu MMD (mg/99 puffs)	<0.1	<0.08	<0.001	<0.001	<0.00004	<0.00002	<0.000004	<0.00016	<0.18
blu CCHP (mg/99 puffs)	<0.1	<0.05	<0.003	<0.0004	<0.00004	<0.00002	<0.000004	<0.00014	<0.15
SKYCIG CTB (mg/99 puffs)	<0.1	<0.06	<0.0010	<0.008	<0.00006	<0.000013	<0.000014	<0.00004	<0.17
SKYCIG CMB (mg/99 puffs)	<0.1	<0.09	<0.0014	<0.008	<0.00006	<0.000030	<0.000014	<0.00004	<0.20
Air Blank (blu Set) (mg/99 puffs)	<0.1	<0.06	<0.001	<0.0004	<0.00004	<0.00002	<0.000004	<0.00015	<0.16
Air Blank (SKYCIG Set) (mg/99 puffs)	<0.1	<0.05	<0.0009	<0.008	<0.00006	<0.000013	<0.000014	<0.00006	<0.16

< Indicates some or all values were below method limits of quantitation or detection, number of replicates = 3–5.
[a] Formaldehyde, acetaldehyde, acrolein propionaldehyde, crotonaldehyde, MEK, butyraldehyde.
[b] Hydroquinone, resorcinol, catechol, phenol, m-+p-cresol, o-cresol.
[c] 1,3-Butadiene, isoprene, acrylonitrile, benzene, toluene, styrene.
[d] Beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, nickel, selenium, tin.
[e] NNN, NAT, NAB, NNK.
[f] 1-Aminonaphthalene, 2-aminonaphthalene, 3-aminobiphenyl, 4-aminobiphenyl.
[g] Naphthalene, acenaphthylene, acenaphthene, fluorine, phenanthrene, anthracene, fluoranthene, pyrene, benzanthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, B(a)P, indeno[1,2,3-cd]pyrene, benzo(g,h,i)perylene.

Table 5
Analytical characterization of commercial e-cigarettes and conventional cigarettes collected using CAN parameters – select cigarette HPHC methodology (μg/puff) summary by analyte classes.

	CO	Carbonyls[a]	Phenolics[b]	Volatiles[c]	Metals[d]	TSNAs[e]	PAA[f]	PAH[g]	Sum
Marlboro Gold Box	2967	211	22	157	<0.026	0.0604	0.00264	0.244	<3357 μg
L&B Original	2683	230	32	124	<0.024	0.0290	0.00232	0.267	<3069
L&B Menthol	2778	251	24	130	<0.042	0.0257	0.00236	0.213	<3183
blu Classic Tobacco Disposable	<1.0	<0.7	<0.01	<0.01	<0.0004	<0.0002	<0.00004	<0.002	<1.7
blu Magnificent Menthol Disposable	<1.0	<0.8	<0.01	<0.01	<0.0004	<0.0002	<0.00004	<0.002	<1.8
blu Cherry Crush High Premium	<1.0	<0.5	<0.03	<0.004	<0.0004	<0.0002	<0.00004	<0.001	<1.5
SKYCIG Classic Tobacco Bold	<1.0	<0.6	<0.01	<0.08	<0.0006	<0.0001	<0.00014	<0.0004	<1.7
SKYCIG Crown Menthol Bold	<1.0	<0.9	<0.01	<0.08	<0.0006	<0.0003	<0.00014	<0.0004	<2.0
Air Blank (blu Set)	<1.0	<0.6	<0.01	<0.004	<0.0004	<0.0002	<0.00004	<0.002	<1.6
Air Blank (SKYCIG Set)	<1.0	<0.5	<0.01	<0.08	<0.0006	<0.0001	<0.00014	<0.001	<1.6

< Indicates some or all values were below method limits of quantitation or detection, number of replicates = 3–5.
[a] Formaldehyde, acetaldehyde, acrolein propionaldehyde, crotonaldehyde, MEK, butyraldehyde.
[b] Hydroquinone, resorcinol, catechol, phenol, m-+p-cresol, o-cresol.
[c] 1,3-Butadiene, isoprene, acrylonitrile, benzene, toluene, styrene.
[d] Beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, nickel, selenium, tin.
[e] NNN, NAT, NAB, NNK.
[f] 1-Aminonaphthalene, 2-aminonaphthalene, 3-aminobiphenyl, 4-aminobiphenyl.
[g] Naphthalene, acenaphthylene, acenaphthene, fluorine, phenanthrene, anthracene, fluoranthene, pyrene, benzanthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, B(a)P, indeno[1,2,3-cd]pyrene, benzo(g,h,i)perylene.

Table 6
Per puff comparisons of quantifiable analytes for blu eCigs products from CAN puffing – yields and ratios to conventional product yields.

	Marlboro Gold Box μg/puff	blu MMD μg/puff	MGB/blu MMD
Acrolein	16.4 ± 0.2	0.19 ± 0.06	86
Phenol	1.53 ± 0.16	0.0017[a]	900

[a] Fewer than three replicates were quantifiable; no standard deviation is listed.

Table 7
Per puff comparisons of quantifiable analytes for SKYCIG products from CAN puffing – yields and ratios to conventional product yields.

	L&B average μg/puff	SKYCIG CTB μg/puff	SKYCIG CMB μg/puff	L&B average/SKYCIG CTB	L&B average/SKYCIG CMB
Acetaldehyde	174	–	0.32[a]	–	544
Acrolein	17	0.15 ± 0.02	–	113	–
Propionaldehyde	12	–	0.11 ± 0.05	–	109
N-Nitrosoanatabine	0.010	–	0.0002 ± 0.0001	–	50

[a] Fewer than three replicates were quantifiable; no standard deviation is listed.

All analytes tested were present in the cigarette smoke at quantifiable levels except for select metals. These results are consistent with internal historical results for commercial cigarettes tested under the CAN smoking regime. For the cigarette samples, the total yield range was 3069–3350 μg/puff of HPHCs tested.

Of the 55 HPHCs tested in aerosol, 5 were quantifiable in an e-cigarette sample but not the associated air blank. The quantifiable results for aerosol are listed in Tables 6 and 7 in contrast with the conventional cigarettes from the same geographical region. The five analytes which were quantifiable were statistically different ($p < 0.05$) at levels 50–900 times lower than the cigarette smoke samples. Phenol was quantified in one e-cigarette product at 900 times lower than cigarette smoke. N-Nitrosoanatabine was quantified in one product at 50 times lower than cigarette smoke. Three carbonyls (acrolein, acetaldehyde, and propionaldehyde) were quantified at 86–544 times lower than cigarette smoke.

All other analytes were not quantifiable above the air blanks in aerosol samples. The e-cigarettes and air blanks total yields for analytes were <2 μg/puff which is 99% less than the approximately 3000 μg/puff quantified for the cigarette smoke samples. Thus, the results support the premise of potentially reduced exposure to HPHCs for the e-cigarette products compared to conventional cigarette smoke.

4. Conclusions

The purpose of this study was to determine content and delivery of e-cigarette ingredients and to compare e-cigarette aerosol to conventional cigarettes with respect to select HPHCs for which conventional cigarette smoke is routinely tested. Routine analytical methods were adapted and verified for e-cigarette testing. Aerosol collection was conducted using conventional smoking machines and an intense puffing regime. As machine puffing cannot, and is not intended to, mimic human puffing, results of this study are limited to the scope of the comparisons made between the e-cigarette and conventional cigarette products tested.

The main ingredients for the e-cigarettes tested were consistent with disclosed ingredients: glycerin and/or propylene glycol ($\geqslant$75%), water ($\leqslant$18%), and nicotine ($\sim$2%). Machine-puffing of these products under a standardized intense regime indicated a direct transfer of these ingredients to the aerosol while maintaining an aerosol composition similar to the e-liquid. Nicotine yields to the aerosol were approximately 30 μg/puff or less for the e-cigarette samples and were 85% lower than the approximately 200 μg/puff from the conventional cigarettes tested.

Testing of the e-cigarette aerosol indicates little or no detectable levels of the HPHC constituents tested. Overall the cigarettes yielded approximately 3000 μg/puff of the HPHCs tested while the e-cigarettes and the air blanks yielded <2 μg. Small but measurable quantities of 5 of the 55 HPHCs tested were found in three of the e-cigarette aerosol samples at 50–900 times lower levels than measurable in the cigarette smoke samples. Overall, the deliveries of HPHCs tested for the e-cigarette products tested were more like the study air blanks than the deliveries for the conventional cigarettes tested. Though products tested, collection parameters, and analytical methods are not in common between this study and others, the results are very consistent. Researchers have reported that most or all of the HPHCs tested were not detected or were at trace levels. Burstyn (2014) used data from approximately 50 studies to estimate e-cigarette exposures compared to workplace threshold limit values (TLV) based on 150 puffs taken over 8 h. The vast majority of the analytes were estimated as $\ll$1% of TLV and select carbonyls were estimated as <5% of TLV. Cheng (2014) reviewed 29 publications reporting no to very low levels of select HPHCs relative to combustible cigarettes, while noting that some of the tested products exhibited considerable variability in their composition and yield. Goniewicz et al. (2014) tested a range of commercial products and reported quantifiable levels for select HPHCs in e-cigarette aerosols at 9- to 450-fold lower levels than those in cigarette smoke that in some instances were on the order of levels determined for the study reference (a medicinal nicotine inhaler). Laugesen (2009) and Theophilus et al. (2014) have presented results for commercial e-cigarette product liquids and aerosols having no quantifiable levels of tested HPHCs, or extremely low levels of measurable constituents relative to cigarette smoke. Additionally, findings from several recent studies indicate that short-term use of e-cigarettes by adult smokers is generally well-tolerated, with significant adverse events reported relatively rarely (Etter, 2010; Polosa et al., 2011, 2014; Caponnetto et al., 2013; Dawkins and Corcoran, 2014; Hajek et al., 2014). Thus, the results obtained in the aforementioned studies and in the present work broadly support the potential for e-cigarette products to provide markedly reduced exposures to hazardous and potentially hazardous smoke constituents in smokers who use such products as an alternative to cigarettes.

Additional research related to e-cigarette aerosol characterization is warranted. For example, continued characterization of

major components and flavors is needed. Establishment of standardized puffing regimes and reference products would greatly aid sharing of knowledge between researchers. Continued methods' refinement may be necessary for improved accuracy for quantitation of analytes at the low levels determined in this study. To that end, it is critical that negative controls and steps to avoid sample contamination be included when characterizing e-cigarette aerosol since analytes are on the order of what has been measured in the background levels of a laboratory setting. Though researchers have reported quantification of select analytes, great care must be taken when interpreting results at such trace levels.

Conflicts of interest

The company for which the study authors work and the companies that manufacture the e-cigarettes tested for this study are owned by the same parent company.

Acknowledgments

We thank the analytical testing laboratories at Lorillard Tobacco Company for methods development and testing and Drs. Brown, D'Ruiz, Heck and Stevens for technical discussions.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.yrtph.2014.10.010.

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E-cigarettes are less harmful than smoking

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Summary Full Text Tables and Figures References

The Lancet Editorial[1] criticising Public Health England's review of electronic cigarettes (e-cigarettes) focused on three supposed short-comings of our paper:[2] a lack of hard evidence, no formal criteria used, and so relied on the opinions of participants, and potential bias arising from the selection of participants and the declared conflicts of interest of some authors.[2] As authors of the original paper,[2] we believe that these three criticisms have over-generalised the evidence issue, did not respect the knowledge and experience of the experts selected, and did not take into account the many measures used to minimise potential bias.

First, regarding the lack of evidence, an abundance of evidence is available about the harm of cigarettes. The paucity of evidence for serious harm to users of e-cigarettes over the years since they were first marketed in 2006, with millions purchased, in itself is evidence. Additionally, biomarkers of potential harm of e-cigarettes are broadly reassuring.[3]

Second, we used the approach of decision conferencing,[4] sought from participants their expert judgments and not opinions. The criteria and their definitions were taken from three drug harm studies, the Advisory Council on the Misuse of Drug's original formulation,[5] the 2010 study of UK drug harms published in *The Lancet*,[6] and the 2013 replication for EU drug harms.[7] Judgments about scores were based on data along with our own knowledge and experience of the extent of harm and plausible causal mechanisms for harm. If data were available, these were discussed openly about their validity and reliability by the group, but if data were sparse or absent we relied on logical inferences (eg, the dearth of evidence of dying directly from an overdose of smoking led us to infer that cigarettes are not very harmful on that criterion and gave it a low score, but assigned e-cigarettes a higher harm score for that effect because the nicotine solution in the cartridges could potentially be directly accessed). A strength of the multicriteria decision analysis (MCDA) model[8] is

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that it incorporates data and the judgments about the relevance of the data, thus capturing meaningful differences in the importance of their effects.

Third, we selected experts on the basis of their publications, experience, and generally acknowledged professional standing to have diverse perspectives and expertise that could be relevant to assess harms from nicotine products. We included experts on behavioural pharmacology, legal aspects of tobacco control, smoking policy, toxicology, neuropsychopharmacology, psychopharmacology, public health sciences, and internal medicine, who collectively have published more than 300 scientific reports relevant to understand nicotine and tobacco harms. We feel that it was misleading of *The Lancet*[1] to characterise the authors[2] as having "no prespecified expertise in tobacco control" because the project was about relative harms of nicotine products not tobacco policy.

Regarding the concern about author conflicts of interest,[1] the decision conference process is designed to ensure that participants challenge each other. Additionally, the facilitator ensured that peer review operated on-the-spot throughout the creation and exploration of the MCDA model.[8] Consistency checks and sensitivity of overall results to the input scores and weights were thoroughly explored; the model results were very robust to imprecision in data and the few disagreements among the experts. As a result, a single participant with a potential bias could not have had any meaningful influence on the process outcome.

Potential sources of conflicts of interests were disclosed at the 2013 MCDA meeting (July, 2013, London, UK). Any conflicts from the previous 3 years before the meeting were disclosed in the published paper.[2] We were informed by EuroSwiss Health (Trélex, Switzerland) that they do not receive funding from any tobacco or e-cigarette manufacturers; a requirement we had before accepting their funding. We received no funds from tobacco or e-cigarette manufacturers and, as stated in our paper,[2] EuroSwiss Health and Lega Italiana Anti Fumo (LIAF) had no influence on the MCDA process.

We are confident that the nicotine products we studied were assessed by an appropriately structured process with a requisite diversity of research experts who engaged in constructive discourse in building a model that represented the most scientifically sound assessment of the relative harms of nicotine products. Our model's results for harms to users of e-cigarettes provided Public Health England with the basis for their correct calculation to estimate that e-cigarettes are 95% less harmful to users than smoking. Or, as we prefer, smoking is estimated to be twenty times more harmful to users than vaping e-cigarettes.

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Effect of continuous smoking reduction and abstinence on blood pressure and heart rate in smokers switching to electronic cigarettes

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Abstract

We present prospective blood pressure (BP) and hear rate (HR) changes in smokers invited to switch to e-cigarettes in the ECLAT study. BP and HR changes were compared among (1) different study groups (users of high, low, and zero nicotine products) and (2) pooled continuous smoking phenotype classification (same phenotype from week 12 to -52), with participants classified as quitters (completely quit smoking), reducers (≥50 % reduction in smoking consumption) and failures (<50 % or no reduction in smoking consumption). Additionally, the latter comparison was repeated in a subgroup of participants with elevated BP at baseline. No significant changes were observed among study groups for systolic BP, diastolic BP, and HR. In 145 subjects with a continuous smoking phenotype, we observed lower systolic BP at week 52 compared to baseline but no effect of smoking phenotype classification. When the same analysis was repeated in 66 subjects with elevated BP at baseline, a substantial reduction in systolic BP was observed at week 52 compared to baseline (132.4 ± 12.0 vs. 141.2 ± 10.5 mmHg, $p < 0.001$), with a significant effect found for smoking phenotype classification. After adjusting for weight change, gender and age, reduction in systolic BP from baseline at week 52 remains associated significantly with both smoking reduction and smoking abstinence. In conclusion, smokers who reduce or quit smoking by switching to e-cigarettes may lower their systolic BP in the long term, and this reduction is apparent in smokers with elevated BP. The current study adds to the evidence that quitting smoking with the use of e-cigarettes does not lead to higher BP values, and this is independently observed whether e-cigarettes are regularly used or not.

Keywords

Smoking cessation Smoking reduction Electronic cigarette Blood pressure Heart rate Tobacco harm reduction

Introduction

Cigarette smoking is the single most important cause of preventable premature mortality in the world [1]. It is responsible for 50 % of all avoidable deaths in smokers, half of these due to cardiovascular disease [2]. It has been estimated that the 10-year fatal cardiovascular risk is doubled in smokers, while for young smokers the risk for myocardial infarction is up to

fivefold higher compared to non-smokers [2, 3, 4]. The risk associated with smoking is primarily related to the amount of tobacco smoked daily, and shows a clear dose–response relationship with no lower limit for deleterious effects [5, 6].

The interaction between smoking and blood pressure (BP) is complex. Smoking causes an immediate elevation of BP and heart rate (HR) due to stimulation of the sympathetic nervous system [7]. However, there is controversy over the independent chronic effect of smoking on BP [8, 9]. In fact, epidemiological studies show that smoking cessation may be associated with an elevated risk for future development of hypertension, which has been attributed to weight gain [10, 11, 12]. In already established hypertension, smoking is associated with an elevated risk for cardiovascular disease; thus quitting smoking is unquestionably among the most important steps patients with elevated BP can take to improve their cardiovascular health [13, 14] [15]. Surprisingly, however, data on the long-term effects of smoking cessation or reduction on BP (and HR) is very limited, and results are unclear, with studies reporting lower, higher or unchanged BP values in smokers compared with non-smokers [16].

Electronic cigarettes (ECs) are an alternative source of nicotine, sharing many similarities with smoking in the behavioural aspect of use [17, 18]. Users are predominantly smokers, who report using the electronic cigarettes long term to reduce cigarette consumption or quit smoking, to relieve tobacco withdrawal symptoms, and to continue having a 'smoking' experience but with much reduced health risks [19, 20, 21]. Data from two recent prospective randomised controlled trials show that ECs can aid smoking cessation and reduction [22, 23].

Herein, we present the effects of smoking reduction and abstinence on resting blood pressure (BP) and heart rate (HR) from the ECLAT study—a prospective 12-month double-blind, controlled, randomised clinical three-arm trial designed to evaluate smoking reduction, smoking abstinence and adverse events in apparently healthy smokers not intending to quit after switching to a popular EC brand ('Categoria'; Arbi Group Srl, Italy). [23] Blood pressure (BP) and heart rate (HR) were compared amongst (1) different study groups (users of high, low, and zero nicotine products) and (2) pooled continuous smoking phenotype classification, with participants classified as quitters (completely quit smoking), reducers (≥50 % reduction in smoking consumption) and failures (<50 % or no reduction in smoking consumption). The latter comparison was repeated in a subgroup of participants with abnormal elevated BP at baseline, to examine the possibility of BP reduction, which would be unlikely to be observed in participants with normal BP at baseline.

Methods

Details of participants' characteristics and study design have been previously described [23]. The ethics review board (ERB) of the "Policlinico-Vittorio Emanuele" Hospitals approved the study in June 1, 2010, and participants gave written informed consent prior to participation. The clinicaltrial.gov team subsequently approved the study. The authors confirm that all ongoing and related trials for this drug/intervention are registered. The smokers were recruited during the period June 2010–February 2011 with a final follow-up visit at week 52. The trial registry describes the trial as observational, with a 24-week follow-up, but was conducted as a three-arm RCT with a 52-week follow-up because we decided to monitor the long-term impact of different nicotine levels on smoking cessation or reduction, BP and HR. This is a post hoc analysis, since BP and HR were not officially among the primary or secondary outcomes of trial in the registry entry, but were considered important as safety indicators.

Participants

Regular smokers not intending to quit were invited to try ECs ("Categoria", Arbi Group Srl, Italy) as a less harmful alternative to tobacco smoke that could be freely used as a complete substitute for conventional cigarettes. Subjects were made aware that the purpose of the current assessment was to quantify reductions in cigarette consumption by switching to EC use, and the impact on their resting BP and HR on a regular basis at follow-up visits. No financial incentive was offered for participation.

Inclusion criteria were: (1) smoke ≥10 tobacco cigarettes per day (cig/day), for at least the past 5 years, (2) age 18–70 years, (3) in good general health; (4) not currently attempting to quit smoking or wishing to do so in the next 30 days and (5) committed to follow the trial procedures.

Exclusion criteria were: (1) history of cardiovascular disease, respiratory disease, psychiatric disorder or major depression; (2) regular medication use; (3) current or past history of alcohol abuse; (4) use of smokeless tobacco or nicotine replacement therapy, and (5) pregnancy or breastfeeding.

Study design

Eligible participants were enrolled in a prospective 12-month randomised, controlled trial consisting of nine office visits at the University Hospital's smoking cessation clinic (Centro per la Prevenzione e Cura del Tabagismo - CPCT; Università di Catania, Italy). A prospective evaluation of conventional cigarettes consumption, BP and HR was carried out at nine time points (baseline and eight follow-up visits at week 2, 4, 6, 8, 10, 12, 24, and 52). Participants were randomised into three study arms to receive an e-cigarette kit with either "Original" (2.4 % nicotine—Group A), or "Categoria" (1.8 % nicotine—Group B), or "Original" without nicotine ("sweet tobacco" aroma—Group C) cartridges (Fig. 1). The randomization sequence was computer generated, and blinding was ensured by the identical external appearance of the cartridges.

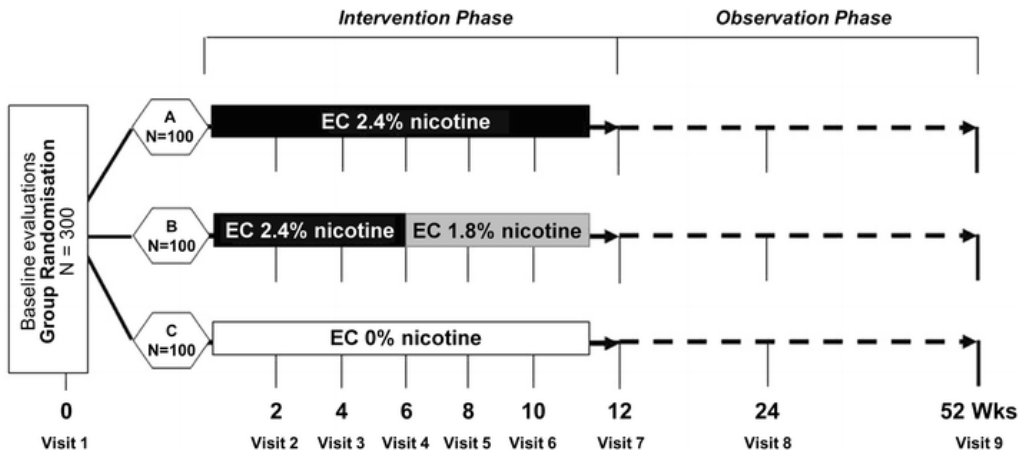

Fig. 1

Schematic diagram of the ECLAT study design. Smokers not currently attempting to quit smoking or wishing to do so in the next 30 days were randomised in three study groups: group A (receiving 12 weeks of 2.4 % "Original" nicotine cartridges), group B (receiving 6 weeks of 2.4 % "Original" nicotine cartridges and a further 6 weeks with 1.8 % "Categoria" nicotine cartridges), and group C (receiving 12 weeks of no-nicotine "Original" cartridges). Participants in each group were prospectively reviewed for up to 52 weeks during which smoking habits, eCO levels, BP, HR and body weight were assessed at each study visits

At baseline (visit 1), socio-demographic factors, smoking history, Fagerström Test for cigarette dependence (FTCD) scores and levels of carbon monoxide in exhaled breath—eCO (Micro CO, Micro Medical Ltd, UK) were annotated. Additionally, BP, HR, and body weight were recorded.

Participants were then given a free e-cigarette kit with a full supply of cartridges, and were trained on how to correctly use the product. They were told to use the study product ad libitum (but up to a maximum of four cartridges/day) in the anticipation of reducing cigarette smoking, and to take notes of the daily consumption of conventional cigarettes and cartridge use in their study diaries.

Participants were then invited to return to the CPCT at follow-up visits (visits 2–7) to: (1) receive further free supply of cartridges (with the exception of visit 7) together with the study diaries for the residual study periods, (2) record their eCO levels, (3) have their BP and HR measured, and (4) return completed study diaries and unused study products. At the end of study visit 7, no more cartridges were provided by the investigators, but participants were advised to continue using their EC if they wished to do so. Body weight was also measured at this visit.

Study participants attended two additional follow-up visits at week 24 (visit 8) and at week 52 (visit 9) to report product use and the number of cigarettes per day smoked, and to re-check eCO levels. Resting BP, HR, and body weight were recorded again.

Office BP and HR measurements

For office systolic and diastolic BP measurements, we followed the methods recommended by the Seventh Report of the Joint National Committee on prevention, detection, evaluation, and treatment of high blood pressure [24]. After a 5-minute rest, BP and HR measurements were obtained by a semi-automated oscillometric sphygmomanometer (Smart Pressure, CA-MI Snc, Parma, Italy). Two measurements in the sitting position, spaced 1–2 min apart, were obtained at each visit. Measurements were taken late in the morning, and participants were asked not to smoke/vape or consume caffeinated drinks for at least 30 min prior to each visit. The average of two measurements was considered for analysis.

Products tested

The "Categoria" EC (model "401") was used in this study. It is a three-piece model that closely resembles a conventional cigarette, activated by a rechargeable 3.7 V-90 mAh lithium-ion battery. Disposable cartridges used in this study were of three different types, but of identical appearance: 2.4 % "Original" (2.27 ± 0.13 % nicotine), 1.8 % "Categoria" (1.71 ± 0.09 % nicotine) and "Original" without nicotine ("sweet tobacco" aroma). Detailed toxicology and nicotine content analyses of these cartridges had been carried in a laboratory certified by the Italian Institute of Health and can be found at: http://www.categoriacigarette.com/it/studi-e-ricerche/analisi/analisi-2010. The "Categoria" EC kit and cartridges were provided free of charge by the local distributor, Arbi Group Srl, Italy.

Smoking phenotypes

Smoking abstinence was defined as complete self-reported abstinence from tobacco smoking (not even a puff) since the previous study visit, which was biochemically verified by eCO levels of ≤7 ppm. Smokers in this category are classified as

quitters. Smoking reduction was defined as sustained self-reported ≥50 % reduction in the number of cig/day from baseline (eCO levels were measured to verify smoking status and confirm a reduction compared to baseline) [25]. Smokers in this category are classified as reducers. Smokers who were not categorised in the above categories were classified as failures. The study analysed the effects of BP and HR among continuous smoking phenotypes, which was defined as having the same phenotype from week 12 to 52. Given that long-term changes in BP and HR may become apparent only some time after the change in smoking phenotype, the analysis was performed among participants who had a sustained smoking phenotype for at least 40 weeks.

Statistical analyses

In our primary analysis, BP and HR values were compared among the study groups (Group A, B, and C: per-protocol analysis). Descriptive data are presented as mean ± standard deviation (SD) or medians and interquartile range (IQ) for normally and not normally distributed variables, respectively. Baseline differences between groups were evaluated by χ^2 test for categorical variables, and one-way analysis of variance (ANOVA) and Fisher protected LSD for parametric variables; Kruskall–Wallis test was used for non-parametric variables. Repeated measures ANOVA was used to assess changes in systolic BP, diastolic BP and HR from baseline to wek-52, with time as within subject and study group as between subject factors.

In our secondary analysis, BP and HR values were compared among continuous smoking phenotypes, combining datasets from study groups A, B and C (pooled analysis). To evaluate differences at baseline among phenotypes, χ^2 test, one-way ANOVA, and Fisher's least significance difference, and Kruskall–Wallis test were used. Repeated measures ANOVA was used to assess changes in systolic BP, diastolic BP and HR, with time (2 time points, baseline and week 52) as within subject and continuous smoking phenotypes (3 phenotypes) as between subject factors. Given that it was improbable (and clinically insignificant) to detect improvements in subjects with normal BP at baseline, the same comparisons were repeated in a subgroup of participants with elevated BP at baseline. These were defined as having high-normal or higher BP values (systolic BP ≥130 mmHg or diastolic BP ≥85 mmHg) [15]. To assess whether continuous smoking phenotypes were associated with changes in BP from baseline to week 52, a linear regression analysis was performed. The difference in BP between baseline and week 52 (ΔBP = week 52–baseline BP) was introduced as dependent variable, and continuous smoking phenotype, age, gender and weight change were introduced as independent factors.

The analyses were carried out using Statistical Package for Social Sciences (SPSS Inc., Chicago, IL) for Windows version 20.0 and two-tailed p values of <0.05 were considered significant.

Results

After screening 417 subjects, a total of 300 (190 males) regular smokers (190 males) were eligible and consented to participate in the study. The baseline characteristics of the participants per study group are presented in Table 1. Baseline characteristics were similar among study groups A, B, and C, with the exception of participants' age. No difference was observed in systolic BP, diastolic BP, and HR at baseline.

Table 1

Baseline characteristics of ECLAT study participants for the overall sample and separately for each treatment arms

	Overall sample (no. = 300)	**Group A (no. = 100)**	**Group B (no. = 100)**	**Group C (no. = 100)**	***P***
Gender (males/females)	190/110	61/39	66/34	63/37	NS
Age (years ± SD)	44.0 ± 12.5	45.9 ± 12.8	43.9 ± 12.2	42.2 ± 12.5	0.040*
Pack years [median (IQR)]	24.9 (14.0–37.0)	24.0 (14.3–37.0)	25.3 (16.9–38.8)	25.5 (12.0–35.0)	NS
Cig/day [median (IQR)]	20.0 (15.0–25.0)	19.0 (14.0–25.0)	21.0 (15.0–26.0)	22.0 (15.0–27.0)	NS
eCO [median (IQR)]	20.0 (15.0–28.0)	19.0 (15.5–29.0)	22.0 (16.0–29.0)	19.5 (14.0–28.0)	NS

FTND (mean ± SD)	5.8 ± 2.2	5.6 ± 2.3	6.0 ± 2.1	5.8 ± 2.2	NS
Past attempts to quit (% yes)	51	56	48	47	NS
Systolic BP (mmHg)	128.0 ± 15.3	127.8 ± 14.2	129.6 ± 17.1	126.7 ± 14.4	NS
Diastolic BP (mmHg)	78.7 ± 10.3	79.6 ± 9.8	78.4 ± 11.4	78.1 ± 9.7	NS
HR (beats per minute)	79.2 ± 1.7	78.2 ± 12.1	80.6 ± 12.7	78.8 ± 10.0	NS
Body weight (kg)	75.0 ± 15.0	74.0 ± 14.2	76.1 ± 15.3	74.8 ± 15.7	NS

Differences among groups were evaluated by χ^2 test for categorical variables, one-way analysis of variance (ANOVA) and Fisher protected LSD for parametric variables, and Kruskall–Wallis test for non-parametric variables

SD standard deviation, *IQR* interquartile range, *cig/day* cigarettes smoked per day, *eCO* exhaled carbon monoxide, *FTCD* Fagerström test of cigarette dependence, *BP* blood pressure, *HR* heart rate

* Difference between groups A and C (one-way ANOVA, Fisher's least significance difference)

Two hundred and twenty-five subjects (75.0 %) returned at week 12, 211 (70.3 %) at week 24, and 183 (61.0 %) at week 52 for the final follow-up visit. Baseline characteristics of those who were lost to follow-up were not significantly different from participants who completed the study (with the exception of gender; males were 58 % among subjects present at week 52 visit and 71 % among those lost to follow-up, $p = 0.03$), and no significant difference was observed in drop-out rates among study groups at any study visit.

Overall, reduction and quit rates (%) in the ECLAT study were not significantly different among study groups. In particular, at week 52 the quit rates were 13 % in Group A, 9 % in Group B, and 4 %in Group C. More details about success rates and tolerability with ECs have been reported in the ECLAT study [23]. The time trends of systolic BP, diastolic BP, and HR (in % of baseline value) from all participants that were examined at each follow-up visit are presented in Fig. 2. A slight but significant decrease in systolic BP was found at week 52 (123.1 ± 13.8 mmHg) with respect to baseline (128.0 ± 15.3 mmHg, $p = 0.004$). No significant effect of study groups was observed in any of the parameters.

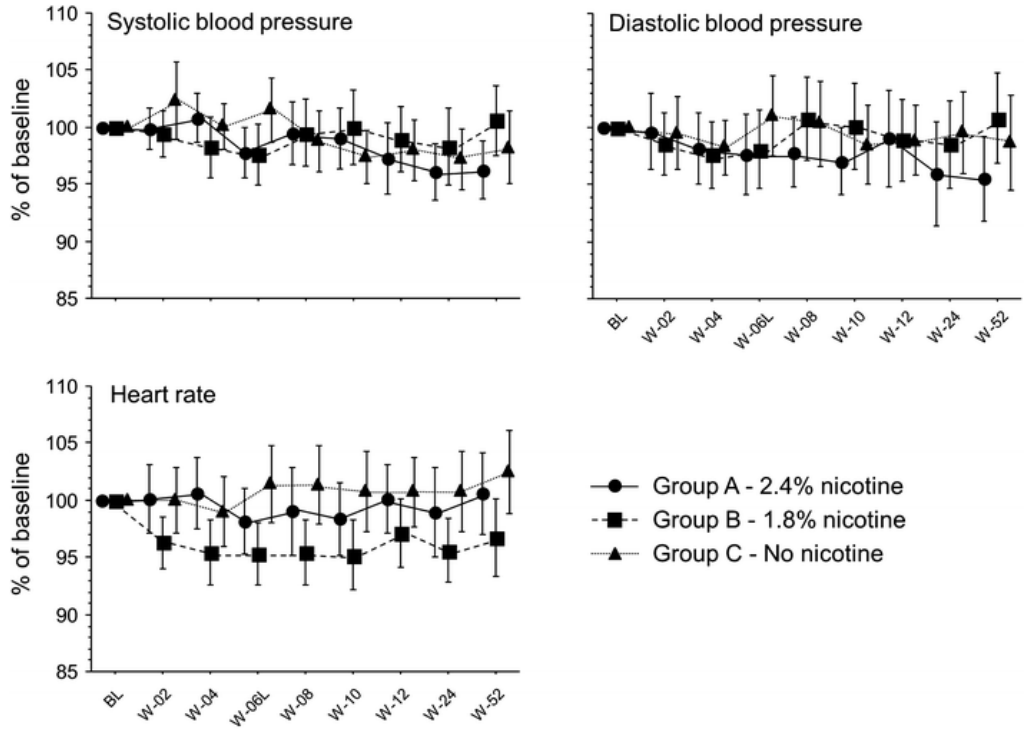

Fig. 2

Time course of systolic blood pressure, diastolic blood pressure, and heart rate (in % of baseline) for each step (means and 95 % CI) separately for study groups (A, B, and C). Within subjects changes were significant ($p = 0.004$) only for SBP, while no between subject effect (Group) was found (repeated measures ANOVA)

Among the 183 subjects who completed the follow-up visit at week 52, 145 had a continuous smoking phenotype from week 12 to week 52. The baseline characteristics of these participants are illustrated in Table 2. A small but statistically significant reduction in systolic BP was observed at week 52 compared to baseline (122.6 ± 13.3 vs. 126.0 ± 15.6 mmHg, respectively, $p = 0.001$); no effect of smoking phenotype classification was evident. Also, a small reduction in diastolic BP was observed at week 52 compared to baseline (75.2 ± 9.4 vs. 76.7 ± 9.9 mmHg, respectively, $p = 0.02$). No significant change in HR was observed (81.2 ± 13.0 vs 80.1 ± 11.8 beats/min, p = NS).

Table 2

Baseline characteristics of ECLAT study participants ($N = 145$) with continuous smoking phenotype classification from week 12 to week 52

	Failures (no. = 93)	**Reducers (no. = 34)**	**Quitters (no. = 18)**	***P* value**
Gender (M/F)	50/43	22/12	14/4	0.126*
Age (years, mean ± SD)	41.6 ± 13.0	45.4 ± 14.4	44.8 ± 10.5	0.276**
Pack years (median, IQ range)	24.5 (11.1–35.0)	28.3 (15.0–45.0)	23.0 (16.8–33.6)	0.301***
Cig/day (median, IQ range)	20 (15–25)	18 (15–30)	19 (15–20)	0.399***
eCO (median, IQ range)	21 (14–29)	20 (15–26)	17 (12–20)	0.108***
FTND (mean ± SD)	5.9 ± 2.1	5.2 ± 2.1	5.1 ± 2.3	0.182**

Systolic blood pressure (mmHg, mean ± SD)	124.0 ± 15.4	129.4 ± 15.0	130.2 ± 16.9	0.103**
Diastolic blood pressure (mmHg, mean ± SD)	75.8 ± 10.2	77.4 ± 9.7	79.7 ± 7.9	0.281**
Heart rate (beats per min, mean ± SD)	82.3 ± 13.1	79.0 ± 12.5	79.2 ± 13.2	0.350**
Weight (kg, mean ± SD)	70.7 ± 12.5	69.6 ± 12.4	74.4 ± 13.5	0.399**

* χ^2 test

** One-way analysis of variance (ANOVA) and Fisher protected LSD

*** Kruskall–Wallis test

From the subjects with continuous smoking phenotypes, 66 had elevated BP at baseline. When the above-mentioned analysis was repeated in these subjects, a statistically significant reduction in systolic BP was observed at week 52 compared to baseline (132.4 ± 12.0 vs. 141.2 ± 10.5 mmHg, respectively, $p < 0.001$). A significant effect is found for the continuous smoking phenotype classification, with quitters exhibiting the highest systolic BP reduction (16.3 ± 11.3 mmHg, $p = 0.005$), while Reducers and Failures show reductions of 10.8 ± 10.1 and 6.0 ± 12.5 mmHg, $p < 0.001$ and $p = 0.002$, respectively (Fig. 3). A significant reduction in diastolic BP was also observed at week 52 compared to baseline (77.6 ± 10.2 vs. 82.5 ± 9.8 mmHg, $p = 0.001$). No change in HR is found (79.3 ± 13.5 vs. 82.7 ± 14.5 beats/min, respectively, p = NS). No effect of smoking phenotype classification is evident for both diastolic BP and HR. No significant difference in BP changes from baseline is observed in quitters who stop using EC compared to quitters who still use EC (combined for groups A–C).

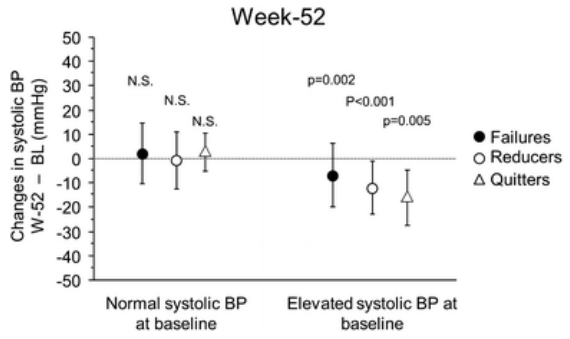

Fig. 3

Changes (mean ± SD, absolute mmHg) in systolic blood pressure (SBP) from baseline to week 52 for continuous smoking phenotypes, separately for subjects with normal and elevated SBP at baseline. *P* values for statistical significance of changes from baseline are shown

Of note, changes in body weight from baseline diff among smoking phenotype classifications. Quitters show a small but statistically significant increase in mean body weight from 74.7 ± 12.5 kg at baseline to 75.3 ± 13.5 at week 52 ($p = 0.038$), while no significant changes are observed in reducers or failures. After adjusting for weight change, gender and age, the mean reduction in systolic BP from baseline at week 52 remains associated significantly with both smoking reduction ($p = 0.046$ for reducers) and smoking abstinence ($p = 0.003$ for quitters) (Table 3). The β coefficient for quitters is more that twofold greater in absolute value compared to reducers.

Table 3

Multiple linear regression model in which the SBP change from BL to week 52 was entered as dependent variable and tested against continuous smoking phenotype classification, sex, age, and weight change as independent variables

Parameter	**β coefficient**	**95 % CI lower**	**95 % CI upper**	***P* value**
Reducers (ref: failures)	−6.76	−13.39	−0.13	0.046

Quitters (ref: failures)	−14.25	−23.70	−4.81	0.003
Sex (female, ref. male)	−4.93	−10.91	1.04	0.106
Age	−0.05	−0.25	0.16	0.659
Weight change (kg)[a]	0.49	−1.38	0.4	0.280

[a]Weight change at week 52 with respect to baseline

Discussion

This is the first study to investigate long-term changes in BP and HR in smokers who reduce or quit smoking by using ECs in a randomised control trial. Success rates (i.e., ≥50 % smoking reduction from baseline and complete abstinence from tobacco smoking) have been reported in the ECLAT study [*23*]. Herein, we describe a statistically significant reduction in systolic BP at week 52 in participants with elevated BP at baseline, which is associated with smoking reduction or abstinence even after adjusting for confounding factors. Moreover, similar changes in BP from baseline are observed in quitters who stopped using ECs compared to quitters who still use ECs.

Given the well-established effect of smoking on acute vasopressor and tachycardic responses and increased arterial stiffness, the observed reduction in systolic BP after long-lasting smoking reduction or abstinence is not surprising [*26*–*28*]. Nonetheless, the epidemiological evidence is not unequivocal, with some studies showing lower BP values in smokers compared with non-smokers, others reporting no association between smoking habit and blood pressure], and a few others showing that smoking is associated with high BP [*29*–*35*]. The current study, which evaluated the effect of a continuous smoking phenotype for 40 weeks (week 12 to 52) on BP, adds to the evidence that quitting does not lead to higher BP values, and this is observed independently of whether ECs are regularly used or not. Population studies have important methodological limitations that may predispose to heterogeneous results. First, these studies rely on self-reported tobacco use and casual collection of BP measurements. Second, because of their cross-sectional design, the observed relationship between levels of smoking and changes in BP does not imply causation. Last but not least, there is the possibility that such studies do not take into account other population characteristics (e.g., age, gender, weight increase, caffeine and alcohol intake), which may play a crucial role when determining potential causation. Moreover, these observational studies were conducted more than 30 years ago, and it is possible that confounders and cut-off limits in particular, might not be valid at the present time. Indeed, the impact of chronic cigarette smoking on BP assessed in a recent cross-sectional study of 33,860 randomly selected adults shows that older male smokers (>45 years old) have d higher systolic (but not diastolic) BP compared to non-smokers when adjusted for age, body mass index, social class, and alcohol intake [*9*].

Although smoking is not currently considered a risk factor for the development of hypertension, the impact of smoking cessation in patients with elevated or high-normal blood pressure has not been studied adequately (for example, in interventional prospective trials) [*15*]. In the present randomised controlled trial, a small reduction in BP at week 52 compared to baseline is observed in the whole study population, but no effect of smoking phenotype classification is found. This is not surprising, because it is highly unlikely to detect improvements in smokers with no history of hypertension, and with a normal BP at baseline. Moreover, it is unlikely that any reduction observed in subjects with baseline normal BP is of clinical significance. Although none of the participants was diagnosed as hypertensive, a proportion of them had high-normal or higher BP levels at baseline. In this subgroup of 66 smokers, a more substantial reduction in systolic and diastolic BP at week 52 is observed, with a significant effect now being found for smoking phenotype classification. The findings are important since it is well-established that high-normal BP is a risk factor for future development of hypertension, and is associated with an increased risk of myocardial infarction and coronary artery disease [*36*, *37*]. Mild BP elevations have also been associated with an increased thickness of the carotid media and intima, altered cardiac morphological features and left ventricular diastolic dysfunction [*38*–*40*]. Lifestyle changes are recommended in these cases, among which smoking cessation is particularly important. It is, therefore, reassuring that in our smoking cessation study both reducers and quitters have higher reductions in systolic bp compared to failures. the much stronger association observed in quitters, indicates that complete smoking abstinence provides greater benefit compared to smoking reduction.

Of note, the observed reduction in systolic BP remains significantly associated with both smoking reduction and smoking abstinence even after adjusting for age, gender, and weight change in the multiple linear regression analysis. Given the trivial weight gain in quitters at week 52 (only about 0.6 kg), this was not surprising. The observed weight gain is much lower than that reported in the literature [*41*, *42*], despite the fact that quitters were classified based on continuous abstinence over 40 weeks. This suggests that the combination of nicotine delivery and replacement of the rituals

associated with smoking behaviour during ECs use might have been the cause for the observed weight gain mitigation in quitters.

In agreement with the findings from other research groups, positive improvements in systolic BP after smoking cessation are noted not only in quitters, but also in reducers [*43*, *44*]. This suggests that the harmful effects of cigarette smoke on the vascular system can potentially be reversed. By substantially reducing exposure to conventional cigarettes' hazardous toxicants and achieving clinically relevant BP reductions, EC use may not only improve the cardiovascular risk profile but also confer an overall health advantage in smokers unable or unwilling to quit who are also at risk of developing arterial hypertension compared to continuing smoking. The use of low risk nicotine-containing products (including ECs) should be investigated as a safer alternative approach to harm reversal (i.e., specific reversal of BP elevation), and, in general, to harm reduction (i.e., overall reduction of cardiovascular risk associated with tobacco smoking) [*45*].

Our RCT has the advantage of an interventional prospective trial approach, which minimises the possibility of reverse causality of case–control and cross-sectional studies. Smoking abstinence was biochemically verified at each study visit and BP and HR monitoring was assessed making sure that participants were not smoking/vaping for at least 30 min prior to each measurements. The effects of specific continuous smoking phenotypes were investigated on BP and HR values in the same smokers over several time points for up to 1 year.

There are, however, some limitations. Firstly, participants in this study may represent a self-selected sample (e.g., smokers not intending to quit switching to ECs), which is not representative of all smokers quitting or reducing tobacco smoking. However, it still represents a good cohort of participants to ascertain the effects on BP and HR. Secondly, approximately 40 % of the participants failed to attend their final follow-up visit. Although high attrition rates in smoking cessation studies are not uncommon, this, together with the use of a continuous smoking phenotype classification, and the absence of financial incentive to study participants, might have further contributed to small sample size in some smoking phenotype subgroup cohorts. Thus, results should be interpreted with caution.

Additionally, confounding factors (e.g., salt intake, diet, recreational exercise, alcohol intake) which may have an influence on BP measures were not taken into account. Last but not least, findings from the early first generation e-cigarette ("cigalikes") under investigation may not be extended to newer-generation devices. It is anticipated that more advanced devices, by allowing a more fulfilling vaping experience compared to "cigalikes", can be more efficient at reducing or quitting smoking. Whether or not this would indeed have an impact on BP is a separate research question, which requires future testing.

Conclusions

Smokers who reduce or quit smoking by using ECs may lower their systolic BP in the long term, and this reduction is particularly apparent in smokers with an elevated BP. By showing BP reductions when reducing or stopping smoking for a sufficient period of time, this study adds to the current evidence that EC use appears to be a less harmful alternative to tobacco smoking [*46*].

In view of the limitation of the previous research applied to this area of clinical science, this paper is likely to set improved methodological approach for future studies addressing the role of smoking cessation and reduction on BP and HR as well as other relevant cardiovascular outcomes. Clinicians are asking for reliable and accurate health information in regular EC users. The evidence-based notion that substitution of conventional cigarettes with ECs is unlikely to raise significant health concerns can improve counselling between physicians and their cardiovascular patients using or intending to use ECs.

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Compliance with ethical standards

Conflict of interest

KF has no relevant conflict of interest to declare in relation to this work. His institution has received unrestricted funds from e-cigarette companies in 2013, which were used to perform 2 (unpublished) research studies on e-cigarettes. RP has received lecture fees and research funding from Pfizer and GlaxoSmithKline, manufacturers of stop smoking medications. He has also served in the past as a consultant for Pfizer and Arbi Group Srl, an Italian distributor of e-Cigarettes. RP is currently scientific advisor for LIAF, Lega Italiana Anti Fumo (Italian acronym for Italian Anti Smoking League). FC, PC, DC, JBM, EB, MC and CR have no relevant conflict of interest to declare in relation to this work.

Statement of human and animal rights

All procedures performed in our studies were in accordance with ethical standards of the 1964 Helsinki declaration and its later amendments. Our article does not contain any studies with human and animals performed by any of the authors.

Informed consent

Informed consent was obtained from all individual participants included in the study.

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Peering through the mist: What does the chemistry of contaminants in electronic cigarettes tell us about health risks?

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Abstract

The aim of this paper is to review available data on chemistry of aerosols and liquids of electronic cigarettes and to make predictions about compliance with occupational exposure limits of personal exposures of vapers (e-cigarette users) to compounds found in the aerosol. Both peer-reviewed and "grey" literatures were accessed and more than 9000 observations of highly variable quality were extracted. Comparisons to the most universally recognized workplace exposure standards, Threshold Limit Values (TLVs), were conducted under "worst case" assumptions about both chemical content of aerosol and liquids as well as behavior of vapers. The calculations reveal that there was no evidence of potential for exposures of e-cigarette users to contaminants that are associated with risk to health at a level that would warrant attention if it were an involuntary workplace exposures by approaching half of TLV. The vast majority of predicted exposures are <<1% of TLV. Predicted exposures to acrolein and formaldehyde are typically <5% TLV. Considering exposure to the aerosol as a mixture of contaminants did not indicate that exceeding half of TLV for mixtures was plausible. Only exposures to the declared major ingredients -- propylene glycol and glycerin -- warrant attention because of precautionary nature of TLVs for exposures to hydrocarbons with no established toxicity. Comparing the exposure to nicotine to existing occupational exposure standards is not valid so long as nicotine-containing liquid is not mislabeled as nicotine-free. It must be noted that the quality of much of the data that was available for these assessment was poor, and so much can be done to improve certainty in this risk assessment. However, the existing research is of the quality that is comparable with most workplace assessments for novel technologies. In summary, an analysis of current state of knowledge about chemistry of liquids and aerosols associated with electronic cigarettes indicates that there is no evidence that vaping produces inhalable exposures to *contaminants* of the aerosol that would warrant health concerns by the standards that are used to ensure safety of workplaces. However, the aerosol generated during vaping as a whole (contaminants *plus declared ingredients*), if it were an emission from industrial process, creates personal exposures that would justify surveillance of health among exposed persons in conjunction with investigation of means to keep health effects as low as reasonably achievable. Exposures of bystanders are likely to be orders of magnitude less, and thus pose no apparent concern.

Keywords**:** vaping, e-cigarettes, tobacco harm reduction, risk assessment, aerosol, occupational exposure limit

Introduction

Electronic cigarettes (also known as e-cigarettes) are generally recognized as a safer alternative to combusted tobacco products (reviewed in [1]), but there are conflicting claims about the degree to which these products warrant concern for the health of the vapers (e-cigarette users). A vaper inhales aerosol generated during heating of liquid contained in the e-cigarette. The technology and patterns of use are summarized by Etter [1], though there is doubt about how current, complete and accurate this information is. Rather conclusive evidence has been amassed to date on comparison of the chemistry of aerosol generated by electronic cigarettes to cigarette smoke [2-8]. However, it is meaningful to consider the question of whether aerosol generated by electronic cigarettes would warrant health concerns on its own, in part because vapers will include persons who would not have been smokers and for whom the question of harm reduction from smoking is therefore not relevant, and perhaps more importantly, simply because there is value in minimizing the harm of those practicing harm reduction.

One way of approaching risk evaluation in this setting is to rely on the practice, common in occupational hygiene, of relating the chemistry of industrial processes and the emissions they generate to the potential worst case of personal exposure and then drawing conclusions about whether there would be interventions in an occupational setting based on comparison to occupational exposure limits, which are designed to ensure safety of unintentionally exposed individuals. In that context, exposed individuals are assumed to be adults, and this assumption appears to be suitable for the intended consumers of electronic cigarettes. "Worst case" refers to the maximum personal exposure that can be achieved given what is known about the process that generates contaminated atmosphere (in the context of airborne exposure considered here) and the pattern of interaction with the contaminated atmosphere. It must be noted that harm reduction notions are embedded in this approach since it recognizes that while elimination of the exposure may be both impossible and undesirable, there nonetheless exists a level of exposure that is associated with negligible risks. To date, a comprehensive review of the chemistry of electronic cigarettes and the aerosols they generate has not been conducted, depriving the public of the important element of a risk-assessment process that is mandatory for environmental and occupational health policy making.

The present work considers both the contaminants present in liquids and aerosols as well as the declared ingredients in the liquids. The distinction between exposure to declared ingredients and contaminants of a consumer product is important in the context of comparison to occupational or environmental exposure standards. Occupational exposure limits are developed for unintentional exposures that a person does not elect to experience. For example, being a bread baker is a choice that does not involve election to be exposed to substances that cause asthma that are part of the flour dust (most commonly, wheat antigens and fungal enzymes). Therefore, suitable occupational exposure limits are created to attempt to protect individuals from such risk on the job, with no presumption of "assumed risk" inherent in the occupation. Likewise, special regulations are in effect to protect persons from unintentional exposure to nicotine in workplaces (http://www.cdc.gov/niosh/docs/81-123/pdfs/0446.pdf; accessed July 12, 2013), because in environments where such exposures are possible, it is reasonable to protect individuals who do not wish to experience its effects. In other words, occupational exposure limits are based on protecting people from involuntary and unwanted exposures, and thus can be seen as appropriately more stringent than the standards that might be used for hazards that people intentionally choose to accept.

By contrast, a person who elects to lawfully consume a substance is subject to different risk tolerance, as is demonstrated in the case of nicotine by the fact that legally sold cigarettes deliver doses of nicotine that exceed occupational exposure limits[9]: daily intake of 20 mg of nicotine, assuming nearly 100% absorption in the lungs and

inhalation of 4 m^3 of air, corresponds to roughly 10 times the occupational exposure limit of 0.5 mg/m^3 atmosphere over 8 hours[10]. Thus, whereas there is a clear case for applicability of occupational exposure limits to contaminants in a consumer product (e.g. aerosol of electronic cigarettes), there is no corresponding case for applying occupational exposure limits to declared ingredients desired by the consumer in a lawful product (e.g. nicotine in the aerosol of an electronic cigarette). Clearly, some limits must be set for voluntary exposure to compounds that are known to be a danger at plausible doses (e.g. limits on blood alcohol level while driving), but the regulatory framework should reflect whether the dosage is intentionally determined and whether the risk is assumed by the consumer. In the case of nicotine in electronic cigarettes, if the main reason the products are consumed is as an alternative source of nicotine compared to smoking, then the only relevant question is whether undesirable exposures that accompany nicotine present health risks, and the analogy with occupational exposures holds. In such cases it appears permissible to allow at least as much exposure to nicotine as from smoking before admitting to existence of new risk. It is expected that nicotine dosage will not increase in switching from smoking to electronic cigarettes because there is good evidence that consumers adjust consumption to obtain their desired or usual dose of nicotine[11]. The situation is different for the vapers who want to use electronic cigarettes without nicotine and who would otherwise not have consumed nicotine. For these individuals, it is defensible to consider total exposure, including that from any nicotine contamination, in comparison to occupational exposure limits. In consideration of vapers who would never have smoked or would have quit entirely, it must be remembered that the exposure is still voluntary and intentional, and comparison to occupational exposure limits is legitimate only for those compounds that the consumer does not elect to inhale.

The specific aims of this review were to:

1. Synthesize evidence on the chemistry of liquids and aerosols of electronic cigarettes, with particular emphasis on the contaminants.
2. Evaluate the quality of research on the chemistry of liquids and aerosols produced by electronic cigarettes.
3. Estimate potential exposures from aerosols produced by electronic cigarettes and compare those potential exposures to occupational exposure standards.

Methods

Literature search

Articles published in peer-reviewed journals were retrieved from *PubMed* (http://www.ncbi.nlm.nih.gov/pubmed/) using combinations of the following keywords: “electronic cigarettes”, “e-cigarettes”, “smoking alternatives”, “chemicals”, “risks”, “electronic cigarette vapor”, “aerosol”, “ingredients”, “e-cigarette liquid”, “e-cig composition”, “e-cig chemicals”, “e-cig chemical composition”, “e-juice electronic cigarette”, “electronic cigarette gas”, “electronic cigars”. In addition, references of the retrieved articles were examined to identify further relevant articles, with particular attention paid to non-peer reviewed reports and conference presentations. Unpublished results obtained through personal communications were also reviewed. The Consumer Advocates for Smoke-free Alternatives Association (CASAA) was asked to review the retrieved bibliography to identify any reports or articles that were missed. The papers and reports were retained for analysis if they reported on the chemistry of e-cigarette liquids or aerosols. No explicit quality control criteria were applied in selection of literature for examination, except that secondary reporting of analytical results was not used. Where substantial methodological problems that precluded interpretation of analytical results were noted, these are described below. For each article that contained relevant analytical results, the compounds quantified, limits of detection, and analytical results were summarized in a spreadsheet. Wherever possible, individual analytical results (rather than averages) were recorded (see electronic **Appendix A**:

https://dl.dropboxusercontent.com/u/4285761/CASAA/eAppendixA.xlsx). Data contained in **Appendix A** is not fully summarized in the current report but can be used to investigate a variety of specific questions that may interest the reader. Each entry in **Appendix A is** identified by a *Reference Manage ID* that is linked to source materials in a list in **Appendix B** (linked via *RefID*: https://dl.dropboxusercontent.com/u/4285761/CASAA/AppendixB.rtf) and attached electronic copies of all original materials (**Biobliography.zip**: https://dl.dropboxusercontent.com/u/4285761/CASAA/bibliography.zip).

Comparison of observed concentrations in aerosol to occupational exposure limits

For articles that reported mass or concentration of specific compounds in the aerosol (generated by smoking machines or from volunteer vapers), measurements of compounds were converted to concentrations in the "personal breathing zone",[a] which can be compared to occupational exposure limits (OELs). The 2013 Threshold Limit Values (TLVs)[10] were used as OELs because they are the most up to date and are most widely recognized internationally when local jurisdictions do not establish their own regulations (see http://www.ilo.org/oshenc/part-iv/occupational-hygiene/item/575; accessed July 3, 2013). Whenever there was an uncertainty in how to perform the calculation, a "worst case" scenario was used, as is the standard practice in occupational hygiene, where the initial aim is to recognize potential for hazardous exposures and to err on the side of caution. The following assumptions were made to enable the calculations that approximate the worst-case personal exposure of a vaper (Equation 1):

1. Air the vaper breathes consists of a small volume of aerosol generated by e-cigarettes that contains a specific chemical plus pristine air;
2. The volume of aerosols inhaled from e-cigarettes is negligible compared to total volume of air inhaled;
3. The period of exposure to the aerosol considered was normalized to 8 hours, for comparability to the standard working shift for which TLVs were developed (this does not mean only 8 hours worth of vaping was considered (see point 4) but rather that amount of breathing used to dilute the day's worth of vaping exposure was 8 hours);
4. Consumption of 150 puffs in 8 hours (an upper estimate based on a rough estimate of 150 puffs by a typical vaper in a day[1]) was assumed to be conservative;
5. Breathing rate is 8 liters per minute [12,13];
6. Each puff contains the same quantity of compounds studied.

$$[mg/m^3] = mg/puff \times puffs/(8\ hr\ day) \times 1/(m^3\ air\ inhaled\ in\ 8\ hr) \qquad Eq.\ 1$$

The only exception to this methodology was when assessing a study of aerosol emitted by 5 vapers in a 60 m^3 room over 5 hours that seemed to be a sufficient approximation of worst-case "bystander" exposure[6]. All calculated concentrations were expressed as the most stringent (lowest) TLV for a specific compound (i.e. assuming the most toxic form if analytical report is ambiguous) and expressed as "percent of TLV". Considering that all the above calculations are approximate and reflecting that exposures in occupational and general environment can easily vary by a factor of 10 around the mean, we added a 10-fold safety factor to the "percent of TLV" calculation. Details of all calculations are provided in an Excel spreadsheet (see electronic **Appendix C**: https://dl.dropboxusercontent.com/u/4285761/CASAA/eAppendixC.xlsx).

No systematic attempt was made to convert the content of the studied liquids into potential exposures because sufficient information was available on the chemistry of aerosols to use those studies rather than making the necessary

[a] Atmosphere that contains air inhaled by a person

simplifying assumptions to do the conversion. However, where such calculations were performed in the original research, the following approach as used: under the (probably false – see the literature on formation of carbonyl compounds below) assumption of no chemical reaction to generate novel ingredients, composition of liquids can be used to estimate potential for exposure if it can be established how much volume of liquid is consumed in given 8 hours, following an algorithm analogous to the one described above for the aerosols (Equation 2):

$$[mg/m^3] = mg/(mL\ liquid) \times (mL\ liquid)/puff \times puffs/(8\ hr\ day) \times 1/(m^3\ air\ inhaled\ in\ 8\ hr) \qquad Eq.\ 2$$

Comparison to cigarette smoke was not performed here because the fact that e-cigarette aerosol is at least orders of magnitude less contaminated by toxic compounds is uncontroversial [2-8].

Results and discussion

General comments on methods

In excess of 9,000 determinations of single chemicals (and rarely, mixtures) were reported in reviewed articles and reports, typically with multiple compounds per electronic cigarette tested [2-8,14-42]. Although the quality of reports is highly variable, if one assumes that each report contains some information, this asserts that quite a bit is known about composition of e-cigarette liquids and aerosols. The only report that was excluded from consideration was work of McAuley et al.[23] because of clear evidence of cross-contamination – admitted to by the authors – with cigarette smoke and, possibly, reagents. The results pertaining to non-detection of tobacco-specific nitrosamines (TSNAs) are potentially trustworthy, but those related to PAH are not since it is incredible that cigarette smoke would contain fewer polycyclic aromatic hydrocarbons (PAH; arising in incomplete combustion of organic matter) than aerosol of e-cigarettes that do not burn organic matter [23]. In fairness to the authors of that study, similar problems may have occurred in other studies but were simply not reported, but it is impossible to include a paper in a review once it is known for certain that its quantitative results are not trustworthy. When in doubt, we erred on the side of trusting that proper quality controls were in place, a practice that is likely to increase appearance of atypical or erroneous results in this review. From this perspective, assessment of concordance among independent reports gains higher importance than usual since it is unlikely that two experiments would be flawed in the same exact manner (though of course this cannot be assured).

It was judged that the simplest form of publication bias – disappearance of an entire formal study from the available literature – was unlikely given the exhaustive search strategy and the contested nature of the research question. It is clearly the case that only a portion of all industry technical reports were available for public access, so it is possible that those with more problematic results were systematically suppressed, though there is no evidence to support this speculation. No formal attempt was made to ascertain publication bias *in situ* though it is apparent that anomalous results do gain prominence in typical reviews of the literature: diethylene glycol[43,44] detected at non-dangerous levels (see details below) in one test of 18 of early-technology products by FDA[22] and one outlier in measurement of formaldehyde content of exhaled air [4] and aldehydes in aerosol generated from one e-cigarette in Japan [37]. It must be emphasized that the alarmist report of aldehydes in experiments presented in [37] is based on the concentration in generated aerosol rather than air inhaled by the vaper over prolonged period of time (since vapers do not inhale only aerosol). Thus, results reported in [37] cannot be the basis of any claims about health risk, a fallacy committed both by the authors themselves and commentators on this work [44].

It was also unclear from [37] what the volume of aerosol sampled was – a critical item for extrapolating to personal exposure and a common point of ambiguity in the published reports. However, in a personal exchange with the authors of [37][July 11, 2013], it was clarified that the sampling pump drew air at 500 mL/min through e-cigarette for 10 min, allowing more appropriate calculations for estimation of health risk that are presented below. Such misleading reporting is common in the field that confuses concentration in the aerosol (typically measured directly) with concentration in the air inhaled by the vaper (never determined directly and currently requiring additional assumptions and modeling). This is important because the volume of aerosol inhaled (maximum ~8 L/day) is negligible compared to the volume of air inhaled daily (8L/min); this point is illustrated in the **Figure**.

A similar but more extreme consideration applies to the exposure of bystanders which is almost certainly several orders of magnitude lower than the exposure of vapers. In part this is due to the absorption, rather than exhalation, of a portion of the aerosol by the vapers: there is no equivalent to the "side-stream" component of exposure to conventional cigarettes, so all of the exposure to bystanders results from exhalation. Furthermore, any environmental contamination that results from exhalation of aerosol by vaper will be diluted into the air prior to entering a bystander's personal breathing zone. Lastly, the number of puffs that affects exposure to bystander is likely to be much smaller than that of a vaper unless we are to assume that vaper and bystander are inseparable.

It is unhelpful to report results in cigarette-equivalents, as in [42], because this does not enable one to estimate exposures of vapers . Moreover, there is no value in comparison of the content of e-cigarette aerosol to cigarette smoke when the two products produce emissions that are orders of magnitude apart. To be useful for risk assessment, the results on the chemistry of the aerosols and liquids must be reported in a form that enables the calculations in Equations 1 and 2. It must be also be noted that typical investigations consisted of qualitative and quantitative phases such that quantitative data is available mostly on compounds that passed the qualitative screen. This biased all reports on concentration of compounds towards both higher levels and chemicals which a particular lab was most adept at analyzing.

Declared Ingredients: comparison to occupational exposure limits

Propylene glycol and glycerin have default or precautionary TLV of 10 mg/m^3 over 8 hours set for all organic mists with no specific exposure limits or identified toxicity (http://www.osha.gov/dts/chemicalsampling/data/CH_243600.html; accessed July 5, 2013). These interim TLVs tend to err on the side of being too high and are typically lowered if evidence of harm to health accumulates. For example, in a study that related exposure of theatrical fogs (containing propylene glycol) to respiratory symptoms [45], "mean personal inhalable aerosol concentrations were 0.70 mg/m^3 (range 0.02 to 4.1)" [46]. The only available estimate of propylene concentration of propylene glycol in the aerosol indicates personal exposure on the order of 3-4 mg/m^3 in the personal breathing zone over 8 hours (under the assumptions we made for all other comparisons to TLVs) [2]. The latest (2006) review of risks of occupational exposure to propylene glycol performed by the Health Council of the Netherlands (known for OELs that are the most protective that evidence supports and based exclusively on scientific considerations rather than also accounting for feasibility as is the case for the TLVs) recommended exposure limit of 50 mg/m^3 over 8 hours; concern over short-term respiratory effects was noted [http://www.gezondheidsraad.nl/sites/default/files/200702OSH.pdf; accessed July 29, 2013]. Assuming extreme consumption of the liquid per day via vaping (5 to 25 ml/day and 50-95% propylene glycol in the liquid)[b], levels of propylene glycol in inhaled air can reach 1-6 mg/m^3. It has been suggested that propylene glycol is

[b] This estimate of consumption was derived from informal reports from vaping community; 5 ml/day was identified as a high but not rare quantity of consumption and 25 ml/day was the high end of claimed use, though some skepticism was expressed about

very rapidly absorbed during inhalation [4,6] making the calculation under worst case scenario of all propylene glycol becoming available for inhalation credible. It must also be noted that when consuming low-nicotine or nicotine-free liquids, the chance to consume larger volumes of liquid increases (large volumes are needed to reach the target dose or there is no nicotine feedback), leading to the upper end of propylene glycol and glycerin exposure. Thus, estimated levels of exposure to propylene glycol and glycerin are close enough to TLV to warrant concern.

Nicotine is present in most liquids and has TLV of 0.5 mg/m^3 for average exposure intensity over 8 hours. If approximately 4 m^3 of air is inhaled in 8 hours, the consumption of 2 mg nicotine from e-cigarettes in 8 hours would place the vaper at the occupational exposure limit. For a liquid that contains 18 mg nicotine/ml, TLV would be reached upon vaping ~0.1-0.2 ml of liquid in a day, and so is achieved for most anyone vaping nicotine-containing e-cigarettes[1]. Results presented in [24] on 16 e-cigarettes also argue in favor of exceedance of TLV from most any nicotine-containing e-cigarette, as they predict >2mg of nicotine released to aerosol in 150 puffs (daily consumption figure adopted in this report). But as noted above, since delivery of nicotine is the purpose of nicotine-containing e-cigarettes, the comparison to limits on unintended, unwanted exposures does not suggest a problem and serves merely to offer complete context. If nicotine is present but the liquid is labeled as zero-nicotine [24,43], it could be treated as a contaminant, with the vaper not intending to consume nicotine and the TLV, which would be most likely exceeded, is relevant. However, when nicotine content is disclosed, even if inaccurately, then comparison to TLV is not valid. Accuracy in nicotine content is a concern with respect to truth in advertising rather than unintentional exposure, due to self-regulation of consumption by persons who use e-cigarettes as a source of nicotine.

Overall, the declared ingredients in the liquid would warrant a concern by standards used in occupational hygiene, provided that comparison to occupational exposure limits is valid, as discussed in the introduction. However, this is not to say that the exposure is affirmatively believed to be harmful; as noted, the TLVs for propylene glycol and glycerin mists is based on uncertainty rather than knowledge. These TLVs are not derived from knowledge of toxicity of propylene glycol and glycerin mists, but merely apply to any compound of no known toxicity present in workplace atmosphere. This aspect of the exposure from e-cigarettes simply has little precedent (but see study of theatrical fogs below). Therefore, the exposure will provide the first substantial collection evidence about the effects, which calls for monitoring of both exposure levels and outcomes, even though there are currently no grounds to be concerned about the immediate or chronic health effects of the exposure. The argument about nicotine is presented here for the sake of completeness and consistency of comparison to TLVs, but in itself does not affect the conclusions of this analysis because it should not be modeled as if it were a contaminant when declared as an ingredient in the liquid.

Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons (PAH) were quantified in several reports in aerosols [5,6,42] and liquids [7,18,41]. These compounds include well-known carcinogens, the levels of which are not subject to TLV but are instead to be kept “as low as reasonably achievable” (the so called ALARA principle)[10]. For PAH, only non-carcinogenic pyrene that is abundant in the general environment was detected at 36 ng/cartridge in 5 samples of liquid [7]; PAHs were not detected in most of the analyses of aerosols, except for chrysene in the analysis of the aerosol of one e-cigarette[42].

Tobacco-Specific Nitrosamines

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whether the latter quantity was truly possible. High-quality formal studies to verify these figures do not yet exist but they are consistent with report of Etter (2012).

The same risk assessment considerations that exist for PAH also hold for carcinogenic tobacco-specific nitrosamines (TSNAs)[47] for which no occupational exposure limits exist because (a) these exposures do not appear to occur in occupational settings often enough to warrant development of TLVs, and (b) it is currently accepted in establishing TLVs that carcinogens do not have minimal thresholds of toxicity. As expected because the TSNAs are contaminants of nicotine from tobacco leaf, there is also evidence of association between nicotine content of the liquid and TSNA concentrations, with reported concentrations <5 ng/cartridge tested [7]. Smaller studies of TSNA content in liquids are variable, with some not reporting any detectable levels [17,32,34] and others clearly identifying these compounds in the liquids when controlling for background contamination (n=9)[22]. Analyses of aerosols indicate that TSNAs are present in amounts that can results in doses of <ng/day[5,32] to µg/day [8] (assuming 150 puffs/day) (see also [42]). The most comprehensive survey of TSNA content of 105 samples of liquids from 11 manufactures indicates that almost all tested liquids (>90%) contained TSNAs in µg/L quantities [35]. This is roughly equivalent to 1/1000 of the concentration of TSNAs in modern smokeless tobacco products (like snus), which are in the ppm range [47]. The TSNA concentration of the liquids is orders of magnitude less than smokeless tobacco products, though the actual dosage from e-cigarettes vs. smokeless tobacco remains to be clearly understood. For example, 10 µg/L (0.01 ppm) of total TSNA in liquid[35] can translate to a daily dose of 0.000025-0.00005 µg from vaping (worst case assumption of 5 ml/day); if 15 g of snus is consumed a day [48] with 1 ppm of TSNAs [47] and half of it were absorbed, then the daily dose is estimated to be 0.008 µg, which is 160-320 times that due to the worst case of exposure from vaping. Various assumptions about absorption of TSNAs alter the result of this calculation by a factor that is dwarfed in magnitude compared to that arising from differences considered above. This is reassuring because smokeless tobacco products, such as snus, pose negligible cancer risk[49], certainly orders of magnitude smaller than smoking (if one considers the chemistry of the products alone). In general, it appears that the cautious approach in face of variability and paucity of data is to seek better understanding of predictors of presence of TSNA in liquids and aerosols so that measures for minimizing exposure to TSNAs from aerosols can be devised. This can include considering better control by manufactures of the nicotine.

Volatile Organic Compounds

Total volatile organic compounds (VOC) were determined in aerosol to be non-detectable[3] except in one sample that appeared to barely exceed the background concentration of 1 mg/m^3 by 0.73 mg/m^3[6]. These results are corroborated by analyses of liquids[18] and most likely testify to insensitivity of employed analytic methods for total VOC for characterizing aerosol generated by e-cigarettes, because there is ample evidence that specific VOC are present in the liquids and aerosols.[c] Information on specific commonly detected VOC in the aerosol is given in **Table 1a**. It must be observed that these reported concentrations are for analyses that first observed qualitative evidence of the presence of a given VOC and thus represent worst case scenarios of exposure when VOC is present (i.e. zero exposures are missing from the overall summary of worst case exposures presented here). For most VOC and aldehydes, one can predict the concentration in air inhaled by a vaper to be <<1% of TLV. The only exceptions to this generalization are:

(a) acrolein: ~1% of TLV (average of 12 measurements) and measurements at a mean of 2% of TLV (average of 150 measurements)[39,40] and

(b) formaldehyde: between 0 and 3% of TLV based on 18 tests (average of 12 measurements at 2% of TLV, the most reliable test) and an average of 150 results at 4% of TLV [39,40].

[c] The term "VOC" loosely groups together all organic compounds present in aerosol and because the declared ingredients of aerosol are organic compounds, it follows that "VOC are present"

Levels of acrolein in exhaled aerosol reported in [6] were below 0.0016 mg/m^3 and correspond to predicted exposure of <1% of TLV (**Table 2**). It must re-emphasized that all calculations based on one electronic cigarette analyzed in [37] are best treated as qualitative in nature (i.e. indicating presence of a compound without any particular meaning attached to the reported level with respect to typical levels) due to great uncertainty about whether the manner in which the e-cigarette was operated could have resulted in overheating that led to generation of acrolein in the aerosol. In fact, a presentation made by the author of [37] clearly stated that the "atomizer, generating high concentration carbonyls, had been burned black" [39,40]. In unpublished work,[39] there are individual values of formaldehyde, acrolein and glyoxal that approach TLV, but it is uncertain how typical these are because there is reason to believe the liquid was overheated; considerable variability among brands of electronic cigarettes was also noted. Formaldehyde and other aldehydes, but not acrolein, were detected in the analysis one e-cigarette [42]. The overwhelming majority of the exposure to specific VOC that are predicted to result from inhalation of the aerosols lie far below action level of 50% of TLV at which exposure has to be mitigated according to current code of best practice in occupational hygiene[50].

Finding of an unusually high level of formaldehyde by Schripp *et al.*[4] – 0.5 ppm predicted vs. 15-minute TLV of 0.3 ppm (not given in **Table 2**) – is clearly attributable to endogenous production of formaldehyde by the volunteer smoker who was consuming e-cigarettes in the experimental chamber, since there was evidence of build-up of formaldehyde prior to vaping and liquids used in the experiments did not generate aerosol with detectable formaldehyde. This places generalizability of other findings from [4] in doubt, especially given that the only other study of exhaled air by vapers who were not current smokers reports much lower concentrations for the same compounds [6] (**Table 2**). It should be noted that the report by Romagna *et al.*[6] employed more robust methodology, using 5 volunteer vapers (no smokers) over an extended period of time. Except for benzene, acetic acid and isoprene, all calculated concentrations for detected VOC were much below 1% of TLV in exhaled air [6]. In summary, these results do not indicate that VOC generated by vaping are of concern by standards used in occupational hygiene.

Diethylene glycol and ethylene glycol became a concern following the report of their detection by FDA[43], but these compounds are not detected in the majority of tests performed to date [3,14,16,18,22]. Ten batches of the liquid tested by their manufacture did not report any diethylene glycol above 0.05% of the liquid [41]. Methods used to detect diethylene glycol appear to be adequate to be informative and capable of detecting the compound in quantities <<1% of TLV[14,16,22]. Comparison to TLV is based on a worst case calculation analogous to the one performed for propylene glycol. For diethylene glycol, TLV of 10 mg/m^3 is applicable (as in the case of all aerosols with no know toxicity by inhalation), and there is a recent review of regulations of this compound conducted for the Dutch government by the Health Council of the Netherlands (jurisdiction with some of the most strict occupational exposure limits) that recommended OEL of 70 mg/m^3 and noted lack of evidence for toxicity following inhalation [http://www.gezondheidsraad.nl/sites/default/files/200703OSH.pdf; accessed July 29; 2013]. In conclusion, even the quantities detected in the single FDA result were of little concern, amounting to less than 1% of TLV.

Inorganic compounds

Special attention has to be paid to the chemical form of compounds when there is detection of metals and other elements by inductively coupled plasma mass spectrometry (ICP-MS)[8,25]. Because the parent molecule that occurs in the aerosol is destroyed in such analysis, the results can be alarmist and not interpretable for risk assessment. For example, the presence of sodium (4.18 µg/10 puffs)[25] does not mean that highly reactive and toxic sodium metal is in the aerosol, which would be impossible given its reactivity, but most likely means the presence of the ubiquitous compound that contains sodium, dissolved table salt (NaCl). If so, the corresponding daily dose of NaCl that arises from

these concentrations from 150 puffs is about 10,000 times lower than allowable daily intake according to CDC (http://www.cdc.gov/features/dssodium/; accessed July 4, 2013). Likewise, a result for presence of silica is meaningless for health assessment unless the crystalline form of SiO_2 is known to be present. When such ambiguity exists, a TLV equivalence calculation was not performed. We compared concentrations to TLVs when it was even remotely plausible that parent molecules were present in the aqueous solution. However, even these are to be given credence only in an extremely pessimistic analyst, and further investigation by more appropriate analytical methods could clarify exactly what compounds are present, but is not a priority for risk assessment. It should also be noted that one study that attempted to quantify metals in the liquid found none above 0.1-0.2 ppm levels [7] or above unspecified threshold [18]. **Table 1b** indicates that most metals that were detected were present at <1% of TLV even if we assume that the analytical results imply the presence of the most hazardous molecules containing these elements that can occur in aqueous solution. For example, when elemental chromium was measured, it is compared to TLV for insoluble chromium IV that has the lowest TLV of all chromium compounds. Analyses of metals given in [42] are not summarized here because of difficulty with translating reported units into meaningful terms for comparison with the TLV, but only mercury (again with no information on parent organic compound) was detected in trace quantities, but arsenic, beryllium, chromium, cadmium, lead and nickel were not. Taken as the whole, it can be inferred that there is no evidence of contamination of the aerosol with metals that warrants a health concern.

Consideration of exposure to a mixture of contaminants

All calculations conducted so far assumed only one contaminant present in clean air at a time. What are the implications of small quantities of various compounds with different toxicities entering the personal breathing zone at the same time? For evaluation of compliance with exposure limits for mixtures, Equation 3 is used:

$$\text{OEL}_{\text{mixture}} = \sum_{i=1}^{n} (C_i / TLV_i), \qquad \text{Eq. 3}$$

where C_i is the concentration of the i^{th} compound (i=1,…,n, where n>1 is the number of ingredients present in a mixture) in the contaminated air and TLV_i is the TLV for the i^{th} compound in the contaminated air; if $\text{OEL}_{\text{mixture}} > 1$, then there is evidence of the mixture exceeding TLV.

The examined reports detected no more than 5-10 compounds in the aerosol, and the above calculation does not place any of them out of compliance with TLV for mixture. Let us imagine that 50 compounds with TLVs were detected. Given that the aerosol tends to contain various compounds at levels, on average, of no more than 0.5% of TLV (**Table 1**), such a mixture with 50 ingredients would be at 25% of TLV, a level that is below that which warrants a concern, since the "action level" for implementation of controls is traditionally set at 50% of TLV to ensure that the majority of persons exposed have personal exposure below mandated limit [50]. Pellerino et al.[2] reached conclusions similar to this review based on their single experiment: contaminants in the liquids that warrant health concerns were present in concentrations that were less than 0.1% of that allowed by law in the European Union. Of course, if the levels of the declared ingredients (propylene glycol, glycerin, and nicotine) are considered, the action level would be met, since those ingredients are present in the concentrations that are near the action level. There are no known synergistic actions of the examined mixtures, so Equation 3 is therefore applicable. Moreover, there is currently no reason to suspect that the trace amounts of the contaminants will react to create compounds that would be of concern.

Conclusions

By the standards of occupational hygiene, current data do not indicate that exposures to vapers from contaminants in electronic cigarettes warrant a concern. There are no known toxicological synergies among compounds in the aerosol, and mixture of the contaminants does not pose a risk to health. However, exposure of vapers to propylene glycol and glycerin reaches the levels at which, if one were considering the exposure in connection with a workplace setting, it would be prudent to scrutinize the health of exposed individuals and examine how exposures could be reduced. This is the basis for the recommendation to monitor levels and effects of prolonged exposure to propylene glycol and glycerin that comprise the bulk of emissions from electronic cigarettes other than nicotine and water vapor. From this perspective, and taking the analogy of work on theatrical fogs [45,46], it can be speculated that respiratory functions and symptoms (but not cancer of respiratory tract or non-malignant respiratory disease) of the vaper is of primary interest. Monitoring upper airway irritation of vapers and experiences of unpleasant smell would also provide early warning of exposure to compounds like acrolein because of known immediate effects of elevated exposures (http://www.atsdr.cdc.gov/toxprofiles/tp124-c3.pdf; accessed July 11, 2013). However, it is questionable how much concern should be associated with observed concentrations of acrolein and formaldehyde in the aerosol. Given highly variable assessments, closer scrutiny is probably warranted to understand sources of this variability, although there is no need at present to be alarmed about exceeding even the occupational exposure limits, since occurrence of occasional high values is accounted for in established TLVs. An important clue towards a productive direction for such work is the results reported in [39,40] that convincingly demonstrate how heating the liquid to high temperatures generates compounds like acrolein and formaldehyde in the aerosol. A better understanding about the sources of TSNA in the aerosol may be of some interest as well, but all results to date consistently indicate quantities that are of no more concern than TSNA in smokeless tobacco products. Exposures to nicotine from electronic cigarettes is not expected to exceed that from smoking due to self-titration[11]; it is only a concern when a vaper does not intend to consume nicotine, a situation that can arise from incorrect labeling of liquids[24,43].

The cautions about propylene glycol and glycerin apply only to the exposure experienced by the vapers themselves. Exposure of bystanders to the listed ingredients, let alone the contaminants, does not warrant a concern as the exposure is likely to be orders of magnitude lower than exposure experienced by vapers. Further research employing realistic conditions could help quantify the quantity of exhaled aerosol and its behavior in the environment under realistic worst-case scenarios (i.e., not small sealed chambers), but this is not a priority since the exposure experienced by bystanders is clearly very low compared to the exposure of vapers, and thus there is no reason to expect it would have any health effects.

The key to making the best possible effort to ensure that hazardous exposures from contaminants do not occur is ongoing monitoring of actual exposures and estimation of potential ones. Direct measurement of personal exposures is not possible in vaping due to the fact the aerosol is inhaled directly, unless, of course, suitable biomarkers of exposure can be developed. The current review did not identify any suitable biomarkers, though cotinine is a useful proxy for exposure to nicotine-containing liquids. Monitoring of potential composition of exposures is perhaps best achieved though analysis of aerosol generated in a manner that approximates vaping, for which better insights are needed on how to modify “smoking machines” to mimic vaping given that there are documented differences in inhalation patterns[51]. These smoking machines would have to be operated under a realistic mode of operation of the atomizer to ensure that the process for generation of contaminants is studied under realistic temperatures. To estimate dosage (or exposure in personal breathing zone), information on the chemistry of aerosol has to be combined with models of the inhalation pattern of vapers, mode of operation of e-cigarettes and quantities of liquid consumed. Assessment of

exhaled aerosol appears to be of little use in evaluating risk to vapers due to evidence of qualitative differences in the chemistry of exhaled and inhaled aerosol.

Monitoring of liquid chemistry is easier and cheaper than assessment of aerosols. This can be done systematically as a routine quality control measure by the manufacturers to ensure uniform quality of all production batches. However, we do not know how this relates to aerosol chemistry because previous researchers have failed to appropriately pair analyses of chemistry of liquids and aerosols. It is standard practice in occupational hygiene to analyze the chemistry of materials generating an exposure, and it is advisable that future studies of the aerosols explicitly pair these analyses with examination of composition of the liquids used to generate the aerosols. Such an approach can lead to the development of predictive models that relate the composition of the aerosol to the chemistry of liquids, the e-cigarette hardware, and the behavior of the vaper, as these, if accurate, can anticipate hazardous exposures before they occur. The current attempt to use available data to develop such relationships was not successful due to studies failing to collect appropriate data. Systematic monitoring of quality of the liquids would also help reassure consumers and is best done by independent laboratories rather than manufactures to remove concerns about impartiality (real or perceived).

Future work in this area would greatly benefit from standardizing laboratory protocols (e.g. methods of extraction of compounds from aerosols and liquids, establishment of “core” compounds that have to be quantified in each analysis (as is done for PAH and metals), development of minimally informative detection limits that are needed for risk assessment, standardization of operation of “vaping machine”, etc.), quality control experiments (e.g. suitable positive and negative controls without comparison to conventional cigarettes, internal standards, estimation of %recovery, etc.), and reporting practices (e.g. in units that can be used to estimate personal exposure, use of uniform definitions of limits of detection and quantification, etc.), all of which would improve on the currently disjointed literature. Detailed recommendations on standardization of such protocols lie outside of scope of this report.

All calculations conducted in this analysis are based on information about patterns of vaping and the content of aerosols and liquids that are highly uncertain in their applicability to “typical” vaping as it is currently practiced and says even less about future exposures due to vaping. However, this is similar to assessments that are routinely performed in occupational hygiene for novel technology as it relied on “worst case” calculations and safety margins that attempt to account for exposure variability. The approach adopted here and informed by some data is certainly superior to some currently accepted practices in the regulatory framework in occupational health that rely purely on description of emission processes to make claims about potential for exposure (e.g.[52]). Clearly, routine monitoring of potential and actual exposure is required if we were to apply the principles of occupational hygiene to vaping. Detailed suggestions on how to design such exposure surveillance are available in [53].

In summary, analysis of the current state of knowledge about the chemistry of *contaminants* in liquids and aerosols associated with electronic cigarettes indicates that there is no evidence that vaping produces inhalable exposures to these contaminants at a level that would prompt measures to reduce exposure by the standards that are used to ensure safety of workplaces. Indeed, there is sufficient evidence to be reassured that there are no such risks from the broad range of the studied products, though the lack of quality control standards means that this cannot be assured for all products on the market. However, aerosol generated during vaping on the whole, when considering the declared ingredients themselves, if it were treated in the same manner as an emission from industrial process, creates personal exposures that would justify surveillance of exposures and health among exposed persons. Due to the uncertainty about the effects of these quantities of propylene glycol and glycerin, this conclusion holds after setting aside concerns about health effects of nicotine. This conclusion holds notwithstanding the benefits of tobacco harm reduction, since

there is value in understanding and possibly mitigating risks even when they are known to be far lower than smoking. It must be noted that the proposal for such scrutiny of "total aerosol" is not based on specific health concerns suggested by compounds that resulted in exceedance of occupational exposure limits, but is instead a conservative posture in the face of unknown consequences of inhalation of appreciable quantities of organic compounds that may or may not be harmful at doses that occur during vaping.

Key Conclusions:

- Even when compared to workplace standards for involuntary exposures, and using several conservative (erring on the side of caution) assumptions, the exposures from using e-cigarettes fall well below the threshold for concern for compounds with known toxicity. That is, even ignoring the benefits of e-cigarette use and the fact that the exposure is actively chosen, and even comparing to the levels that are considered unacceptable to people who are not benefiting from the exposure and do not want it, the exposures would not generate concern or call for remedial action.
- Expressed concerns about nicotine only apply to vapers who do not wish to consume it; a voluntary (indeed, intentional) exposure is very different from a contaminant.
- There is no serious concern about the contaminants such as volatile organic compounds (formaldehyde, acrolein, etc.) in the liquid or produced by heating. While these contaminants are present, they have been detected at problematic levels only in a few studies that apparently were based on unrealistic levels of heating.
- The frequently stated concern about contamination of the liquid by a nontrivial quantity of ethylene glycol or diethylene glycol remains based on a single sample of an early technology product (and even this did not rise to the level of health concern) and has not been replicated.
- Tobacco-specific nitrosamines (TSNA) are present in trace quantities and pose no more (likely much less) threat to health than TSNAs from modern smokeless tobacco products, which cause no measurable risk for cancer.
- Contamination by metals is shown to be at similarly trivial levels that pose no health risk, and the alarmist claims about such contamination are based on unrealistic assumptions about the molecular form of these elements.
- The existing literature tends to overestimate the exposures and exaggerate their implications. This is partially due to rhetoric, but also results from technical features. The most important is confusion of the concentration in aerosol, which on its own tells us little about risk to heath, with the relevant and much smaller total exposure to compounds in the aerosol averaged across all air inhaled in the course of a day. There is also clear bias in previous reports in favor of isolated instances of highest level of chemical detected across multiple studies, such that average exposure that can be calculated are higher than true value because they are "missing" all true zeros.
- Routine monitoring of liquid chemistry is easier and cheaper than assessment of aerosols. Combined with an understanding of how the chemistry of the liquid affects the chemistry of the aerosol and insights into behavior of vapers, this can serve as a useful tool to ensure the safety of e-cigarettes.
- The only unintentional exposures (i.e., not the nicotine) that seem to rise to the level that they are worth further research are the carrier chemicals themselves, propylene glycol and glycerin. This exposure is not known to cause health problems, but the magnitude of the exposure is novel and thus is at the levels for concern based on the lack of reassuring data.

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Figure: Illustrating the difference between concentrations in the aerosol generated by vaping and inhaled air in a day. *Panel A* shows black square that represents aerosol contaminated by some compound as it would be measured by a "smoking machine" and extrapolated to dosage from vaping in one day. This black square is located inside the white square that represents total uncontaminated air that is inhaled in a day by a vaper. The relative sizes of the two squares are exaggerated as the volume of aerosol generated in vaping relative to inhaled air is much smaller in the figure. *Panel B* shows how exposure from contaminated air (black dots) is diluted over a day for appropriate comparison to occupational exposure limits that are expressed in terms of "time-weighted average" or average contamination over time rather than as instantaneous exposures (with the exception of "ceiling limits" that do not affect the vast majority of comparisons in this report). Exposure during vaping occurs in a dynamic process where the atmosphere inhaled by the vaper alternates between the smaller black and larger white squares in *Panel A*. Thus, the concentration of contaminants that a vaper is exposed to over a day is much smaller than that which is measured in the aerosol (and routinely improperly cited as reason for concern about "high" exposures).

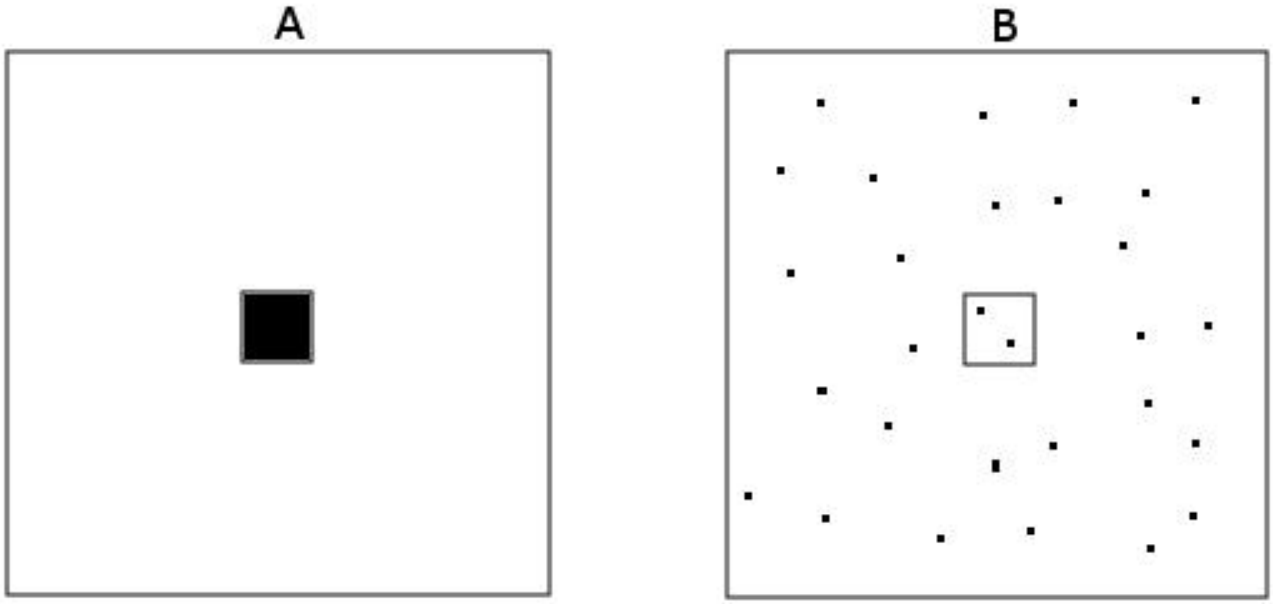

Table 1a: Exposure predictions based on analysis of aerosols generated by smoking machines: Volatile Organic Compounds

Compound	N#	Estimated concentration in personal breathing zone		Ratio of most stringent TLV (%)		Reference
		PPM	mg/m^3	Calculated directly	Safety factor 10	
Acetaldehyde	1	0.005		**0.02**	**0.2**	[5]
	3	0.003		**0.01**	**0.1**	[4]
	12	0.001		**0.004**	**0.04**	[8]
	1	0.00004		**0.0001**	**0.001**	[3]
	1	0.0002		**0.001**	**0.008**	[3]
	150	0.001		**0.004**	**0.04**	[39,40]
	1	0.008		**0.03**	**3**	[37]
Acetone	1	0.002		**0.0003**	**0.003**	[37]
	150	0.0004		**0.0001**	**0.001**	[39,40]
Acrolein	12	0.001		**1**	**13**	[8]
	150	0.002		**2**	**20**	[39,40]
	1	0.006		**6**	**60**	[37]
Butanal	150	0.0002		**0.001**	**0.01**	[39,40]
Crotonaldehyde	150		0.0004	**0.01**	**0.1**	[39,40]
Formaldehyde	1	0.002		**0.6**	**6**	[5]
	3	0.008		**3**	**30**	[4]
	12	0.006		**2**	**20**	[8]
	1	<0.0003		**<0.1**	**<1**	[3]
	1	0.0003		**0.1**	**1**	[3]
	150	0.01		**4**	**40**	[39,40]
	1	0.009		**3**	**30**	[37]
Glyoxal	1		0.002	**2**	**20**	[37]
	150		0.006	**6**	**60**	[39,40]
o-Methylbenzaldehyde	12		0.001	**0.05**	**0.5**	[8]
p,m-Xylene	12		0.00003	**0.001**	**0.01**	[8]
Propanal	3	0.002		**0.01**	**0.1**	[4]
	150	0.0006		**0.002**	**0.02**	[39,40]
	1	0.005		**0.02**	**0.2**	[37]
Toluene	12	0.0001		**0.003**	**0.03**	[8]
Valeraldehyde	150		0.0001	**0.0001**	**0.001**	[39,40]

average is presented when N>1

Table 1b: Exposure predictions based on analysis of aerosols generated by smoking machines: Inorganic Compounds[#]

Element quantified	Assumed compound containing the element for comparison with TLV	N[##]	Estimated concentration in personal breathing zone (mg/m^3)	Ratio of most stringent TLV (%)		Reference
				Calculated directly	Safety factor 10	
Aluminum	Respirable Al metal & insoluble compounds	1	0.002	**0.2**	**1.5**	[25]
Barium	Ba & insoluble compounds	1	0.00005	**0.01**	**0.1**	[25]
Boron	Boron oxide	1	0.02	**0.1**	**1.5**	[25]
Cadmium	Respirable Cd & compounds	12	0.00002	**1**	**10**	[8]
Chromium	Insoluble Cr (IV) compounds	1	3E-05	**0.3**	**3**	[25]
Copper	Cu fume	1	0.0008	**0.4**	**4.0**	[25]
Iron	Soluble iron salts, as Fe	1	0.002	**0.02**	**0.2**	[25]
Lead	Inorganic compounds as Pb	1	7E-05	**0.1**	**1**	[25]
		12	0.000025	**0.05**	**0.5**	[8]
Magnesium	Inhalable magnesium oxide	1	0.00026	**0.003**	**0.03**	[25]
Manganese	Inorganic compounds, as Mn	1	8E-06	**0.04**	**0.4**	[25]
Nickel	Inhalable soluble inorganic compounds, as Ni	1	2E-05	**0.02**	**0.2**	[25]
		12	0.00005	**0.05**	**0.5**	[8]
Potassium	KOH	1	0.001	**0.1**	**1**	[25]
Tin	Organic compounds, as Sn	1	0.0001	**0.1**	**1**	[25]
Zinc	Zinc chloride fume	1	0.0004	**0.04**	**0.4**	[25]
Zirconium	Zr and compounds	1	3E-05	**0.001**	**0.01**	[25]
Sulfur	SO_2	1	0.002	**0.3**	**3**	[25]

The actual molecular form in the aerosol unknown and so worst case assumption was made if it was physically possible (e.g. it is not possible for elemental lithium & sodium to be present in the aerosol); there is no evidence from the research that suggests the metals were in the particular highest risk form, and in most cases a general knowledge of chemistry strongly suggests that this is unlikely. Thus, the TLV ratios reported here probably do not represent the (much lower) levels that would result if we knew the molecular forms.

average is presented when N>1

Table 2: Exposure predictions for volatile organic compounds based on analysis of aerosols generated by volunteer vapers

Compound	N[#]	Estimated concentration in personal breathing zone (ppm)	Ratio of most stringent TLV (%)		Reference
			Calculated directly	Safety factor 10	
2-butanone (MEK)	3	0.04	**0.02**	0.2	[4]
	1	0.002	**0.0007**	0.007	[6]
2-furaldehyde	3	0.01	**0.7**	7	[4]
Acetaldehyde	3	0.07	**0.3**	3	[4]
Acetic acid	3	0.3	**3**	30	[4]
Acetone	3	0.4	**0.2**	2	[4]
Acrolein	1	<0.001	**<0.7**	<7	[6]
Benzene	3	0.02	**3**	33	[4]
Butyl hydroxyl toluene	1	4E-05	**0.0002**	0.002	[6]
Isoprene	3	0.1	**7**	70	[4]
Limonene	3	0.009	**0.03**	0.3	[4]
	1	2E-05	**0.000001**	0.00001	[6]
m,p-Xyelen	3	0.01	**0.01**	0.1	[4]
Phenol	3	0.01	**0.3**	3	[4]
Propanal	3	0.004	**0.01**	0.1	[4]
Toluene	3	0.01	**0.07**	0.7	[4]

average is presented when N>1

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Safety evaluation and risk assessment of electronic cigarettes as tobacco cigarette substitutes: a systematic review

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***Abstract*:** Electronic cigarettes are a recent development in tobacco harm reduction. They are marketed as less harmful alternatives to smoking. Awareness and use of these devices has grown exponentially in recent years, with millions of people currently using them. This systematic review appraises existing laboratory and clinical research on the potential risks from electronic cigarette use, compared with the well-established devastating effects of smoking tobacco cigarettes. Currently available evidence indicates that electronic cigarettes are by far a less harmful alternative to smoking and significant health benefits are expected in smokers who switch from tobacco to electronic cigarettes. Research will help make electronic cigarettes more effective as smoking substitutes and will better define and further reduce residual risks from use to as low as possible, by establishing appropriate quality control and standards.

Keywords: electronic cigarettes, e-liquid, e-vapor, harm reduction, nicotine, safety, tobacco

Introduction

Complete tobacco cessation is the best outcome for smokers. However, the powerful addictive properties of nicotine and the ritualistic behavior of smoking create a huge hurdle, even for those with a strong desire to quit. Until recently, smokers were left with just two alternatives: either quit or suffer the harmful consequences of continued smoking. This gloomy scenario has allowed the smoking pandemic to escalate, with nearly 6 million deaths annually and a predicted death toll of 1 billion within the 21st century [World Health Organization, 2013]. But a third choice, involving the use of alternative and much safer sources of nicotine with the goal to reduce smoking-related diseases is now available: tobacco harm reduction (THR) [Rodu and Godshall, 2006].

Electronic cigarettes (ECs) are the newest and most promising products for THR [Polosa *et al.* 2013b]. They are electrically-driven devices consisting of the battery part (usually a lithium battery), and an atomizer where liquid is stored and is aerosolized by applying energy and generating heat to a resistance encircling a wick. The liquid used mainly consists of propylene glycol, glycerol, distilled water, flavorings (that may or may not be approved for food use) and nicotine. Consumers (commonly called 'vapers') may choose from several nicotine strengths, including non-nicotine liquids, and a countless list of flavors; this assortment is a characteristic feature that distinguishes ECs from any other THR products. Since their invention in 2003, there has been constant innovation and development of more efficient and appealing products. Currently, there are mainly three types of devices available [Dawkins, 2013], depicted in Figure 1. (1) First-generation devices, generally mimicking the size and look of regular cigarettes and consisting of small lithium batteries and cartomizers (i.e. cartridges, which are usually prefilled with a liquid that bathes the atomizer). Batteries may be disposable (to be used once only) or rechargeable. (2) Second-generation devices, consisting mainly of higher-capacity lithium batteries and atomizers with the ability to refill them with liquid (sold in separate bottles). In the most recent atomizers you can simply change the atomizer head (resistance and wick) while keeping the body of the atomizer, thus reducing the operating costs. (3) Third-generation devices (also called 'Mods', from modifications),

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Figure 1. Examples of electronic cigarette devices currently available on the market.

consisting of very large-capacity lithium batteries with integrated circuits that allow vapers to change the voltage or power (wattage) delivered to the atomizer. These devices can be combined with either second-generation atomizers or with rebuildable atomizers, where the consumers have the ability to prepare their own setup of resistance and wick.

Awareness and use (vaping) of ECs has increased exponentially in recent years. Data obtained from the HealthStyles survey showed that, in the US, awareness of ECs rose from 40.9–57.9% from 2010 to 2011, with EC use rising from 3.3–6.2% over the same time period [King *et al.* 2013]. In the United Kingdom, EC use in regular smokers increased from 2.7% in 2010 to 6.7% in 2012 [Dockrell *et al.* 2013]. Similar findings were obtained from the International Tobacco Control Four-Country Survey [Adkison *et al.* 2013]. A recent prospective study in Swiss army recruits showed that 12% of smokers who tried ECs progressed to daily use [Douptcheva *et al.* 2013]. It must be noted that this increase in EC use has occurred despite the concerns raised by public health authorities about the safety and appropriateness of using these products as alternatives to smoking [National Association of Attorneys General, 2013; Food and Drug Administration, 2009; Mayers, 2009].

The popularity of ECs may be due to their ability to deal both with the physical (i.e. nicotine) and the behavioral component of smoking addiction. In particular, sensory stimulation [Rose and Levin, 1991] and simulation of smoking behavior and cigarette manipulation [Hajek *et al.* 1989] are important determinants of a product's effectiveness in reducing or completely substituting smoking. These features are generally absent in nicotine replacement therapies (NRTs) and oral medications for nicotine dependence, whereas ECs are unique in that they provide rituals associated with smoking behavior (e.g. hand-to-mouth movement, visible 'smoke' exhaled) and sensory stimulation associated with it [Farsalinos *et al.* 2013b]. This explains why these products can be effective in reducing consumption of tobacco smoking [Bullen *et al.* 2013; Caponnetto *et al.* 2013b; Polosa *et al.* 2011] and are efficient as long-term substitutes of conventional cigarettes [Farsalinos *et al.* 2013b].

Methods

For this systematic review (Figure 2), we searched the PubMed electronic database by using keywords related to ECs and/or their combination (e-cigarette, electronic cigarette, electronic nicotine delivery systems). We obtained a total of 354 results, and selected 41 studies we judged relevant to research on EC safety/risk profile. Reference lists from these studies were also examined to identify relevant articles. We searched additional information in abstracts presented at scientific congresses (respiratory, cardiovascular, tobacco control, toxicology), and in reports of chemical analyses on EC samples that were available online. We also looked for selected studies on chemicals related to EC ingredients (e.g. nicotine, propylene glycol, glycerol, cinnamaldehyde, microparticles emission, etc.), but not specifically evaluated in EC research. In total, 97 publications were found, from which 15 chemical analyses of single or a limited number of EC samples were excluded because they were discussed in a review paper [Cahn and Siegel, 2011]. In total, 114 studies are cited in this paper.

Risk differences compared with conventional cigarettes and the issue of nicotine

Conventional cigarettes are the most common form of nicotine intake. Smoking-related diseases are pathophysiologically attributed to oxidative stress, activation of inflammatory pathways and the toxic effect of more than 4000 chemicals and carcinogens present in tobacco smoke [Environmental Protection Agency, 1992]. In addition, each puff contains $>1 \times 10^{15}$ free radicals [Pryor and Stone, 1993]. All of these chemicals are emitted mostly during the combustion process, which is absent in ECs. Although the addictive potential of nicotine and related compounds is largely documented [Guillem *et al.*

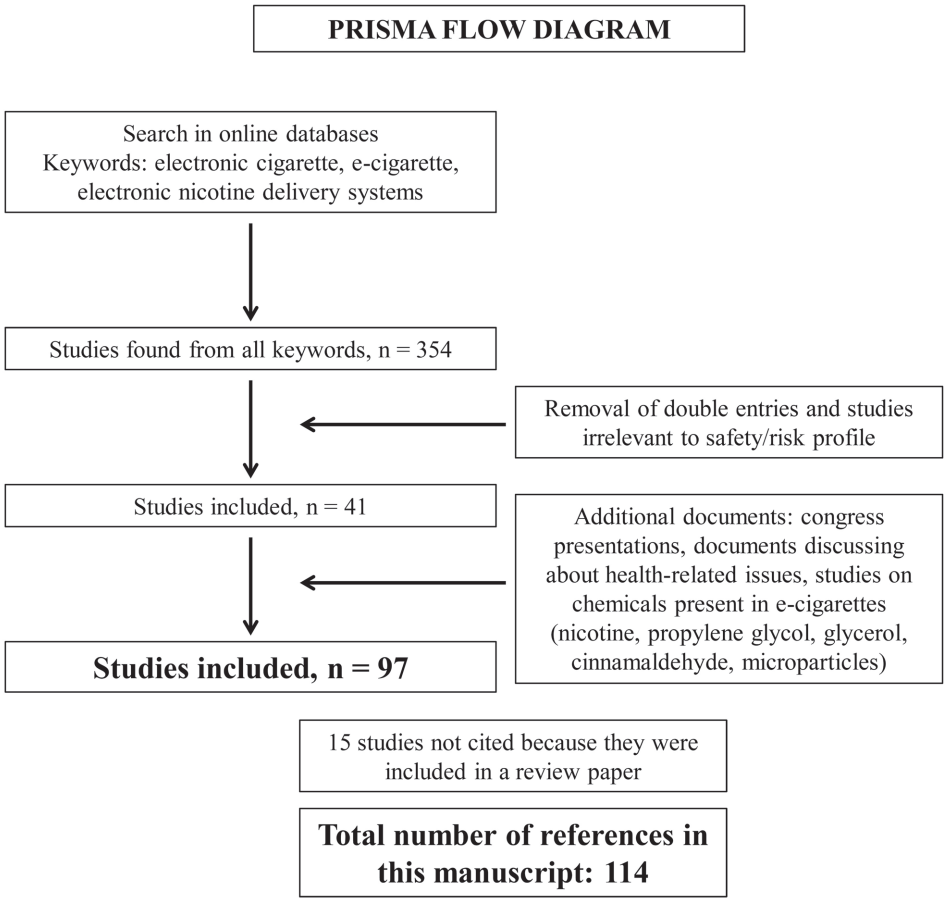

Figure 2. Methodology for literature research and selection of studies.

2005], much less dissemination has been given to the notion that nicotine does not contribute to smoking-related diseases. It is not classified as a carcinogen by the International Agency for Research on Cancer [WHO-IARC, 2004] and does not promote obstructive lung disease. A major misconception, commonly supported even by physicians, is that nicotine promotes cardiovascular disease. However, it has been established that nicotine itself has minimal effect in initiating and promoting atherosclerotic heart disease [Ambrose and Barua, 2004]. It does not promote platelet aggregation [Zevin *et al.* 1998], does not affect coronary circulation [Nitenberg and Antony, 1999] and does not adversely alter the lipid profile [Ludviksdottir *et al.* 1999]. An observational study of more than 33,000 smokers found no evidence of increased risk for myocardial infarction or acute stroke after NRT subscription, although follow up was only 56 days [Hubbard *et al.* 2005]. Up to 5 years of nicotine gum use in the Lung Health Study was unrelated to cardiovascular diseases or other serious side effects [Murray *et al.* 1996]. A meta-analysis of 35 clinical trials found no evidence of cardiovascular or other life-threatening adverse effects caused by nicotine intake [Greenland *et al.* 1998]. Even in patients with established cardiovascular disease, nicotine use in the form of NRTs does not increase cardiovascular risk [Woolf *et al.* 2012; Benowitz and Gourlay, 1997]. It is anticipated that any product delivering nicotine without involving combustion, such as the EC, would confer a significantly lower risk compared with conventional cigarettes and to other nicotine containing combustible products.

The importance of using nicotine in the long-term was recognized several years ago by Russell, indicating that the potential of nicotine delivery systems as long-term alternatives to tobacco should be explored in order to make the elimination of tobacco a realistic future target [Russell, 1991]. However, current regulations restrict the

long-term use of pharmaceutical or recreational nicotine products (such as snus) [Le Houezec *et al.* 2011]. In other words, nicotine intake has been demonized, although evidence suggests that, besides being useful in smoking cessation, it may even have beneficial effects in a variety of disorders such as Parkinson's disease [Nielsen *et al.* 2013], depression [McClernon *et al.* 2006], dementia [Sahakian *et al.* 1989] and ulcerative colitis [Guslandi, 1999]. Obviously, the addictive potential is an important factor in any decision to endorse nicotine administration; however, it should be considered as slight 'collateral damage' with minimal impact to vapers' health compared with the tremendous benefit of eliminating all disease-related substances coming from tobacco smoking. In fact, smokers are already addicted to nicotine; therefore the use of a 'cleaner' form of nicotine delivery would not represent any additional risk of addiction. Surveys have shown that ECs are used as long-term substitutes to smoking [Dawkins *et al.* 2013; Etter and Bullen, 2012]. Although consumers try to reduce nicotine use with ECs, many are unable to completely stop its intake, indicating an important role for nicotine in the ECs' effectiveness as a smoking substitute [Farsalinos *et al.* 2013b].

Nicotine overdose or intoxication is unlikely to occur with vaping, since the amount consumed [Farsalinos *et al.* 2013c] and absorbed [Nides *et al.* 2014; Dawkins and Corcoran, 2013] is quite low. Moreover, although not yet proven, it is expected that vapers will self-titrate their nicotine intake in a similar way to tobacco cigarettes [Benowitz *et al.* 1998]. Last, but not least, there is evidence suggesting that nicotine cannot be delivered as fast and effectively from ECs compared to tobacco cigarettes [Farsalinos *et al.* 2014]. Therefore, it seems that ECs have a huge theoretical advantage in terms of health risks compared with conventional cigarettes due to the absence of toxic chemicals that are generated in vast quantities by combustion. Furthermore, nicotine delivery by ECs is unlikely to represent a significant safety issue, particularly when considering they are intended to replace tobacco cigarettes, the most efficient nicotine delivery product.

Studies on the safety/risk profile of ECs

Findings on the safety/risk profile of ECs have just started to accumulate. However, this research must be considered work in progress given that the safety/risk of any product reflects an evolving body of knowledge and also because the product itself is undergoing constant development.

Existing studies about the safety/risk profile of ECs can be divided into chemical, toxicological and clinical studies (Table 1). Obviously, clinical studies are the most informative, but also the most demanding because of several methodological, logistical, ethical and financial challenges. In particular, exploring safety/risk profile in cohorts of well-characterized users in the long-term is required to address the potential of future disease development, but it would take hundreds of users to be followed for a substantial number of years before any conclusions are made. Therefore, most research is currently focused on *in vitro* effects, with clinical studies confined into evaluation of short-term use or pathophysiological mechanisms of smoking-related diseases.

Chemical studies

Chemical studies are relatively simple and cheap to perform and provide quick results. However, there are several disadvantages with this approach. Research is usually focused on the known specific chemicals (generally those known to be toxic from studies of cigarette smoke) and fails to address unknown, potentially toxic contaminants that could be detected in the liquid or the emitted aerosol. Problems may also arise from the detection of the chemicals in flavors. Such substances, although approved for use in the food industry, have largely unknown effects when heated and inhaled; thus, information on the presence of such substances is difficult to interpret in terms of *in vivo* effects. In fact, chemical studies do not provide any objective information about the effects of use; they can only be used to calculate the risk based on theoretical models and on already established safety levels determined by health authorities. An overview of the chemical studies performed on ECs is displayed in Table 2.

Laugesen performed the first studies evaluating the chemical composition of EC aerosols [Laugesen, 2008, 2009]. The temperature of the resistance of the tested EC was 54°C during activation, which is approximately 5–10% of the temperature of a burning tobacco cigarette. Toxic chemicals such as heavy metals, carcinogenic polycyclic aromatic hydrocarbons and phenols were not detected, with the exception of trivial amounts of mercury (0.17 ng per EC) and traces of formaldehyde and acetaldehyde. Laugesen

Table 1. Types of studies performed to determine safety and to estimate risk from EC use.

Type of studies	Research subject	Advantages	Disadvantages
Chemical studies	Evaluate the chemical composition of liquids and/or aerosol. Examine environmental exposure (passive 'vaping').	Easier and faster to perform. Less expensive. Could realistically be implemented for regulatory purposes.	Usually targeted on specific chemicals. Unknown effects of flavorings when inhaled. No validated protocols for vapor production. Provide no objective evidence about the end results (effects) of use (besides by applying theoretical models).
Toxicological studies	Evaluate the effects on cell cultures or experimental animals.	Provide some information about the effects from use.	Difficult to interpret the results in terms of human *in vivo* effects. More expensive than chemical studies. Need to test aerosol and not liquid. Standards for exposure protocols have not been clearly defined.
Clinical studies	Studies on human *in vivo* effects.	Provide definite and objective evidence about the effects of use.	Difficult and expensive to perform. Long-term follow up is needed due to the expected lag from initiation of use to possible development of any clinically evident disease. For now, limited to acute effects from use.

evaluated emissions based on a toxicant emissions score and reported a score of 0 in ECs compared with a score of 100–134 for tobacco cigarettes (Figure 3). The US Food and Drug Administration (FDA) also performed chemical analyses on 18 commercially available products in 2009 [Westenberger, 2009]. They detected the presence of tobacco-specific nitrosamines (TSNAs) but did not declare the levels found. Small amounts of diethylene glycol were also found in one sample, which was unlikely to cause any harm from normal use. Another study identified small amounts of amino-tandalafil and rimonambant in EC liquids [Hadwiger *et al.* 2010]. Subsequently, several laboratories performed similar tests, mostly on liquids, with Cahn and Siegel publishing a review on the chemical analyses of ECs and comparing the findings with tobacco cigarettes and other tobacco products [Cahn and Siegel, 2011]. They reported that TSNA levels were similar to those measured in pharmaceutical NRTs. The authors concluded that, based on chemical analysis, ECs are far less harmful compared with tobacco cigarettes. The most comprehensive study on TSNAs has been performed recently by a South Korean group, evaluating 105 liquids obtained from local retailers [Kim and Shin, 2013]. On average, they found 12.99 ηg TSNAs per ml of liquid, with the amount of daily exposure to the users estimated to be similar to users of NRTs [Farsalinos *et al.* 2013d]. The estimated daily exposure to nitrosamines from tobacco cigarettes (average consumption of 15 cigarettes per day) is estimated to be up to 1800 times higher compared with EC use (Table 3). Etter and colleagues evaluated the accuracy of nicotine labeling and the presence of nicotine impurities and degradation products in 20 EC liquid samples [Etter *et al.* 2013]. They found that nicotine levels were 85–121% of what was labeled, while nicotine degradation products were present at levels of 0–4.4%. Although in some samples the levels were higher than those specified in European Pharmacopoeia, they are not expected to cause any measurable harm to users.

Besides the evaluation for the presence of TSNAs, analyses have been performed for the detection of carbonyl compounds. It is known that the thermal degradation of propylene glycol and glycerol can lead to the emission of toxic compounds such as aldehydes [Antal *et al.* 1985; Stein *et al.* 1983]. Goniewicz and colleagues evaluated the emission of 15 carbonyls from 12 brands of ECs (mostly first-generation) [Goniewicz *et al.* 2013]. In order to produce vapor, researchers used a smoking machine and followed a regime of 1.8-second puffs with a very short 10-second interpuff interval, which does not represent realistic use [Farsalinos *et al.* 2013c]; although the puff duration was low, interpuff interval was remarkably short, which could potentially lead to overheating. In addition, the same puff number was used in all devices tested, although there was a significant difference in the design and liquid content between devices. Despite these limitations, out of 15 carbonyls, only 3 were detected (formaldehyde, acetaldehyde and acrolein); levels were

Table 2. Summary of chemical toxicity findings.

Study	What was investigated?	What were the key findings?	
		Liquid	Vapor
Laugesen [2009]	Evaluation of 62 toxicants in the EC vapour from Ruyan 16 mg and mainstream tobacco smoke using a standard smoking machine protocol.	N/A	No acrolein, but small quantities of acetaldehyde and formaldehyde found. Traces of TSNAs (NNN, NNK, and NAT) detected. CO, metals, carcinogenic PAHs and phenols not found in EC vapour. Acetaldehyde and formaldehyde from tobacco smoke were 55 and 5 times higher, respectively.
Westenberger [2009]	Evaluation of toxicants in EC cartridges from two popular US brands.	TSNAs and certain tobacco specific impurities were detected in both products at very low levels. Diethylene glycol was identified in one cartridge.	N/A
Hadwiger *et al.* [2010]	Evaluation of four refill solutions and six replacement cartridges advertised as containing Cialis or rimonambant.	Small amounts of amino-tandalafil and rimonambant present in all products tested.	N/A
Cahn and Siegel [2011]	Overview of 16 chemical toxicity studies of EC liquids/vapours.	TSNAs levels in ECs 500- to 1400-fold lower than those in conventional cigarettes and similar to those in NRTs. Other chemicals found very low levels, which are not expected to result in significant harm.	
Pellegrino *et al.* [2012]	Evaluation of PM fractions and PAHs in the vapour generated from cartomizers of an Italian EC brand.	N/A	PM fractions were found, but levels were 6–18 times lower compared with conventional cigarettes. Traces of PAHs detected.
Kim and Shin [2013]	TSNAs (NNN, NNK, NAT, and NAB) content in 105 refill liquids from 11 EC brands purchased in Korean shops.	Total TSNAs averaged 12.99 ng/ml EC liquid; daily total TSNA exposure from conventional cigarettes estimated to be up to 1800 times higher.	N/A
Etter *et al.* [2013]	Nicotine degradation products, ethylene glycol and diethylene glycol evaluation of 20 EC refill liquids from 10 popular brands	The levels of nicotine degradation products represented 0–4.4% of those for nicotine, but for most samples the level was 1–2%. Neither ethylene glycol nor diethylene glycol were detected.	N/A
Goniewicz *et al.* [2013]	Vapours generated from 12 brands of ECs and a medicinal nicotine inhaler using a modified smoking machine protocol	N/A	Carbonyl compounds (formaldehyde, acetaldehyde and acrolein), VOCs (toluene and trace levels of xylene), trace levels of TSNAs (NNN and NNK) and very low levels of metals (cadmium, nickel and lead) were found in almost all examined EC vapours. Trace amounts of formaldehyde, acetaldehyde, cadmium, nickel and lead were also detected from the Nicorette inhalator. Compared with conventional cigarette, formaldehyde, acetaldehyde and acrolein were 9–450 times lower; toluene levels 120 times lower; and NNN and NNK levels 380 and 40 times lower respectively.

(Continued)

Table 2. (Continued)

Study	What was investigated?	What were the key findings?	
		Liquid	Vapor
Williams *et al.* [2013]	Vapour generated from cartomizers of a popular EC brand using a standard smoking machine protocol	N/A	Trace levels of several metals (including tin, copper, silver, iron, nickel, aluminium, chromium, lead) were found, some of them at higher level compared with conventional cigarettes. Silica particles were also detected. Number of microparticles from 10 EC puffs were 880 times lower compared with one tobacco cigarette.
Burstyn [2014]	Systematic review of 35 chemical toxicity studies/ technical reports of EC liquids/vapours.	No evidence of levels of contaminants that may be associated with risk to health. These include acrolein, formaldehyde, TSNAs, and metals. Concern about contamination of the liquid by a nontrivial quantity of ethylene glycol or diethylene glycol remains confined to a single sample of an early technology product and has not been replicated.	

Abbreviations. CO, carbon monoxide; EC, electronic cigarette; NAT, N-Nitrosoanatabine; NNK, 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanone; NNN, N-Nitrosonornicotine; PAHs, polycyclic aromatic hydrocarbons; PM, particulate matter; TSNAs, tobacco-specific nitrosamines; VOCs, volatile organic carbons.

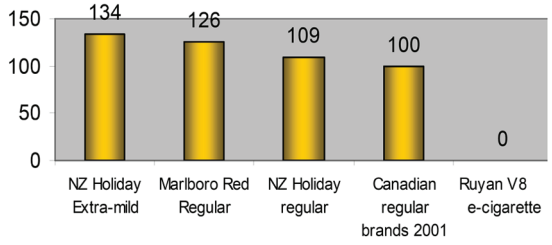

Figure 3. Toxic emissions score, adjusted for nicotine, for electronic cigarette and popular cigarette brands. (Reproduced with permission from Laugesen [2009]).

9–450 times lower compared with emissions from tobacco cigarettes (derived from existing literature but not tested in the same experiment). Formaldehyde and acetaldehyde were also emitted from the nicotine inhalator, although at lower levels. In addition, they examined for the presence of 11 volatile organic carbons and found only trace levels of toluene (at levels from 0.2–6.3 μg per 150 puffs) and xylene (from 0.1–0.2 μg per 150 puffs) in 10 of the samples; toluene levels were 120 times lower compared with tobacco cigarettes (again derived from existing literature but not tested in the same experiment).

Given that ECs have several metal parts in direct contact with the e-liquid, it is quite obvious to expect some contamination with metals in the vapor. Goniewicz and colleagues examined samples for the presence of 12 metals and found nickel, cadmium and lead emitted [Goniewicz *et al.* 2013]; the levels of nickel were similar to those present in a pharmaceutical nicotine inhalator, while lead and cadmium were present at 2–3 times higher levels compared with the inhalator. Still, the absolute levels were very low (few nanograms per 150 puffs). Williams *et al.* [2013] focused their research on the presence of heavy metals and silicate particles emitted from ECs. They tested poor quality first-generation cartomisers and found several metals emitted in the aerosol of the EC, specifying that in some cases the levels were higher compared with conventional cigarettes. As mentioned earlier, it is not unusual to find trace levels of metals in the vapor generated by these products under experimental conditions that bear little relevance to their normal use; however, it is unlikely that such small amounts pose a serious threat to users' health. Even if all the aerosol was absorbed by the consumer (which is not the case since most of the aerosol is visibly exhaled), an average user would be exposed to 4–40 times lower amounts for most metals than the maximum daily dose allowance from impurities in medicinal products [US Pharmacopeia, 2013]. Silicate particles were also found in the EC aerosol. Such particles come from the wick material, however the authors did not clarify whether crystalline silica oxide particles were found, which are responsible for respiratory disease. In total, the number of microparticles (< 1000 nm) estimated to be inhaled by EC users from 10 puffs were 880 times lower compared

Table 3. Levels of nitrosamines found in electronic and tobacco cigarettes. Prepared based on information from Laugesen [2009], Cahn and Siegel [2011] and Kim and Shin [2013].

Product	Total nitrosamines levels (ng)	Daily exposure (ng)	Ratio[4]
Electronic cigarette (per ml)	13	52[1]	1
Nicotine gum (per piece)	2	48[2]	0.92
Winston (per cigarette)	3365	50 475[3]	971
Newport (per cigarette)	3885	50 775[3]	976
Marlboro (per cigarette)	6260	93 900[3]	1806
Camel (per cigarette)	5191	77 865[3]	1497

[1]Based on average daily use of 4ml liquid
[2]Based on maximum recommended consumption of 24 pieces per day
[3]Based on consumption of 15 cigarettes per day
[4] Difference (number-fold) between electronic cigarette and all other products in daily exposure to nitrosamines

with one tobacco cigarette. Similar findings concerning microparticles were reported by Pellegrino and colleagues who found that, for each particulate matter fraction, conventional cigarettes released 6–18 times higher amounts compared with the EC tested [Pellegrino *et al.* 2012].

Burstyn has recently reviewed current data on the chemistry of aerosols and the liquids of ECs (including reports which were not peer-reviewed) and estimated the risk to consumers based on workplace exposure standards (i.e. Threshold Limit Values [TLVs]) [Burstyn, 2014]. After reviewing all available evidence, the author concluded that there was no evidence that vaping produced inhalable exposure to contaminants of aerosol that would warrant health concerns. He added that surveillance of use is recommended due to the high levels of propylene glycol and glycerol inhaled (which are not considered contaminants but ingredients of the EC liquid). There are limited data on the chronic inhalation of these chemicals by humans, although there is some evidence from toxicological studies (which are discussed later in this paper).

In conclusion, chemical studies have found that exposure to toxic chemicals from ECs is far lower compared with tobacco cigarettes. Besides comparing the levels of specific chemicals released from tobacco and ECs, it should be taken into consideration that the vast majority of the >4000 chemicals present in tobacco smoke are completely absent from ECs. Obviously, surveillance of use is warranted in order to objectively evaluate the *in vivo* effects and because the effects of inhaling flavoring substances approved for food use are largely unknown.

Toxicological studies

To date, only a handful of toxicological studies have been performed on ECs, mostly cytotoxicity studies on established cell lines. The cytotoxicity approach also has its flaws. Findings cannot be directly applied to the *in vivo* situation and there is always the risk of over- (as well as under-)estimating the interpretation of the toxic effects in these investigational models. An ample degree of results variability is to be expected from different cell lines and, sometimes, also within the same cell line. Comparing the potential cytotoxicity effects of EC vapor with those resulting from the exposure of cigarette smoke should be mandatory, but standards for vapor production and exposure protocols have not been clearly defined.

Bahl and colleagues [Bahl *et al.* 2012] performed cytotoxicity tests on 36 EC liquids, in human embryonic stem cells, mouse neural stem cells and human pulmonary fibroblasts and found that stem cells were more sensitive to the effects of the liquids, with 15 samples being moderately cytotoxic and 12 samples being highly cytotoxic. Propylene glycol and glycerol were not cytotoxic, but a correlation between cytotoxicity and the number and height of the flavoring peaks in high-performance liquid chromatography was noted. Investigations were just restricted to the effect of EC liquids and not to their vapors, thus limiting the importance of the study findings; this is not a trivial issue considering that the intended use of these products is by inhalation only and that it is unlikely that flavoring substances in the EC liquids will still be present in the aerosol in the same amount due to differences in evaporation temperature [Romagna *et al.* 2013]. Regrettably, a set of experiments with cigarette smoke extracts as

comparator was not included. Of note, the authors emphasized that the study could have underestimated the cytotoxicity by 100 times because when they added the EC liquids to the cell, medium final concentration was 1%. However, cells were cultured for 48 hours with continuous exposure to the liquid, while in real use the lungs come in contact with aerosol instead of liquid, the contact lasts for 1–2 seconds per puff and most of the aerosol is visibly exhaled. Finally, Cinnamon Ceylon, the liquid found to be mostly cytotoxic in this study, was not a refill liquid but a concentrated flavor which is not used in ECs unless it is diluted to 3–5%.

Romagna and colleagues [Romagna *et al.* 2013] performed the first cytotoxicity study of EC vapor on fibroblast cells. They used a standardized ISO 10993-5 protocol, which is used for regulatory purposes of medical devices and products. They tested the vapor of 21 liquid samples containing the same amount of nicotine (9 mg/ml), generated by a commercially available EC device. Cells were incubated for 24 hours with each of these vapors and with smoke from a conventional cigarette. Only one sample was found to be marginally cytotoxic, whereas cigarette smoke was highly cytotoxic (approximately 795% more cytotoxic), even when the extract was diluted up to 25% of the original concentration.

The same group also investigated the cytotoxic potential of 20 EC liquid samples in cardiomyoblasts [Farsalinos *et al.* 2013a]. Vapor was produced by using a commercially available EC device. Samples contained a wide range of nicotine concentrations. A base liquid mixture of propylene glycol and glycerol (no nicotine and no flavorings) was also included as an additional experimental control. Four of the samples examined were made by using cured tobacco leaves in a steeping process, allowing them to impregnate a mixture of propylene glycol and glycerol for several days before being filtered and bottled for use. Of note, this was the first study which evaluated a limited number of samples with an EC device delivering higher voltage and energy to the atomizer (third-generation device). In total, four samples were found to be cytotoxic; three of them were liquids made by using cured tobacco leaves, with cytotoxicity observed at both 100% and 50% extract concentration, while one sample (cinnamon flavor) was marginally cytotoxic at 100% extract concentration only. In comparison, smoke from three tobacco cigarettes was highly cytotoxic, with toxicity observed even when the extract was diluted to 12.5%. The samples made with tobacco leaves were three times less cytotoxic compared with cigarette smoke; this was probably due to the absence of combustion and the significantly lower temperature of evaporation in EC use. Concerning high-voltage EC use, the authors found slightly reduced cell viability without any of the samples being cytotoxic according to the ISO 10993-5 definition. Finally, no association between cell survival and the amount of nicotine present in the liquids was noted.

A recent study evaluated in more detail the cytotoxic potential of eight cinnamon-flavored EC liquids in human embryonic stem cells and human pulmonary fibroblasts [Behar *et al.* 2014]. The authors found that the flavoring substance predominantly present was cinnamaldehyde, which is approved for food use. They observed significant cytotoxic effects, mostly on stem cells but also on fibroblasts, with cytotoxicity associated with the amount of cinnamaldehyde present in the liquid. However, major methodological issues arose from this study. Once again, cytotoxicity was just restricted to EC liquids and not to their vapors. Moreover, the authors mentioned that the amount of cinnamaldehyde differed between liquids by up to 100 times, and this raises the suspicion of testing concentrated flavor rather than refills. By searching the internet and contacting manufacturers, based on the names of samples and suppliers mentioned in the manuscript, it was found that at least four of their samples were not refills but concentrated flavors. Surprisingly, the levels of cinnamaldehyde found to be cytotoxic were about 400 times lower than those currently approved for use [Environmental Protection Agency, 2000].

Few animal studies have been performed to evaluate the potential harm of humectants in EC liquids (i.e. propylene glycol and glycerol) when given by inhalation. Robertson and colleagues tested the effects on primates of inhaling propylene glycol vapor for several months and found no evidence of toxicity on any organ (including the lungs) after post-mortem examination of the animals [Robertson *et al.* 1947]. Similar observations were made in a recent study in rats and dogs [Werley *et al.* 2011]. Concerns have been raised in human use, based on studies of people exposed to theatrical fog [Varughese *et al.* 2005; American Chemistry Council, 2003] or propylene glycol used in the aviation industry [Wieslander *et al.* 2001]. Irritation of the respiratory tract was found, but no permanent lung injury or other

long-term health implications were detected. It should be reminded that, in these circumstances, nonpharmaceutical purity propylene glycol is used and in some cases oils are added, making it difficult to interpret the results in the context of EC use. Evidence for the potential harm of inhaled glycerol is sparse. A study using Sprague–Dawley rats found minimal to mild squamous metaplasia of the epiglottis epithelium in the high-dose group only, without any changes observed in lungs or other organs [Renne *et al.* 1992]. No comparative set of experiments with cigarette smoke was included, but it is well known that exposure to tobacco smoke in similar animal models leads to dramatic changes in the lungs, liver and kidneys [Czekaj *et al.* 2002].

In conclusion, toxicological studies have shown significantly lower adverse effects of EC vapor compared with cigarette smoke. Characteristically, the studies performed by using the liquids in their original liquid form have found less favorable results; however, no comparison with tobacco smoke was performed in any of these studies, and they cannot be considered relevant to EC use since the samples were not tested in the form consumed by vapers. More research is needed, including studies on different cell lines such as lung epithelial cells. In addition, it is probably necessary to evaluate a huge number of liquids with different flavors since a minority of them, in an unpredictable manner, appear to raise some concerns when tested in the aerosol form produced by using an EC device.

Clinical studies and research surveys

Clinical trials can be very informative, but they require monitoring of hundreds of users for many years to adequately explore the safety/risk profile of the products under investigation. Research surveys of EC users, on the other hand, can quickly provide information about the potential harm of these products and are much cheaper to run. However, self-reported data, highly self-selected study populations, and the cross-sectional design are some of the most common limitations of research surveys. Taken together, findings from surveys and follow-up studies of vapers have shown that EC use is relatively safe.

Polosa and colleagues followed up smokers for 24 months, after a 6-month period of intervention during which ECs were given [Polosa *et al.* 2013a]. Only mild symptoms such as mouth and throat irritation and dry cough were observed. Farsalinos and colleagues retrospectively evaluated a group of 111 EC users who had completely quit smoking and were daily EC users for a median period of 8 months [Farsalinos *et al.* 2013b]. Throat irritation and cough were the most commonly reported side effects. Similar findings have been observed in surveys [Dawkins *et al.* 2013; Etter *et al.* 2011]. However, it is expected that dedicated users who have more positive experiences and fewer side effects compared with the general population participate in such studies, therefore interpretation should be done with caution. The only two existing randomized controlled trials have also included detailed EC safety analysis. The ECLAT study [Caponnetto *et al.* 2013b], a three-arm, controlled, randomized, clinical trial designed to compare efficacy and safety of a first-generation device with 7.2, 5.4, or 0 mg nicotine cartridges, reported clinically significant progressive health improvements already by week two of continuous use of the device, and no serious adverse events (i.e. major depression, abnormal behavior or any event requiring an unscheduled visit to the family practitioner or hospitalization) occurred during the study. The ASCEND study [Bullen *et al.* 2013], a three-arm, controlled, randomized, clinical trial designed to compare the efficacy and safety of a first-generation device (with or without nicotine) with nicotine patches, reported no serious adverse events in any of the three study groups.

Few clinical studies have been performed to evaluate the short-term *in vivo* effects of EC use in current or former smokers. Vardavas and colleagues evaluated the acute effects of using an EC for 5 minutes on respiratory function [Vardavas *et al.* 2012]. Although they did not report the results of commonly-used spirometry parameters, they found that a sensitive measure of airways resistance and nitric oxide levels in exhaled breath were adversely affected. Similar elevations in respiratory resistance were reported by other research groups [Palamidas *et al.* 2013; Gennimata *et al.* 2012], who also documented some bizarre elevation in exhaled carbon monoxide levels after EC use; this finding has been challenged by several other studies [Farsalinos *et al.* 2013f; Nides *et al.* 2014; Van Staden *et al.* 2013]. Schober and colleagues found that EC use led to elevated exhaled nitric oxide [Schober *et al.* 2013], contradicting the findings from Vardavas and colleagues [Vardavas *et al.* 2012]. Characteristically, none of the above studies performed any comparative tests after smoking tobacco cigarettes. Flouris and colleagues found

that only smoking had an acute adverse effect on respiratory function [Flouris *et al.* 2013]; no difference was observed after the group of smokers was exposed to active or passive EC use.

Two studies have evaluated the short-term effects of ECs on the cardiovascular system. Farsalinos and colleagues evaluated the acute effects of using ECs with an 11 mg/ml nicotine-containing liquid on hemodynamics and left ventricular function, in comparison with the effects of cigarette smoking [Farsalinos *et al.* 2012]. They found that EC use resulted in a slight elevation in diastolic blood pressure while, after smoking, both systolic and diastolic blood pressure and heart rate were significantly elevated. Obviously, this was due to the relatively low nicotine content of the EC (which is considered medium strength). Diastolic dysfunction was observed in smokers after smoking, which was in line with findings from previous studies. However, no adverse effects were observed in EC users after using the device *ad lib* for 7 minutes. Another study by the same group [Farsalinos *et al.* 2013f], evaluated the acute effects of EC use on coronary flow. In particular, they measured the flow velocity reserve of the left anterior descending coronary artery by echocardiography after intravenous infusion of adenosine, representing the maximal ability of the artery to deliver blood to the myocardium. Smoking was associated with a decline in flow velocity reserve by 16% and an elevation in resistance to flow by 19%. On the contrary, no difference was observed in any of these parameters after using the EC. Blood carboxyhemoglobin levels were also measured in participants; baseline values were significantly higher in smokers compared with vapers and were further elevated after smoking but were not altered after EC use. Similar observations for carboxyhemoglobin levels were observed by Van Staden and colleagues [Van Staden *et al.* 2013].

A clinical case report of a smoker suffering from chronic idiopathic neutrophilia was published. According to that report [Farsalinos and Romagna, 2013], switching from smoking to EC use led to a reversal of the condition after 6 months. In addition, C-reactive protein levels, which were consistently elevated for more than 6 years, decreased to normal levels. Another case report of a patient with lipoid pneumonia was published, with the condition attributed to glycerin-based EC liquids used by the patient [McCauley *et al.* 2012]. However, glycerin is an alcohol (polyol) and thus it is impossible to cause lipoid pneumonia. Only oil-based liquids could be the cause for this condition; such liquids should not be used with ECs.

One study evaluated the acute effects of tobacco and EC use on white blood cell count [Flouris *et al.* 2012]. Smoking one tobacco cigarette caused an immediate elevation in white blood cells, neutrophils and lymphocytes, indicating acute inflammatory distress. On the contrary, no differences were observed after using ECs.

In conclusion, clinical studies evaluating the effects of short-term EC use on selected cardiovascular and respiratory functional outcomes have shown that even if some harmful effects of vaping are reported, these are considerably milder compared with smoking conventional cigarettes. However, it is difficult to assess the prognostic implications of these studies; longer-term data are needed before any definite conclusions are made.

Passive vaping

Passive smoking is an established risk factor for a variety of diseases [Barnoya and Navas-Acien, 2013]. Therefore, it is important from a public health perspective to examine the impact of EC use on bystanders. Indirect data can be derived from chemical studies in vapor mentioned above, which show that the potential of any significant adverse effects on bystanders is minimal. In fact, since sidestream exposure is nonexistent in EC (aerosol is produced only during activation of the device, while tobacco cigarettes emit smoke even when no puffs are taken), such studies are undoubtedly overestimating the risk of environmental exposure.

Few studies have focused on second-hand vaping. McAuley and colleagues [McAuley *et al.* 2012], although mentioning indoor air quality in the title of their study and finding minimal health-related impact, did not in fact evaluate second-hand vaping because aerosol was produced from an EC device and was evaluated without previously being inhaled by any user. Moreover, there were some problems with cross-contamination with tobacco cigarette smoke, which made the results somewhat questionable, at least for some of the parameters tested. Schripp and colleagues [Schripp *et al.* 2013] evaluated the emissions from an EC by asking a volunteer to use three different EC devices in a closed 8 m^3 chamber. From a selection of 20 chemicals analyzed, only formaldehyde, acrolein, isoprene, acetaldehyde and acetic acid were

detected. The levels were 5–40 times lower compared with emissions from a conventional cigarette. For formaldehyde, the authors specifically mentioned that the levels were continuously rising from the time the volunteer entered the room, even before he started using the EC. Moreover, no acute elevation was observed when the smoker used the three EC devices, contrary to the acute elevation and spiking of levels when a tobacco cigarette was lit. The authors concluded that formaldehyde was not emitted from the ECs but was due to human contamination, since low amounts of formaldehyde of endogenous origin can be found in exhaled breath [Riess *et al.* 2010]. Romagna and colleagues [Romagna *et al.* 2012] evaluated chemicals released in a realistic setting of a 60 m^3 room, by asking five smokers to smoke *ad lib* for 5 hours and five vapers to use ECs *ad lib* for a similar period of time on two separate days. Nicotine, acrolein, toluene, xylene and polycyclic aromatic hydrocarbons were detected in room air after the smoking session, with the amount of total organic carbon (TOC) reaching to 6.66 mg/m^3. In contrast, after the EC session, only glycerol was detected in minimal levels (72 $\mu g/m^3$), while TOC reached a maximum level of 0.73 mg/m^3. Characteristically, the amount of TOC accumulated after 5 hours of EC use was similar to the amount found after just 11 minutes of smoking. The study on heavy metals mentioned previously [Williams *et al.* 2013] could also be used to examine any potential risk of bystanders' exposure to toxic metals. The levels of heavy metals found in vapor were minimal, and considering the dispersion of these molecules in the whole room air, it is unlikely that any of these metals could be present in measurable quantities in the environment. Therefore, the risk for bystanders would be literally nonexistent. Contrary to that, Schober and colleagues [Schober *et al.* 2013] found that levels of aluminum were raised by 2.4 times in a 45 m^3 room where volunteers were asked to use ECs for 2 hours. This is a highly unexpected finding which cannot be supported by the findings of the study by Williams and colleagues [Williams *et al.* 2013]; because the levels found in the latter could not result in such elevation of the environmental levels of aluminum, unless nothing is retained in or absorbed from the lungs. Moreover, Schober and colleagues [Schober *et al.* 2013] found that levels of polycyclic aromatic hydrocarbons (PAHs) were raised by 20% after EC use. However, a major methodological problem of this study is that control environmental measurements were performed on a separate day and not on the same day of EC use. This is a major limitation, because the levels of environmental PAHs have significant diurnal and day-to-day variations [Ravindra *et al.* 2008]; therefore, it is highly likely that the differences in levels of PAHs (which are mainly products of combustion and are not expected to be emitted from EC use) represented changes due to environmental conditions and not due to EC use. Bertholon and colleagues [Bertholon *et al.* 2013] examined the EC aerosol exhaled from a user, in comparison with exhaled smoke from a smoker. The authors found that particle size diameters were 0.29–0.033μm. They observed that the half life of EC aerosol was 11 seconds compared with 20 minutes for cigarette smoke, indicating that risk of passive vaping exposure is significantly lower compared with passive smoking.

The recent findings by Czogala and colleagues [Czogala *et al.* 2013] led to similar conclusions. The authors compared the emissions of electronic and conventional cigarettes generated by experienced dual users in a ventilated full-sized room and found that ECs may emit detectable amounts of nicotine (depending on the specific EC brand tested), but no carbon monoxide and volatile organic carbons. However, the average ambient levels of nicotine of ECs were 10 times lower than those of conventional cigarettes (3.32 ± 2.49 *versus* 31.60 ± 6.91 $\mu g/m^3$).

In his review and comparison with TLVs, Burstyn found that emissions from ECs to the environment are not expected to pose any measurable risk for bystanders [Burstyn, 2014].

An issue that needs further clarification relates to the findings of microparticles emitted from ECs. In most studies, these findings are presented in a way implying that the risk is similar to environmental or smoking microparticles. In reality, it is not just the size but the composition of the microparticles that matters. Environmental microparticles are mainly carbon, metal, acid and organic microparticles, many of which result from combustion and are commonly called particulate matter. Particulate matter exposure is definitely associated with lung and cardiovascular disease [Peters, 2005; Seaton *et al.* 1995]. In the case of ECs, microparticles are expected to consist mostly of propylene glycol, glycerol, water and nicotine droplets. Metal and silica nanoparticles may also be present [Williams *et al.* 2013], but, in general, emissions from ECs are incomparable to environmental particulate matter or cigarette smoke microparticles.

Flouris and colleagues [Flouris *et al.* 2013] performed the only clinical study evaluating the respiratory effects of passive vaping compared with passive smoking. Researchers found significant adverse effects in spirometry parameters after being exposed to passive smoking for 1 hour, while no adverse effects were observed after exposure to passive vaping.

Although evaluating the effects of passive vaping requires further work, based on the existing evidence from environmental exposure and chemical analyses of vapor, it is safe to conclude that the effects of EC use on bystanders are minimal compared with conventional cigarettes.

Miscellaneous safety issues

Specific subpopulations: psychiatric and chronic obstructive pulmonary disorder patients

A challenging population subgroup with unique smoking patterns is that of psychiatric patients and in particular schizophrenic patients. This subpopulation is characterized by a very high smoking prevalence [De Leon and Diaz, 2005] with an excess of smoking-related mortality [Brown *et al.* 2000]. Currently, only NRTs are recommended to treat nicotine dependence in this specific subpopulation, but in general they are not particularly effective [Aubin *et al.* 2012]. ECs could be used as an alternative to smoking products in this group. Caponnetto and colleagues performed a prospective 12-month pilot study to evaluate the efficacy of EC use in smoking reduction and cessation in a group of 14 patients with schizophrenia [Caponnetto *et al.* 2013a]. In 50% of participants, smoking consumption went from 30 to 15 cigarettes per day at 52 weeks of follow up, while 14.3% managed to quit smoking. Importantly, no deterioration in their psychiatric condition was observed, and side effects were mild and temporary. The results were promising although an outdated EC device was used in this study.

There is also anecdotal evidence that successful smoking cessation could be attained by using an EC in smokers with other psychiatric conditions such as depression [Caponnetto *et al.* 2011a]. Both patients described in this case series stated that EC use was well tolerated and no adverse events were reported.

Considering that first-line oral medications for nicotine addiction are contraindicated in such patients (prescribing information for bupropion and varenicline carry a 'black-box' warning for certain psychiatric conditions), ECs may be a promising tool in these challenging patient groups.

Another subpopulation that may benefit from regular EC use is that of respiratory patients with chronic obstructive pulmonary disease (COPD), a progressive disease characterized by a persistent inflammatory response to tobacco smoke that generally leads to decline in lung function, respiratory failure, cor pulmonale and death. Consequently, smoking cessation plays a crucial part in the management of COPD patients. However, the available evidence in the medical literature indicates that COPD patients who smoke respond poorly to smoking cessation efforts [Schiller and Ni, 2006]. To date, no formal efficacy and safety assessment of EC use in COPD patients has been conducted. There is only evidence from a case report of inveterate smokers with COPD and a documented history of recurring relapses, who eventually quit tobacco smoking on their own by using an EC [Caponnetto *et al.* 2011b]. Significant improvement in quality of life and reduction in the number of disease exacerbations were noted. EC use was well tolerated with no reported adverse events.

Accidental nicotine exposure

Accidental ingestion of nicotine, especially by children, or skin contact with large amounts of liquid or highly concentrated nicotine solution can be an issue. However, the historically referenced lethal dose of 60 mg has recently been challenged in a review by Mayer [Mayer, 2013]; he found that the lethal levels currently reproduced in every document originated from dubious experiments performed in the 19th century. Based on post-mortem studies, he suggested that the acute dose associated with a lethal outcome would be 500–1000 mg. Taking into account that voluminous vomiting is the first and characteristic symptom of nicotine ingestion, it seems that far higher levels of nicotine need to be ingested in order to have lethal consequences.

A surveillance system of adverse events has been developed by the FDA, which identifies safety concerns in relation to tobacco products. Since 2008, 47 adverse events were reported for ECs

[Chen, 2013]. Eight of them were serious events such as hospitalizations for pneumonia, heart failure, seizures and hypotension and burns. A case of second-degree burns was caused by a battery explosion, which is generally a problem observed in lithium batteries and has occurred in other products (such as mobile phones). The author emphasized that the reported events were not necessarily associated with EC use but may have been related to pre-existing conditions or other causes. No condition was characteristically associated with EC use.

A recent review of the California Poison Control System database from 2010 to 2012 identified 35 cases (14 children) associated with EC exposure (accidental exposure in 25 cases) [Cantrell, 2013]. A total of five patients were evaluated in an emergency department and all were discharged within 4 hours. Nausea, vomiting, dizziness and oral irritation were most commonly reported. Taken together, data from surveillance systems of adverse events suggest that short-term adverse effects and accidental exposures to EC cartridges are unlikely to result in serious toxicity.

Notwithstanding, avoiding preventable contact with highly concentrated nicotine solution remains important; this can be achieved by specific labeling of the products, child-proof caps and proper education of consumers. There is no evidence that nicotine-containing EC liquids should be treated in any different way compared with other consumer products used every day in households (such as bleach, washing machine powder, etc.).

Electrical accidents and fires

The electronic equipment of ECs may be the cause for accidents. ECs are mainly composed of lithium batteries. There have been reports of explosions of batteries, caused either by prolonged charging and use of improper chargers or by design defects. Similar accidents have occurred with batteries of other popular devices, such as mobile phones. Therefore, this does not occur specifically with ECs, however, quality standards of production should be used in order to avoid such accidents.

Smoking is a major cause of residential fires. Between 2008 and 2010, an estimated annual average of 7600 smoking-related fires occurred in residential buildings in the US [US Fire Administration, 2012]. They account for only 2% of all residential building fires but for 14% of fire deaths. Since ECs are activated only when used by the person and there is no combustion involved, there is the potential to avoid the risk of smoking-related fires.

Use by youngsters and nonsmokers

Although beyond the scope of this review, it is important to briefly discuss the potential for addiction from EC use. It should be acknowledged that nicotine is addictive, although recent studies have shown that several other chemicals present in tobacco are associated with a significant enhancement of the addictiveness of nicotine [Lotfipour *et al.* 2011; Rose, 2006; Guillem *et al.* 2005]. Still, nicotine intake should not be recommended to nonsmokers. Smokers are already addicted to nicotine, thus ECs will be a cleaner form of nicotine intake, while at the same time they will maintain their sensory stimulation and motor simulation of smoking; these are important aspects of the addiction to smoking. Regulatory authorities have expressed concern about EC use by youngsters or by never-smokers, with ECs becoming a gateway to smoking or becoming a new form of addiction. However, such concerns are unsubstantiated; research has shown that EC use by youngsters is virtually nonexistent unless they are smokers. Camenga and colleagues [Camenga *et al.* 2013] examined the use of ECs and tobacco in a group of adolescents, in a survey conducted in three waves. In the first wave of the survey (February 2010), 1719 adolescents were surveyed from which only one nonsmoker was found to be using ECs. In the second and third wave of the surveys, only five nonsmoking adolescents were using ECs. In fact, these are adolescents who reported first ever use of ECs in the past 30 days; therefore they were not necessarily regular or daily EC consumers. The increased prevalence of EC use from 0.9% in 2010 to 2.3% in 2011 concerned smoking adolescents, therefore it should be considered a positive finding that smokers are experimenting with the significantly less harmful ECs. Similarly, the Medicines and Healthcare Products Regulatory Agency (MHRA) found that less than 1% of EC users are never-smokers [MHRA, 2013]. Data from the Centers for Disease Control [2013] National Youth Tobacco Survey reported doubling in EC experimentation by 13–18 year old students from 1.1% in 2011 to 2.1% in 2012; however, 90.6% of them were smokers. From the whole population, only 0.5% were nonsmokers experimenting with ECs.

Once again, participants were asked about ever experimenting with an EC in the past 30 days, not regular or daily EC use. Recently, a survey of more than 75,000 students in South Korea was published [Lee *et al.* 2013]. Although they found that 12.6% of them were daily smokers (8.6% were using only tobacco cigarettes and 3.6% were using both tobacco and ECs), only 0.6% of nonsmokers had used ECs in the past 30 days. Although the above mentioned data have been used as arguments to support the fact that a new epidemic of nicotine addiction through the use of ECs is appearing, in reality they are showing that any experimentation with ECs is done by smokers. This is in fact a positive finding, and could lead to reduced smoking prevalence through adoption of EC use. Therefore, ECs could serve as gateway from smoking; on the contrary, there is no evidence indicating that they could be a gateway to smoking. It is promising to see that penetration of EC use in youngsters is virtually nonexistent, especially when you take into consideration that there is currently no official regulation in most countries to prohibit the access to ECs by youngsters.

Conclusion

Existing evidence indicates that EC use is by far a less harmful alternative to smoking. There is no tobacco and no combustion involved in EC use; therefore, regular vapers may avoid several harmful toxic chemicals that are typically present in the smoke of tobacco cigarettes. Indeed, some toxic chemicals are released in the EC vapor as well, but their levels are substantially lower compared with tobacco smoke, and in some cases (such as nitrosamines) are comparable with the amounts found in pharmaceutical nicotine products. Surveys, clinical, chemistry and toxicology data have often been mispresented or misinterpreted by health authorities and tobacco regulators, in such a way that the potential for harmful consequences of EC use has been largely exaggerated [Polosa and Caponnetto, 2013]. It is obvious that some residual risk associated with EC use may be present, but this is probably trivial compared with the devastating consequences of smoking. Moreover, ECs are recommended to smokers or former smokers only, as a substitute for conventional cigarettes or to prevent smoking relapse; thus, any risk should be estimated relative to the risk of continuing or relapsing back to smoking and the low efficacy of currently approved medications for smoking cessation should be taken into consideration [Moore *et al.* 2009; Rigotti *et al.* 2010;Yudkin *et al.* 2003]. Nonetheless, more research is needed in several areas, such as atomizer design and materials to further reduce toxic emissions and improve nicotine delivery, and liquid ingredients to determine the relative risk of the variety of compounds (mostly flavorings) inhaled. Regulations need to be implemented in order to maintain the current situation of minimal penetration of EC use in nonsmokers and youngsters, while manufacturers should be forced to provide proof for the quality of the ingredients used and to perform tests on the efficiency and safety of their products. However, any regulatory decisions should not compromise the variability of choices for consumers and should make sure that ECs are more easily accessible compared with their main competitor, the tobacco cigarette. Consumers deserve, and should make, informed decisions and research will definitely promote this. In particular, current data on safety evaluation and risk assessment of ECs is sufficient enough to avert restrictive regulatory measures as a consequence of an irrational application of the precautionary principle [Saitta *et al.* 2014].

ECs are a revolutionary product in tobacco harm reduction. Although they emit vapor, which resembles smoke, there is literally no fire (combustion) and no 'fire' (suspicion or evidence that they may be the cause for disease in a similar way to tobacco cigarettes). Due to their unique characteristics, ECs represent a historical opportunity to save millions of lives and significantly reduce the burden of smoking-related diseases worldwide.

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Konstantinos Farsalinos is a researcher at Onassis Cardiac Surgery Center. He has never been funded by the pharmaceutical or the tobacco

industry. For some of his studies, the institution has received financial compensation from electronic cigarette companies for the studies' cost. His salary is currently being paid by a scholarship grant from the Hellenic Society of Cardiology.

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Characterization of chemicals released to the environment by electronic cigarettes use (ClearStream-AIR project): is passive vaping a reality?[3]

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Abstract

Background Electronic cigarettes (e-CIG) have been marketed as a safer alternative habit to tobacco smoking. We have developed a group of research protocols to evaluate the effects of e-CIG on human health, called ClearStream. No studies have adequately evaluated the effects of e-CIG use on the release of chemicals to the environment. The purpose of this study was to identify and quantify the chemicals released on a closed environment from the use of e-CIG (ClearStream-AIR).

Methods A 60 m^3 closed-room was used for the experiment. Two sessions were organized, the first using 5 smokers and the second using 5 users of e-CIG. Both sessions lasted 5 h. Between sessions, the room was cleaned and ventilated for 65 h. Smokers used cigarettes containing 0.6 mg of nicotine while e-CIG users used commercially available liquid (FlavourArt) with nicotine concentration of 11 mg/ml. We measured total organic carbon (TOC), toluene, xylene, carbon monoxide (CO), nitrogen oxides (NO_x), nicotine, acrolein, poly-aromatic hydrocarbons (PAHs) glycerin and propylene glycol levels on the air of the room.

Results During the smoking session, 19 cigarettes were smoked, administering 11.4 mg of nicotine (according to cigarette pack information). During the e-CIG session, 1.6 ml of liquid was consumed, administering 17.6 mg of nicotine. During the smoking session we found: TOC=6.66 mg/m^3, toluene=1.7 µg/m^3, xylene=0.2 µg/m^3, CO=11 mg/m^3, nicotine=34 µg/m^3, acrolein=20 µg/ml and PAH=9.4 µg/m^3. No glycerin, propylene glycol and NO_x were detected after the smoking session. During the e-CIG session we found: TOC=0.73 mg/m^3 and glycerin=72 µg/m^3. No toluene, xylene, CO, NO_x, nicotine, acrolein or PAHs were detected on room air during the e-CIG session.

Conclusions Passive vaping is expected from the use of e-CIG. However, the quality and quantity of chemicals released to the environment are by far less harmful for the human health compared to regular tobacco cigarettes. Evaporation instead of burning, absence of several harmful chemicals from the liquids and absence of sidestream smoking from the use of the e-CIG are probable reasons for the difference in results.

Introduzione

La rapida espansione, negli ultimi anni, del mercato della sigaretta elettronica, legata in parte alla possibilità di utilizzarla anche nei luoghi in cui è vietato fumare, ha fatto sorgere alcune perplessità sulla sua sicurezza in questi contesti. Ad oggi però queste perplessità si basano più su ragionamenti di tipo ipotetico che su valutazioni scientifiche. Scopo di questo esperimento, è quello di iniziare a comprendere e misurare qual è l'impatto del fumo elettronico sull'atmosfera di un ambiente chiuso, confrontandolo con il fumo tradizionale.

Protocollo

Per l'esperimento è stata predisposta una stanza, con un volume pari a circa $60\,m^3$, all'interno della quale sono stati allestiti dei sistemi di campionamento dell'aria.

Al fine di garantire una maggiore sensibilità e per rimuovere la variabile legata al ricircolo d'aria, l'esperimento è stato condotto in un ambiente senza rinnovo d'aria esterna.

I parametri analizzati sono stati:

- CO
- NO_x
- Acroleina
- Idrocarburi Policiclici Aromatici (IPA)
- Carbonio Organico Totale (COT)
- Sostanze Organiche Volatili (SOV)
- Nicotina
- Glicerina
- Glicole Propilenico

Alcuni di questi parametri (CO, NO_x, COT) sono stati monitorati in continuo. Per tutti gli altri sono state impiegate delle fiale e delle membrane specifiche per catturare le varie famiglie di composti in esame in modo cumulativo.

Procedura

L'esperimento si è svolto in 2 sessioni, una per i fumatori ed una per i *vaper*[1], della durata di 5 h ciascuna ed ha coinvolto, per ogni sessione, 5 volontari.

[1] Termine anglosassone gergale, utilizzato per indicare un utilizzatore abituale di sigaretta elettronica.

Introduction

The rapid expansion of the e-cigarette market in recent years, due in part to the fact that they can be used also in no smoking areas, has given rise to perplexities on their safety in these contexts. However, thus far, these perplexities are based more on hypothetical reasons rather than scientific evaluations. The aim of this experiment is to understand and to measure what kind of impact e-cigarettes use has on a closed environment atmosphere compared to traditional cigarette smoking.

Protocol

A $60\,m^3$ volume room was used for the experiment. This room was fitted with air sampling systems.

In order to guarantee a higher sensitivity and remove air recirculation-dependant variables, the experiment was performed without renewal of indoor air.

The following parameters were analyzed:

- CO
- NO_x
- Acrolein
- Polycyclic Aromatic Hydrocarbons (PAHs).
- Total Organic Carbon (TOC)
- Volatile Organic Compounds (VOCs)
- Nicotine
- Glycerine
- Propylene Glycol

Some of these parameters (CO, NO_x, TOC) were monitored continuously. For all the other parameters, in order to capture the various types of compounds cumulatively, vials and specific membranes were used.

Procedures

The experiment was divided in two sessions: one for vapers[1] and one for smokers. Each session lasted 5 h and involved 5 volunteers.

Between the sessions the room was cleaned and ventilated for 65 h, in order to restore the original

[1] English slang term indicating an electronic cigarette user.

Tra le due sessioni la stanza è stata pulita ed arieggiata per complessive 65 h al fine di ripristinare le condizioni di neutralità iniziali.

Sessioni di Campionamento

Nel corso delle due prove, dopo aver allestito la stanza per il campionamento e rilevato i parametri di partenza, 5 volontari hanno fumato le loro sigarette o usato la loro personale sigaretta elettronica, a seconda della sessione in corso.

Ai volontari è stato spiegato che avrebbero potuto fumare/*svapare*[2] nelle quantità e nei tempi più adatti alle loro personali esigenze, a condizione di svolgere questa attività sempre all'interno del locale predisposto per l'esperimento.

La permanenza nel locale è stata tassativamente limitata al tempo strettamente necessario a fumare/*svapare*.

L'accesso e la permanenza nel locale sono stati consentiti ad un massimo di 3 volontari contemporaneamente.

La porta della stanza è rimasta chiusa se non per il tempo necessario ad entrare o ad uscire.

Tutti i volontari hanno firmato un consenso informato prima di prendere parte allo studio.

Per la sessione fumatori, si è provveduto ad annotare il numero di sigarette fumate, mentre per la sessione *vaper* è stato valutato il peso del liquido consumato, con una bilancia di precisione.

Volontari

I volontari fumatori avevano un età media di circa 21 anni con una storia media di 6.5 anni di fumo ed un consumo medio giornaliero di circa 17 sigarette. Il contenuto di nicotina delle sigarette fumate era pari a 0.6 mg per sigaretta. Nel corso della sessione di campionamento sono state fumate complessivamente 19 sigarette, che hanno dispensato ai fumatori circa 11.4 mg di nicotina, basandosi su quanto riportato sul pacchetto.

I *vaper* hanno dichiarato di usare la sigaretta elettronica in maniera esclusiva da circa 3 mesi (min 1, max 6) con un consumo giornaliero di liquido[3] pari a 1.5 ml e un contenuto di nicotina medio di 11 mg/ml. Tutti i volontari, hanno usato un liquido commerciale (*Heaven Juice* tradizionale) prodotto dalla ditta FlavourArt, e un commerciale EGO Pulse della Smokie's®.

Durante la sessione di campionamento sono stati vaporizzati 1760 mg di liquido, pari a 1.6 ml contenenti

[2] Termine gergale largamente usato, derivato dall'inglese *to vape*, ed impiegato per indicare l'azione di chi fuma una sigaretta elettronica.

[3] Tutti i liquidi per sigaretta elettronica utilizzati nell'esperimento erano del tipo *Heaven Juice Tradizionale* di FlavourArt, contenenti circa il 40% di glicerolo USP, circa il 50% di glicole propilenico USP, da 0.9% a 1.8% di nicotina USP, <1% di componente aromatica, acqua depurata, secondo quanto ricavato dalla documentazione fornita del produttore.

neutral conditions.

Sampling Sessions

For the two tests, the room was initially prepared for the sampling and analyzed for baseline conditions. Then, 5 volunteers smoked their cigarettes or e-cigarettes, depending on the session.

Volunteers were allowed to smoke/vape[2] as much as and whenever they wanted, provided that they used the room set for the experiment.

The time that volunteers spent in the room was strictly limited to smoking/vaping.

Only a maximum of 3 volunteers were allowed in the room at the same time.

The door of the room was opened only to let volunteers in or out.

Informed consent was obtained by all subjects before participating to the study.

During the smokers' session, the number of smoked cigarettes was noted down. During the vapers' session, the weight of consumed liquid, was evaluated using a precision scale.

Volunteers

The mean age of smokers was about 21 years and they were smoking on average 17 cigarettes per day for 6.5 years. The nicotine content in the smoked cigarettes was 0.6 mg per cigarette. During the sampling session, a total of 19 cigarettes were smoked which dispensed about 11.4 mg of nicotine, according to the information on cigarette packs.

Vapers declared that they had been using e-cigarettes exclusively for about 3 months (min 1, max 6), with a liquid[3] daily intake of 1.5 ml, and an average nicotine content of 11 mg/ml.

For e-cigarette users, a commercially available liquid (Heaven Juice traditional) produced by FlavourArt was used, and a commercial EGO Pulse device by Smokie's®.

During the sampling session, 1760 mg of liquid were vaporized, which is equal to 1.6 ml containing

[2] English term *to vape* indicating the act of e-smoking.

[3] Heaven Juice Traditional e-cigarette liquids by Flavour Art were used during the experiment. They contained about 40% of USP glycerol, 50% of USP propylene glycol, from 0.9% to 1.8% of USP nicotine, <1% aromatic component, purified water, according to the information provided by the producer.

Composti Analizzati Analyzed compounds	Supporto di campionamento Sampling medium	Litri campionati (teorici) Sampled liters (theoretical)	Metodo Method
Nicotina **Nicotine**	Fiala XAD-2 XAD-2 vial	600	NIOSH 2544
Glicoli - Glicerina **Glycols - Glycerine**	Filtro in fibra di vetro + fiala XAD-7 Glass fiber filter + XAD-7 vial	600	NIOSH 5523
Idrocarburi Policiclici Aromatici (IPA) **Polycyclic Aromatic Hydrocarbons (PAHs)**	Filtro in fibra di vetro + fiala XAD-2 Glass fiber filter + XAD-2 vial	600	NIOSH 5515
Acroleina **Acrolein**	Fiala di Silica gel + DPNH Silica gel vial + DPNH	60	NIOSH 2018
SOV **VOCs**	Fiala di carbone attivo Activated carbon vial	60	UNI EN 13649

Tab. 1: Metodi utilizzati per il campionamento dei composti. / Methods used for substances sampling.

to da *FlavourArt* e un dispositivo EGO Pulse di Smokie's®.

Durante la sessione di campionamento, sono stati vaporizzati 1760 mg di liquido, pari a circa 1.6 ml e contenenti circa 17.6 mg di nicotina.

Materiali e Metodi

Per le metodiche di campionamento sono state adottate diverse procedure sia della normativa UNI che NIOSH, impiegando differenti fiale SKC specifiche per i diversi componenti da ricercare. Per alcune molecole sono state utilizzate anche delle membrane filtranti in fibra di vetro o in PTFE con porosità di 0.8 µm (Tab. 1).

Ogni fiala è stata collegata ad un campionatore aspirante portatile, calibrato e impostato per aspirare uno specifico volume, in funzione della durata dell'esperimento e delle specifiche della metodica in uso.

A questi sistemi di campionamento cumulativo, sono stati affiancati, un rilevatore di CO, CO_2, NO_x, e un rilevatore di COT a ionizzazione di fiamma FID.

A fine esperimento, le fiale e le membrane sono state sigillate e trasportate presso i laboratori ABICH S.r.l.[4] per le analisi.

Risultati

Le analisi dei campioni hanno evidenziato numerose e sostanziali differenze tra fumo di sigaretta e fumo elettronico, sia in termini di impatto sulla qualità dell'aria, sia anche in termini di tossicità. (Tab. 2).

Per il campionamento sono state impiegate delle membrane in PTFE e siamo rimasti colpiti dal co-

[4]ABICH S.r.l., Verbania (VB), Italia

about 17.6 mg of nicotine.

Materials and Methods

Considering the sampling methodologies different procedures both from UNI and NIOSH have been used. Different SKC vials specific for the different components to search were used. For some molecules, also fiberglass or PTFE 0.8 µm porosity membrane filters were used (Tab. 1).

Each vial was linked with a portable suction sampler, calibrated and set to aspirate a specific volume, depending on the duration of the experiment and on the method details.

In addition to these cumulative sampling systems, a CO and CO_2 and NO_x detector and a FID flame ionization TOC detector were used.

At the end of the experiment, the vials and the membranes were sealed and taken to the ABICH S.r.l.[4] labs for the analysis.

Results

The sampling analysis underlined many and fundamental differences between cigarette smoking and e-cigarette smoking, both in terms of impact on air quality and also on toxicity. (Tab. 2).

PTFE membranes have been used for the sampling. We were surprised by the colour of the mem-

[4]ABICH S.r.l.,Verbania (VB), Italy

Parametro Parameter	Volume Campionato* Sampled Volume* [L]	Concentrazione Media* Mean Concentration* [mg/m^3]	
		Sigaretta Tradizionale Traditional Cigarette	Sigaretta Elettronica Electronic Cigarette
Nicotina / Nicotine	600	0.034	< 0.001**
Glicerina / Glycerine	600	< 0.001**	0.072
Glicolene Propilenico / Propylene Glycol	600	< 0.01**	< 0.01**
Acroleina / Acrolein	60	0.020	< 0.0016**

Tempo di campionamento: 300 minuti. / Sampling time: 300 minutes.

* dati relativi alle condizioni operative di riferimento (20°C e 0.101 MPa) riprodotte dall'attrezzatura / values refer to ideal working conditions (20°C and 0.101 MPa) simulated by the equipment

** inferiore alla soglia rilevabile dalla metodica / below the instrument sensitivity

Tab. 2: Sostanze rilevate. / Detected substances.

lore assunto dalle membrane alla fine delle sessioni. Questo, pur non costituendo un dato analitico di per sé, in qualche modo ci ha dato un'idea dei risultati che avremmo ottenuto (Fig. 3 e 4).

Fig. 3: Membrana in PTFE al termine della sessione di fumo tradizionale. / PTFE membrane at the end of the cigarette smoking session.

Fig. 4: Membrana in PTFE al termine della sessione di fumo elettronico. / PTFE membrane at the end of the e-cigarette session.

CO (Monossido di Carbonio) [12] Il monossido di carbonio non ha mostrato alcuna variazione con il fumo elettronico, rimanendo al di sotto dei limiti di rilevabilità dello strumento, mentre il fumo di sigaretta ha prodotto un costante incremento della sua concentrazione durante tutta la durata del campionamento, raggiungendo un picco di 11 mg/m^3, valore questo, al di sopra della soglia di legge (10 mg/m^3)[5] (Fig. 5).

Il monossido di carbonio è un gas tossico con una elevata affinità per l'emoglobina, compromettendo

CO (Carbon Monoxide) [12] The levels of carbon monoxide did not show any variation during e-cigarette smoking, remaining below the detection limits of the tool. On the contrary cigarette smoking produced a steady elevation in CO throughout the sampling period. It reached a peak of 11 mg/m^3, which is above the legal threshold (10 mg/m^3)[5] (Fig. 5).

Carbon monoxide is a toxic gas with a high affinity for haemoglobin, compromising its ability to transport oxygen. Smokers, continue to exhale out high levels of CO several hours after smoking their

[5]Decreto Legislativo 13 agosto 2010, n. 155. Attuazione della direttiva 2008/50/CE relativa alla qualità dell'aria ambiente e per un'aria più pulita in Europa.

[5]Legislative decree 13th August 2010, n.155. Application of the directive 2008/50/CE concerning the quality air in the environment for a clearer air in Europe.

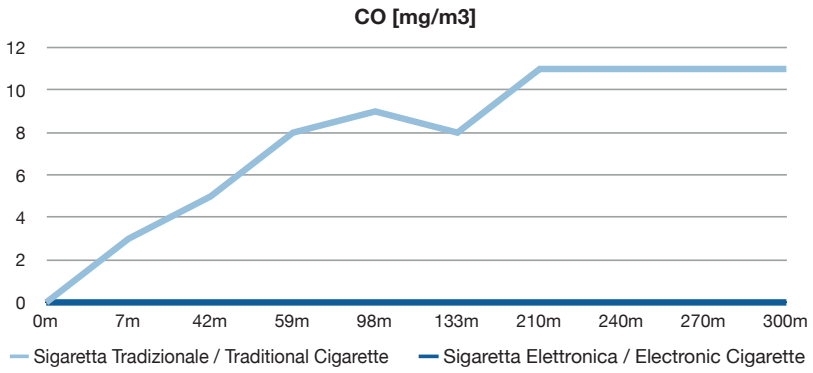

Fig. 5: Concentrazione di CO durante l'esperimento. / CO concentration during the experiment.

la sua capacità di trasportare ossigeno. Un fumatore continua ad emettere elevati livelli di monossido di carbonio, anche molte ore dopo aver fumato l'ultima sigaretta [5].

Nicotina Tra gli aspetti più interessanti, abbiamo osservato che la nicotina, pur presente nei liquidi utilizzati per l'esperimento, non è stata rilevata durante la sessione relativa al fumo elettronico. Per contro sono stati dosati 34 µg/m^3 di nicotina, con il fumo tradizionale. Va precisato che, stando a quanto riportato sui pacchetti, la quota di nicotina inalata dai fumatori, ammonta complessivamente a circa 11.4 mg, mentre i *vaper* hanno inalato nicotina per un totale di 17.6 mg. Tuttavia la quota di nicotina indicata sul pacchetto tiene conto solo della quota inalata, senza fornire alcuna informazione relativa a quella effettivamente presente nella sigaretta e liberata nell'aria durante la sua combustione.

Basandosi sui risultati osservati è possibile dedurre che il fumo di sigaretta produce una contaminazione da nicotina nell'aria, almeno 35 volte superiore a quella del fumo elettronico, il che equivale a dire che servono almeno 35 *vaper* per produrre un livello di nicotina equivalente a quello prodotto da un singolo fumatore.

Se inoltre avessimo bilanciato le prove, chiedendo ai fumatori, di consumare sigarette, in quantità tali da eguagliare il consumo di nicotina dei *vaper*, questi avrebbero dovuto fumare circa 29 sigarette, producendo una concentrazione di nicotina stimata in circa 52 µg/m^3.

Argomentare sulle ragioni di questi risultati è estremamente difficile, si potrebbe ipotizzare che esista per i *vaper* una differente cinetica di assorbimento della nicotina, o più semplicemente che le quantità in gioco siano estremamente contenute se paragonate a quelle effettivamente liberate dal fumo tradizionale. Ma al di là di queste ipotesi, tutte da verificare, il risultato in sé rimane un fatto: 5 *vaper* che utilizzano la sigaretta elettronica, per 5 h, in una last cigarette, even if the last cigarette was put out many hours before [5].

Nicotine Among all, the most interesting aspects we observed was that nicotine was not detected in air during the e-smoking session, although liquids used for experiments contained it. On the other hand, 34 µg/m^3 of nicotine were found during the smoking session. It should be made clear that, according to the information on packs, the amount of nicotine inhaled by smokers was about 11.4 mg, while the amount of nicotine inhaled by vapers was about 17.6 mg. However the amount of nicotine reported on packs is the inhaled amount. This information does not give details about the real amount of nicotine inside the cigarettes and released in the air during combustion and from side stream smoke.

Based on the observed results, we can conclude that cigarette smoking produces nicotine contamination in the air at least 35 times higher than e-smoking. This means that we need at least 35 vapers to produce nicotine level in air similar to the level produced by a single smoker.

Moreover if we had balanced the tests, asking cigarette smokers to consume the amount of cigarettes necessary to match the amount of nicotine used by vapers, the latter should have smoked about 29 cigarettes, producing an expected nicotine concentration of about 52 µg/m^3.

It's extremely difficult to discuss about the reasons for these results. We could suppose that there is a different absorption kinetics for nicotine. Or maybe the amount in play is extremely low, when compared to the nicotine amount released during traditional smoking. However beyond all these hypotheses, which have not been verified, there is one fact: 5 vapers using e-cigarettes for 5 h in a small room without renewal of indoor air do not produce detectable levels of nicotine in the air.

Parametro Parameter	Volume Campionato* [L] Sampled Volume*	Concentrazione Media* [µg/m³] Mean Concentration*	
		Sigaretta Tradizionale Traditional Cigarette	Sigaretta Elettronica Electronic Cigarette
Metiletilchetone / Methylethylketone	60	4.2	4.4
1-etil-3-metil benzene / 1-ethyl-3-methylbenzene	60	0.2	3.4
Limonene / Limonene	60	12.5	0.1
Decano / Decane	60	0.4	4.2
Undecano / Undecane	60	4.2	0.7
Dodecano / Dodecane	60	3.7	0.3
Cedrene / Cedrene	60	0.3	0.9
Longifolene / Longifolen	60	18.3	30.3
Toluene / Toluene	60	1.7	-
O,m,p – Xilene / o,m,p – Xylene	60	0.2	-
1-etil-2-metil benzene / 1-ethyl-2-methylbenzene	60	4.9	-
1,2,4-trimetil benzene / 1,2,4-Trimethylbenzene	60	0.3	-
Mentene / Menthene	60	0.5	-
BHT (Butilidrossitoluene / Butylhydroxytoluene)	60	-	0.4
Terpene / Terpene (u.s.)	60	-	2.3
Longiciclene / Longicyclene	60	-	2.2
Cariofillene / Caryophillene	60	-	1.0
n.i. totali / total u.s.	60	14.7	12.6

n.i. sostanza non identificabile / u.s. unidentifiable substance

Tempo di campionamento: 300 minuti. / Sampling time: 300 minutes.

* dati relativi alle condizioni operative di riferimento (20°C e 0.101 MPa) riprodotte dall'attrezzatura / values refer to ideal working conditions (20°C and 0.101 MPa) simulated by the equipment

** inferiore alla soglia rilevabile dalla metodica / below the instrument sensitivity

Tab. 6: Sostanze Organiche Volatili. / Volatile Organic Compounds.

stanza di piccole dimensioni e senza rinnovo d'aria, non producono livelli rilevabili di nicotina nell'aria.

Glicole Propilenico Altro parametro inatteso è il glicole propilenico, che non è stato rilevato durante la prova con il fumo elettronico, pur costituendo il 50% del liquido[3].

Questo curioso fenomeno è stato osservato anche in un altro studio simile [11]. Anche questo studio non ha rilevato nicotina nel vapore passivo di una stanza sperimentale (significativamente più piccola della stanza da noi utilizzata). Alcuni esperimenti suggeriscono che l'assorbimento del glicole propilenico per via inalatoria sia estremamente rapido [17] e questo potrebbe spiegare perché questa molecola pur così abbondante non è stata rilevata.

Glicerina e Acroleina Non è stata rilevata glicerina relativamente al fumo di sigaretta, mentre ne è stata rilevata una traccia con il fumo elettronico, pari a 72 µg, valore molto al di sotto della soglia di

Propylene Glycol Results on propylene glycol were also unexpected. During e-smoking tests, propylene glycol was not detected, although 50% of liquid[3] consisted of propylene glycol.

This curious phenomenon has also been observed in a similar study [11]. Even in that case, nicotine was not detected in an experimental room of the passive vaping (which was significantly smaller than the room we used). Some studies suggest that propylene glycol absorption via inhalation is extremely rapid [17]. This could explain why this molecule has not been detected even though it was present in significant amounts in the liquid used.

Glycerine and Acrolein No glycerine was detected in air during cigarette smoking. On the other hand, 72 µg/m^3 were detected during e-smoking. This amount is much lower than the threshold safety

Parametro Parameter	Volume Campionato* [L] Sampled Volume*	Concentrazione Media* [µg/m³] Mean Concentration*	
		Sigaretta Tradizionale Traditional Cigarette	Sigaretta Elettronica Electronic Cigarette
Naftalene / Naphthalene	600	**2.78**	< 0.02**
Acenaftilene / Acenaphthylene	600	< 0.02**	< 0.02**
Acenaftene / Acenaphthene	600	**0.19**	< 0.03**
Fluorene / Fluorene	600	**0.47**	< 0.06**
Fenantrene / Phenanthrene	600	**0.37**	< 0.08**
Antracene / Anthracene	600	< 0.04**	< 0.04**
Fluorantene / Fluoranthene	600	**0.13**	< 0.02**
Pirene / Pyrene	600	< 0.01**	< 0.01**
Benzo(a)antracene / Benzo(a)anthracene	600	< 0.16**	< 0.16**
Crisene / Chrysene	600	**5.46**	< 0.14**
Benzo(b)fluorantene / Benzo(b)fluoranthene	600	< 0.33**	< 0.33**
Benzo(k)fluorantene / Benzo(k)fluoranthene	600	< 0.74**	< 0.74**
Benzo(a)pirene / Benzo(a)pyrene	600	< 0.62**	< 0.62**
Indeno(1,2,3-cd)pirene / Indeno(1,2,3-cd)pyrene	600	< 1.47**	< 1.47**
Dibenzo(a,h)antracene / Dibenzo(a,h)anthracene	600	< 1.47**	< 1.47**
Benzo(ghi)perilene / Benzo(g,h,i)perylene	600	< 1.60**	< 1.60**

Tempo di campionamento: 300 minuti. / Sampling time: 300 minutes.

* dati relativi alle condizioni operative di riferimento (20°C e 0.101 MPa) riprodotte dall'attrezzatura / values refer to ideal working conditions (20°C and 0.101 MPa) simulated by the equipment

** inferiore alla soglia rilevabile dalla metodica / below the instrument sensitivity

Tab. 7: Idrocarburi Policiclici Aromatici. / Polycyclic Aromatic Hydrocarbons.

azione (TWA-TLV 10 mg/m^3) e ben al di sotto della soglia definita di rischio moderato o irrilevante [4].

Tuttavia, bisogna rilevare che l'acroleina, molecola che si forma della disidratazione ad elevate temperature della glicerina, era presente e ben rilevabile nell'aria della stanza, durante la prova dei fumatori (20 $\mu g/m^3$).

È noto infatti che la glicerina viene spesso aggiunta ai tabacchi come umettante e durante la combustione si trasformi in acroleina [3]. L'assenza di processi di combustione nel fumo elettronico, è di fondamentale importanza per comprendere come mai l'acroleina non sia stata rilevata nell'aria durante la prova.

L'acroleina è una sostanza notoriamente molto tossica e irritante, inoltre è attualmente sospetta per avere un ruolo nei processi di cancerogenesi [1].

limit (TWA-TLV 10 mg/m^3) and much lower than the threshold for moderate risk [4].

However, it's important to note that acrolein, a molecule formed by dehydration of glycerine due to high temperatures, was present in the air of the room during cigarette smoking test (20 $\mu g/m^3$).

In fact, it is well known that glycerine is often added to moisten tobacco. During combustion glycerine is transformed into acrolein [3]. The fact that no combustion is involved when using e-cigarettes probably plays a fundamental role in the absence of acrolein from indoor air during their use.

As everyone knows, acrolein is a very toxic and irritating substance. Moreover it is currently suspected of having a fundamental role in the carcinogenic process [1].

SOV Dall'analisi delle sostanze organiche volatili, sono state evidenziate fondamentalmente componenti aromatiche, in particolare il longifolene, tipico dell'aroma di pino, era presente in entrambe le prove. È probabile che questo composto facesse parte dei prodotti detergenti o deodoranti impiegati per pulire la stanza prima dell'esperimento. In merito

VOCs During the analysis of volatile organic compounds, aromatic components were detected, in particular longifolen, typical of pine aroma, in both tests. One of the detergents used to clean the room before the test could have contained this compound. Regarding cigarette smoking, xylene and toluene were detected. These are two very common toxic

al fumo di sigaretta, si rilevano comunque tracce di xilene e toluene, due composti tossici, normalmente presenti nel fumo di sigaretta. Il limonene, terpene dell'olio essenziale di limone, è stato rilevato solo durante la prova con il fumo tradizionale ed in effetti questa molecola è stata riscontrata anche da altri studi come componente del fumo di sigaretta [11] (Tab. 6).

IPA Tra i composti più rilevanti, in termini di tossicità cronica del fumo di tabacco, ci sono certamente gli idrocarburi policiclici aromatici. Questi composti, prodotti durante il processo di combustione, sono noti per gli effetti cancerogeni e mutageni.

La prova ha identificato 6 dei 16 IPA ricercati, durante la sessione con il fumo tradizionale, mentre non è stato rilevato nulla con il fumo elettronico (Tab. 7).

COT [15] L'analisi del carbonio organico totale, non ci dà informazioni specifiche sulla tossicità. È un modo per valutare globalmente la quantità di materia organica immessa nell'aria, senza distinguere tra sostanze tossiche e non tossiche. Tuttavia questo parametro ci fornisce una visione globale del grado di contaminazione dell'aria, durante tutta la durata dell'esperimento.

Nel grafico è possibile osservare l'andamento dei livelli di COT nell'aria durante le 5 h di campionamento.

Dal grafico è stato sottratto il valore di fondo presente all'inizio del campionamento ($1\,mg/m^3$).

Due aspetti sono interessanti a mio parere. In primo luogo i livelli massimi con il fumo di sigaretta sono oltre 9 volte più alti che con il fumo elettronico, in secondo luogo, il fumo impiega appena 11 minuti, a raggiungere il valore massimo raggiunto dalla sigaretta elettronica ($0.73\,mg/m^3$), nel tempo di 5 h (Fig. 8).

compounds in cigarette smoking. Limonene which is an oil lemon terpene, was detected only during the traditional smoking test. In fact this molecule was found as a component in cigarette smoke even in other studies [11] (Tab. 6).

PHAs Polycyclic aromatic hydrocarbons are, without doubt, among the most important compounds in terms of chronic toxicity caused by tobacco smoking. These substances, which are produced during the combustion process, are well known for their carcinogenic and mutagenic effects.

During the traditional cigarette smoking session, 6 out of 16 PAHs were identified. Nothing was identified during the e-cigarette session (Tab. 7).

TOC [15] The total organic carbon analysis does not give us specific information about toxicity. It is a measure of the overall amount of organic matter released in the air. There is no distinction between toxic and non-toxic substances. However this parameter gives us a global view of the degree of contamination of air, throughout the whole experiment.

The chart shows the TOC level trends in the air during the 5 h sampling.

The chart does not contain the original value of air at the beginning of the sample ($1\,mg/m^3$).

In my opinion there are two interesting aspects which should be underlined. Firstly, the maximum levels during cigarette smoking sessions are 9 times higher than the e-smoking session. Secondly, cigarette smoking takes just 11 minutes to reach a value similar to the maximum value measured for the e-cigarette ($0.73\,mg/m^3$), in 5 h (Fig. 8).

Conclusioni

L'esperimento su descritto ha evidenziato, limitatamente ai parametri osservati, che il fumo elettronico non comporta l'immissione nell'aria di un ambiente chiuso, di sostanze tossiche o cancerogene in quantità rilevabili. Ulteriori studi sono necessari, per approfondire e meglio definire tutti gli aspetti coinvolti, ma questa valutazione preliminare suggerisce che l'impatto del fumo elettronico passivo, se confrontato con quello del fumo di sigaretta, è talmente ridotto da essere appena rilevabile e non presenta le caratteristiche di tossicità e di cancerogenicità rilevate nel fumo di sigaretta. L'assenza di combustione e la mancanza di fumo secondario (*sidestream smoke*), noto per i suoi effetti tossici [2, 6], sono probabilmen-

Conclusions

The above experiment, within the limits of the observed parameters, has underlined that e-smoking does not produce detectable amounts of toxic and carcinogenic substances in the air of an enclosed space. Further studies are needed to better understand all the involved aspects. However this preliminary assessment indicates that passive vaping impact, when compared to the traditional cigarette smoking, is so low that it is just detectable, and it does not have the toxic and carcinogenic characteristics of cigarette smoking. The absence of combustion and the lack of sidestream smoking, with its known toxic effects [2, 6] are probably the main reasons for the differences observed in air pollution characteristics

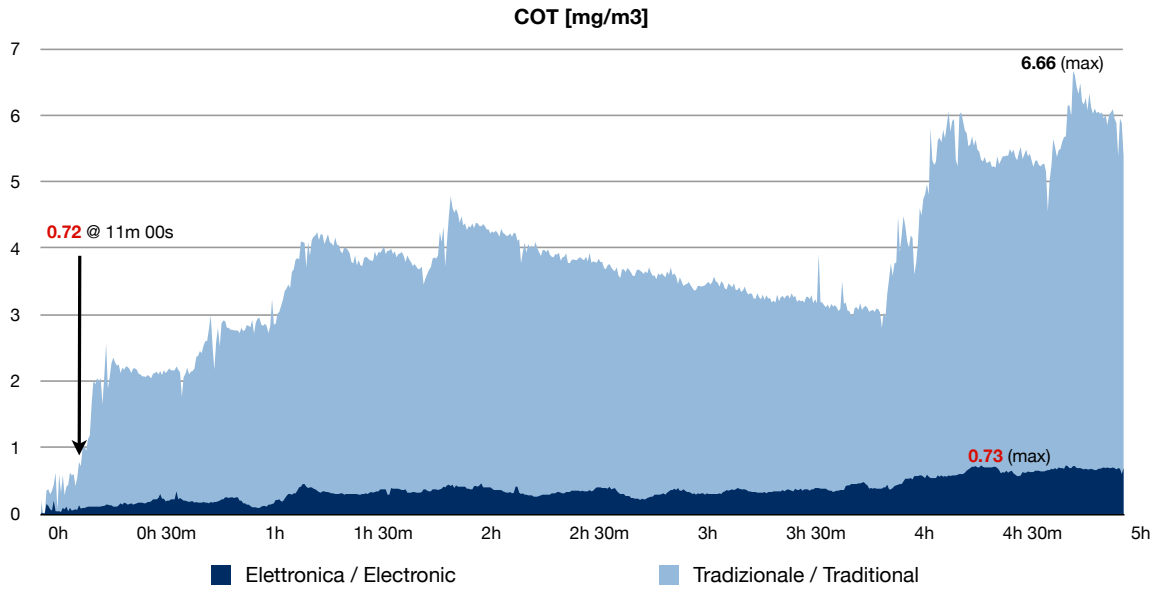

Fig. 8: Carbonio Organico Totale. / Total Organic Carbon.

te alla base delle differenze osservate, in termini di inquinamento dell'aria, tra fumo di tabacco e fumo elettronico.

Come considerazione finale, basandosi sui risultati ottenuti e sui dati dell'ARPA in materia di inquinamento urbano, potrebbe essere meno salutare, respirare l'aria di una grande città nell'ora di punta, piuttosto che sostare in una stanza con qualcuno che usa una sigaretta elettronica.

between e-cigarettes and tobacco smoking.

On the base of the obtained results and on ARPA data about urban pollution, we can conclude by saying that could be more unhealty to breath air in big cities compared to staying in the same room with someone who is vaping.

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CATEGORY NEWS > TOBACCO
March 15, 2016

Three More Findings from the FDA's Tobacco Study

PATH study data on youth access, poly-use and reduced-harm products

Published in *CSP Daily News*

By Melissa Vonder Haar, Tobacco Editor, CSP

CHICAGO -- Data from the U.S. Food and Drug Administration (FDA) and National Institute of Health's landmark Population Assessment of Tobacco and Health (PATH) long-term tobacco use study was presented for the first time during this month's Society for Research on Nicotine and Tobacco Conference. While a lot of the data focused on electronic cigarettes, Cowen Group analyst Vivien Azer broke down three other interesting data points from the FDA's presentation.

25

1. 75% of Minors Get Cigarettes from Social Sources: Perhaps the most important retailer takeaway from the PATH study was the reinforcement of the fact that minors are not getting their cigarettes from retailers, but from social sources. Of the 15- to 17-year-old smokers surveyed as part of the PATH study, 43% said they'd obtained cigarettes in the past 30 days from either asking someone or someone offering; 32% said they'd given someone else money to purchase cigarettes; just 14% said they'd bought cigarettes themselves.

2. 43% of Minors Reported Using Two or More Tobacco Products: "While cigarettes remain the largest segment in the tobacco category, the PATH study also examined closely the growing trend of poly-use among tobacco users," Azer wrote in a research note. "Poly-use was slightly more common among youth, with 43% of 12- to 17-year-olds reporting they used at least two tobacco products."

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Cigarettes were the most used product, with 76% of adult and 71% of minor poly-users saying they use cigarettes. Electronic cigarettes were next (45% of adults and 54% of youths), followed by cigarillos (38% of adults, 46% of youths).

3. Only 3.1% of Non-Tobacco Consumers are Interested in Reduced-Harm Products: "Looking beyond e-cigs, the PATH survey also looked to evaluate the appeal of reduced-harm products," wrote Azer. "Among current experimental and established smokers, more than half expressed interest in reduced-risk products, and more important, only 3.1% of nicotine naive consumers expressed such an interest."

Specifically, 54.5% of current established smokers were interested in reduced-harm products, while 51.3% of current experimental smokers and 22% of consumers who had ever used tobacco expressed interest. For non-nicotine naive consumers, 25.8% of recent former smokers and 8.6% of long-term former smokers were attentive to reduced-harm products.

KEYWORDS: cigarettes, electronic cigarettes

By Melissa Vonder Haar, Tobacco Editor, CSP
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Why Cramer Is 'Mad' About CST

CNBC host likes spinoffs, and here are the reasons (video)

UK: Bristol mobilizes to convert smokers to vaping

This week in the UK, for the National Stop Smoking Day, the municipality of Bristol goes to the street to meet the smokers in the hope of converting them to vaping.

*By **Ghyslain Armand** - March 10, 2016*

Actions in specialty shops

The Municipal Council of Bristol, UK, recommends using the vaporizer as an alternative to tobacco and will meet smokers in the street, this week, with the intention of converting them to this alternative to tobacco.

For the National Stop Smoking Day, municipal teams will visit four electronic cigarette shops located in the city center to offer carbon monoxide test and show how levels in the body differ between smokers and vapers.

Try all available methods

Interviewed by Bristol Post, HI France Councillor, a former smoker, recognizes “how difficult it can be to quit smoking”. He “encourages smokers who are trying to wean to try all methods”. The municipality wants to advise the long-term smokers with this public health message: “Electronic cigarettes are a better option than tobacco. [...] There is no better time than today to stop.”

Marcus Munafo, professor at the University of Bristol, shares the same opinion and regrets that “many people do not realize that the vaporizer is less dangerous than conventional cigarettes”.

In Bristol, where Imperial Brands has its headquarters, the prevalence of smoking is 21.3%. According to the Bristol Post, smokers have the opportunity to triple their chances of withdrawal by using an electronic cigarette while following the recommendations of local support center for smoking cessation.

Several myths associated with the e-cigarette should further be undermined, develops the newspaper. First **misconception** is the **renormalization of the act of smoking**. This is false; the prevalence of smoking is decreasing in England. In addition, the electronic cigarette is **not a gateway to smoking** for children, almost all English vapers are former smokers. In addition, **accidents involving electronic cigarettes** are very rare and are usually caused by negligence.

Ghyslain Armand

Currently living in France I am the chief editor of PGVG Magazine. I've been writing about vaping for the past 4 years. I also lead conferences on this topic for international events such as Vapexpo (Paris).

8 September 2009

E-cigarettes: harmless inhaled or exhaled

No second hand smoke

CHEMICALS IN SMOKE and E-cigarette MIST

Leading chemicals only	Cigarette SMOKE	E-cigarette MIST
Nicotine per puff	YES 0.1 mg/puff	YES 0.01 mg/puff
Propylene glycol	NO 0 mg/puff	YES 0.7 mg/puff
Carbon monoxide	YES	NONE
Acrolein	YES	NONE
Hydrogen cyanide	YES	NONE
CARCINOGENS	1,3-Butadiene and 20+ others:	Trace amounts of a few only:
Acetaldehyde	YES	TRACE
Acrylonitrile	YES	NONE
Arsenic	YES	NONE
Benzalphapyrene	YES	NONE
Benzene	YES	NONE
Cadmium	YES	NONE
NNN, NNK (nitrosamines)	YES	TRACE

Second hand *cigarette* smoke is a mixture of mainstream and sidestream smoke. It contains the same toxicants as mainstream smoke, but at reduced levels. It is responsible for about 8% of the deaths caused by direct smoking.

Second hand mist from an *e-cigarette* is not smoke at all, and does not contain any substance known to cause death, short or long term, in the quantities found. It becomes invisible within a few seconds, and is not detectable by smell**.**

Exhaled breath after e-cigarette use has been tested for CO only. No increase in CO was found.

The e-cigarette does not create side-stream smoke. Exhaled breath after e-smoking contains even less nicotine per puff, as much of the nicotine inhaled is absorbed. Similarly, propylene glycol is largely absorbed and little is exhaled.

No harm found in e-cigarette mist

Nicotine is not harmful in the quantities mentioned.[1]

Propylene glycol is harmless – it is used in making theatrical fog and as an ingredient in soaps, personal lubricants and intravenous medicines.

---

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Some smokers need satisfying replacement products to help them quit smoking

Attitudes, Beliefs, and Practices Regarding Electronic Nicotine Delivery Systems in Patients Scheduled for Elective Surgery

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Abstract

Smokers are at increased risk of postoperative complications. Electronic nicotine delivery systems (ENDS; or electronic cigarettes) could be a useful tool to reduce harm in the perioperative period. This pilot study examined the attitudes, beliefs, and practices of smokers scheduled for elective surgery regarding ENDS. This was a cross-sectional survey of current cigarette smokers who were evaluated in a preoperative clinic before elective surgery at Mayo Clinic. Measures included demographic characteristics, smoking history, 2 indices assessing the perception of how smoking affected health risks, ENDS use history, and 3 indices assessing interest in, perceived benefits of, and barriers to using ENDS in the perioperative period. Of the 112 smokers who completed the survey, 62 (55%) had tried ENDS and 24 (21%) reported current use. The most commonly stated reason for using ENDS was to quit smoking. Approximately 2 in 3 participants would be willing to use ENDS to help them reduce or eliminate perioperative cigarette use, and similar proportions perceived health benefits of doing so. Of the factors studied, only attempted to quit within the last year was significantly associated with increased interest in the perioperative use of ENDS (*P*=.03). Compared with participants who had tried ENDS (n=62), those who had never tried ENDS (n=50) had a significantly increased interest in the perioperative use of ENDS. A substantial proportion of patients scheduled for elective surgery had tried ENDS and would consider using ENDS to reduce perioperative use of cigarettes.

URL:
http://www.mayoclinicproceedings.org/article/S0025-6196%2814%2900997-5/abstract

Public Health England

Protecting and improving the nation's health

E-cigarettes: an evidence update

A report commissioned by Public Health England

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Contents

Foreword

The role and impact of electronic cigarettes has been one of the great debates in public health in recent years and we commissioned this independent review of the latest evidence to ensure that practitioners, policy makers and, most importantly of all, the public have the best evidence available.

Many people think the risks of e-cigarettes are the same as smoking tobacco and this report clarifies the truth of this.

In a nutshell, best estimates show e-cigarettes are 95% less harmful to your health than normal cigarettes, and when supported by a smoking cessation service, help most smokers to quit tobacco altogether.

We believe this review will prove a valuable resource, explaining the relative risks and benefits of e-cigarettes, in terms of harm reduction when compared with cigarettes and as an aid to quitting.

We will continue to monitor the position and will add to the evidence base and guidance going forward.

Duncan Selbie, Chief Executive, PHE

Key messages

1. Smokers who have tried other methods of quitting without success could be encouraged to try e-cigarettes (EC) to stop smoking and stop smoking services should support smokers using EC to quit by offering them behavioural support.

2. Encouraging smokers who cannot or do not want to stop smoking to switch to EC could help reduce smoking related disease, death and health inequalities.

3. There is no evidence that EC are undermining the long-term decline in cigarette smoking among adults and youth, and may in fact be contributing to it. Despite some experimentation with EC among never smokers, EC are attracting very few people who have never smoked into regular EC use.

4. Recent studies support the Cochrane Review findings that EC can help people to quit smoking and reduce their cigarette consumption. There is also evidence that EC can encourage quitting or cigarette consumption reduction even among those not intending to quit or rejecting other support. More research is needed in this area.

5. When used as intended, EC pose no risk of nicotine poisoning to users, but e-liquids should be in ‘childproof' packaging. The accuracy of nicotine content labelling currently raises no major concerns.

6. There has been an overall shift towards the inaccurate perception of EC being as harmful as cigarettes over the last year in contrast to the current expert estimate that using EC is around 95% safer than smoking.

7. Whilst protecting non-smoking children and ensuring the products on the market are as safe and effective as possible are clearly important goals, new regulations currently planned should also maximise the public health opportunities of EC.

8. Continued vigilance and research in this area are needed.

Executive summary

Following two previous reports produced for Public Health England (PHE) on e-cigarettes (EC) in 2014, this report updates and expands on the evidence of the implications of EC for public health. It covers the EC policy framework, the prevalence of EC use, knowledge and attitudes towards EC, impact of EC use on smoking behaviour, as well as examining recent safety issues and nicotine content, emissions and delivery. Two literature reviews were carried out to update the evidence base since the 2014 reports and recent survey data from England were assessed.

EC use battery power to heat an element to disperse a solution of propylene glycol or glycerine, water, flavouring and usually nicotine, resulting in an aerosol that can be inhaled by the user (commonly termed vapour). EC do not contain tobacco, do not create smoke and do not rely on combustion. There is substantial heterogeneity between different types of EC on the market (such as cigalikes and tank models). Acknowledging that the evidence base on overall and relative risks of EC in comparison with smoking was still developing, experts recently identified them as having around 4% of the relative harm of cigarettes overall (including social harm) and 5% of the harm to users.

In England, EC first appeared on the market within the last 10 years and around 5% of the population report currently using them, the vast majority of these smokers or recent ex-smokers. Whilst there is some experimentation among never smokers, regular use among never smokers is rare. *Cigarette* smoking among youth and adults has continued to decline and there is no current evidence in England that EC are renormalising smoking or increasing smoking uptake. Instead, the evidence reviewed in this report point in the direction of an association between greater uptake of EC and reduced smoking, with emerging evidence that EC can be effective cessation and reduction aids.

Regulations have changed little in England since the previous PHE reports with EC being currently governed by general product safety regulations which do not require products to be tested before being put on the market. However, advertising of EC is now governed by a voluntary agreement and measures are being introduced to protect children from accessing EC from retailers. Manufacturers can apply for a medicinal licence through the Medicines and Healthcare products Regulatory Agency (MHRA) and from 2016, any EC not licensed by the MHRA will be governed by the revised European Union Tobacco Products Directive (TPD).

A summary of the main findings and policy implications from the data chapters now follows.

Summary of Chapter 3: UK policy framework

The revised TPD will introduce new regulations for EC or refill containers which are not licensed by the MHRA. The cap on nicotine concentrations introduced by the TPD will take high nicotine EC and refill liquids off the market, potentially affecting heavier smokers seeking higher nicotine delivery products.

The fact that no licensed EC are yet on the market suggests that the licensing route to market is not commercially attractive. The absence of non-tobacco industry products going through the MHRA licensing process suggests that the process is inadvertently favouring larger manufacturers including the tobacco industry, which is likely to inhibit innovation in the prescription market.

Policy implications

- From May 2016, following the introduction of the revised TPD, ECs will be more strictly regulated. As detailed elsewhere in the report, the information we present does not indicate widespread problems as a result of EC. Hence, the current regulatory structure appears broadly to have worked well although protecting non-smoking children and ensuring the products on the market are as safe and effective as possible are clearly important goals. New regulations currently planned should be implemented to maximise the benefits of EC whilst minimising these risks.

- An assessment of the impact of the TPD regulations on the UK EC market will be integral to its implementation. This should include the degree to which the availability of safe and effective products might be restricted.

- Much of England's strategy of tobacco harm reduction is predicated on the availability of medicinally licensed products that smokers want to use. Licensed ECs are yet to appear. A review of the MHRA EC licensing process therefore seems appropriate, including manufacturers' costs, and potential impact. This could include a requirement for MHRA to adapt the processes and their costs to enable smaller manufacturers to apply, and to speed up the licensing process. The review could also assess potential demand for the EC prescription market and what types of products would be most appropriate to meet that demand.

Summary of Chapter 4: Prevalence of e-cigarette use in England/Great Britain

Adults: Around one in 20 adults in England (and Great Britain) use EC. Current EC users are almost exclusively smokers (~60%) or ex-smokers (~40%), that is smokers who now use EC and have stopped smoking altogether. EC use among long-term ex-smokers is considerably lower than among recent ex-smokers. Current EC use among

never smokers is very low, estimated to be 0.2%. The prevalence of EC use plateaued between 2013-14, but appeared to be increasing again in 2015.

Youth: Regular EC use among youth is rare with around 2% using at least monthly and 0.5% weekly. EC use among young people remains lower than among adults: a minority of British youth report having tried EC (~13%). Whilst there was some experimentation with EC among never smoking youth, prevalence of use (at least monthly) among never smokers is 0.3% or less.

Overall, the adult and youth data suggest that, despite some experimentation with EC among never smokers, EC are attracting few people who have never smoked into regular use.

Trends in EC use and smoking: Since EC were introduced to the market, cigarette smoking among adults and youth has declined. In adults, overall nicotine use has also declined (not assessed for youth). These findings, to date, suggest that the advent of EC is not undermining, and may even be contributing to, the long-term decline in cigarette smoking.

Policy implications

- Trends in EC use among youth and adults should continue to be monitored using standardised definitions of use.
- Given that around two-thirds of EC users also smoke, data are needed on the natural trajectory of ‘dual use’, ie whether dual use is more likely to lead to smoking cessation later or to sustain smoking (see also Chapter 6).
- As per existing NICE guidance, all smokers should be supported to stop smoking completely, including ‘dual users’ who smoke and use EC.

Summary of Chapter 5: Smoking, e-cigarettes and inequalities

Smoking is increasingly concentrated in disadvantaged groups who tend to be more dependent. EC potentially offer a wide reach, low-cost intervention to reduce smoking and improve health in disadvantaged groups.

Some health trusts and prisons have banned the use of EC which may disproportionately affect more disadvantaged smokers.

Policy implications

- Consideration could be given to a proactive strategy to encourage disadvantaged smokers to quit smoking as quickly as possible including the use of EC, where appropriate, to help reduce health inequalities caused by smoking.

- EC should not routinely be treated in the same way as smoking. It is not appropriate to prohibit EC use in health trusts and prisons as part of smokefree policies unless there is a strong rationale to do so.

Summary of Chapter 6: E-cigarettes and smoking behaviour

Recent studies support the Cochrane Review findings that EC can help people to quit smoking and reduce their cigarette consumption. There is also evidence that EC can encourage quitting or cigarette consumption reduction even among those not intending to quit or rejecting other support. It is not known whether current EC products are more or less effective than licensed stop smoking medications, but they are much more popular, thereby providing an opportunity to expand the number of smokers stopping successfully. Some English stop smoking services and practitioners support the use of EC in quit attempts and provide behavioural support for EC users trying to quit smoking; *self-reported* quit rates are at least comparable to other treatments. The evidence on EC used *alongside smoking* on subsequent quitting of smoking is mixed.

Policy implications

- Smokers who have tried other methods of quitting without success could be encouraged to try EC to stop smoking and stop smoking services should support smokers using EC to quit by offering them behavioural support.

- Research should be commissioned in this area including:
  - longitudinal research on the use of EC, including smokers who have not used EC at the beginning of the study
  - the effects of using EC while smoking (temporary abstinence, cutting down) on quitting, and the effects of EC use among ex-smokers on relapse
  - research to clarify the factors that i) help smokers using EC to quit smoking and ii) deter smokers using EC from quitting smoking, including different EC products/types and frequency of use and the addition of behavioural support, and how EC compare with other methods of quitting which have a strong evidence base

- It would be helpful if emerging evidence on EC (including different types of EC) and how to use EC safely and effectively could be communicated to users and health professionals to maximise chances of successfully quitting smoking.

Summary of Chapter 7: Reasons for use and discontinuation

A number of surveys in different populations provide evidence that reducing the harm from smoking (such as through cutting down on their cigarette consumption or helping with withdrawal during temporary abstinence) and the desire to quit smoking cigarettes are the most important reasons for using EC. Curiosity appears to play a major role in experimentation. Most trial of EC does not lead to regular use and while there is less evidence on why trial does not become regular use, it appears that trial due to curiosity is less likely to lead to regular use than trial for reasons such as stopping smoking or reducing harm. Dissatisfaction with products and safety concerns may deter continued EC use.

Policy implications

- Smokers frequently state that they are using EC to give up smoking. They should therefore be provided with advice and support to encourage them to quit smoking completely.

- Other reasons for use include reducing the harm from smoking and such efforts should be supported but with a long-term goal of stopping smoking completely.

Summary of Chapter 8: Harm perceptions

Although the majority of adults and youth still correctly perceive EC to be less harmful than tobacco cigarettes, there has been an overall shift towards the inaccurate perception of EC being at least as harmful as cigarettes over the last year, for both groups. Intriguingly, there is also some evidence that people believe EC to be less harmful than medicinal nicotine replacement therapy (NRT).

Policy implications

- Clear and accurate information on relative harm of nicotine, EC and tobacco cigarettes is needed urgently (see also Chapter 10).

- Research is needed to explore how health perceptions of EC are developed, in relation to tobacco cigarettes and NRT, and how they can be influenced.

Summary of Chapter 9: E-cigarettes, nicotine content and delivery

The accuracy of labelling of nicotine content currently raises no major concerns. Poorly labelled e-liquid and e-cartridges mostly contained less nicotine than declared. EC used

as intended pose no risk of nicotine poisoning to users. However, e-liquids should be in 'childproof' packaging.

Duration and frequency of puffs and mechanical characteristics of EC play a major role in determining nicotine content in vapour. Across the middle range of nicotine levels, in machine tests using a standard puffing schedule, nicotine content of e-liquid is related to nicotine content in vapour only weakly. EC use releases negligible levels of nicotine into ambient air with no identified health risks to bystanders. Use of a cigalike EC can increase blood nicotine levels by around 5 ng/ml within five minutes of use. This is comparable to delivery from oral NRT. Experienced EC users using the tank EC can achieve much higher blood nicotine levels over a longer duration, similar to those associated with smoking. The speed of nicotine absorption is generally slower than from cigarettes but faster than from NRT.

Policy implications

- General labelling of the strength of e-liquids, along the lines used for example indicating coffee strength, provides sufficient guidance to consumers.

- Regulatory interventions should ensure optimal product safety but make sure EC are not regulated more strictly than cigarettes and can continue to evolve and improve their competitiveness against cigarettes.

Summary of Chapter 10: Safety of e-cigarettes in light of new evidence

Two recent worldwide media headlines asserted that EC use is dangerous. These were based on misinterpreted research findings. A high level of formaldehyde was found when e-liquid was over-heated to levels unpalatable to EC users, but there is no indication that EC users are exposed to dangerous levels of aldehydes; stressed mice poisoned with very high levels of nicotine twice daily for two weeks were more likely to lose weight and die when exposed to bacteria and viruses, but this has no relevance for human EC users. The ongoing negative media campaigns are a plausible explanation for the change in the perception of EC safety (see Chapter 8).

None of the studies reviewed above alter the conclusion of Professor Britton's 2014 review for PHE. While vaping may not be 100% safe, most of the chemicals causing smoking-related disease are absent and the chemicals which are present pose limited danger. It has been previously estimated that EC are around 95% safer than smoking. This appears to remain a reasonable estimate.

Policy implications

- There is a need to publicise the current best estimate that using EC is around 95% safer than smoking.
- Encouraging smokers who cannot or do not want to stop smoking to switch to EC could be adopted as one of the key strategies to reduce smoking related disease and death.

Summary of Chapter 11: Other health and safety concerns

There is a risk of fire from the electrical elements of EC and a risk of poisoning from ingestion of e-liquids. These risks appear to be comparable to similar electrical goods and potentially poisonous household substances.

Policy implications

- The risks from fire or poisoning could be controlled through standard regulations for similar types of products, such as childproof containers (contained within the TPD but which are now emerging as an industry standard) and instructions about the importance of using the correct charger.
- Current products should comply with current British Standard operating standards.
- Records of EC incidents could be systematically recorded by fire services.

Summary of Chapter 12: International perspectives

Although EC use may be lower in countries with more restrictions, these restrictions have not prevented EC use. Overall, use is highest among current smokers, with low numbers of non-smokers reporting ever use. Current use of EC in other countries is associated with being a smoker or ex-smoker, similar to the findings in the UK. EC use is frequently misreported with experimentation presented as regular use. Increases in youth EC trial and use are associated with decreases in smoking prevalence in all countries, with the exception of one study from Poland.

Policy implications

- Future research should continue to monitor and evaluate whether different EC policies across countries are related to EC use and to smoking cessation and smoking prevalence.
- Consistent and agreed measures of trial, occasional and regular EC use among youth and adults are urgently needed to aid comparability.

1. Introduction

Despite the decline in smoking prevalence observed over the last few decades, there remain over eight million smokers in England. Most of these are from manual and more disadvantaged groups in society, including those with mental health problems, on low income, the unemployed and offenders. In some such population groups, the proportion who smoke is over two or three times higher than that in the general population, a level of smoking observed in the general population over 40 years ago. For those who continue to smoke regularly, much of their lives will be of lower quality and spent in poorer health than those who don't smoke, and they will have a one in two chance of dying prematurely, by an average of 10 years, as a direct result of their smoking. Smoking is therefore the largest single contributor to health inequalities as well as remaining the largest single cause of preventable mortality and morbidity in England.

Moving forward, it is therefore important to maintain and enhance England's comprehensive tobacco control strategy in order to motivate and support *all* smokers in society to stop smoking as quickly as possible, and prevent the recruitment of new smokers. Harm reduction guidance, published by the National Institute for Health and Care Excellence in England in 2013, recognised that some smokers struggled to quit abruptly and that cigarettes were a lethal delivery system for nicotine [1]; it is widely accepted that most smokers smoke for the nicotine but die from the other smoke constituents. Harm reduction has been identified as one of the more promising policy options to reduce smoking induced inequalities in health [2]. All experts agree that a well-resourced comprehensive strategy, involving cessation, prevention and harm reduction should make the goal of a smoke-free society in England quickly achievable.

However, the advent of electronic cigarettes (EC) over recent years has caused controversy. In 1991, Professor Michael Russell, a leading English smoking cessation expert from the Institute of Psychiatry, argued that *"it was not so much the efficacy of new nicotine delivery systems as temporary aids to cessation, but their potential as long-term alternatives to tobacco that makes the virtual elimination of tobacco a realistic future target",* and he recommended that "*tobacco should be rapidly replaced by cleaner, less harmful, sources of nicotine"* [3]. Professor Russell was one of the first to recognise the critical role that nicotine played in tobacco use and he identified that whilst there were good ethical and moral reasons not to promote nicotine addiction in society, the harm caused by nicotine was orders of magnitude lower than the harms caused by cigarette smoke. Professor Russell was also a pioneer of new treatments for smoking cessation, in particular, nicotine replacement therapies (NRT). Since then, the number of NRT products has proliferated such that there are now several different delivery routes and modes and countless different dosages and flavours. However, even with a relaxation of the licensing restrictions which increased their accessibility, NRT products have never become popular as an alternative to smoking.

In 2004, the first EC was marketed in China, and EC started to appear in England in 2006/7. The subsequent three years saw a rapid rise in their use. Whilst Professor Russell died in 2009, predating the arrival of these products in England, proponents of EC similarly recognised their potential to contribute towards making a smoke-free society more rapidly achievable [4]. Those against EC, however, believed that they were at best a distraction, at worst a means of undoing decades of progress in reducing smoking [5].

Any new tobacco control strategy for England must therefore incorporate a nicotine strategy, which should include recommendations and an appropriate regulatory framework for EC. This report attempts to inform that strategy by reviewing recent evidence and surveys relating to the **use** of EC and how they **impact smoking behaviour.** The focus is England, although we also draw on evidence from elsewhere in the UK and internationally.

Description of e-cigarettes

EC use battery power to heat an element to disperse a solution that usually contains nicotine. The dispersion of the solution leads to the creation of an aerosol that can be inhaled by the user. The heated solution typically contains propylene glycol or glycerine, water, nicotine, and flavourings. EC do not contain tobacco, do not create smoke and do not rely on combustion. Whilst EC 'smoke' is technically an aerosol, throughout this report we use the established terminology of vapour, vaping and vaper.

There is substantial heterogeneity between different types of EC and the speed with which they are evolving making them difficult to categorise. ECs available in England can be classified into three basic types: (1) EC that are either (a) disposable or (b) use pre-filled cartridges that need to be replaced once emptied. We will refer to these using their most common name, 'cigalikes'. Most cigalikes resemble cigarettes, although it is important to note that some do not; (2) EC that are designed to be refilled with liquid by the user. We will refer to these using their common name 'tank systems'. (3) Finally, some EC products, mostly tank systems that allow users to regulate the power delivery from the batteries to the atomizer. These we refer to as mods or 'variable power EC'.

In the UK, the most prominent brands of cigalikes are now owned by the tobacco industry. To the authors' knowledge only one tobacco company sells a tank model in the UK, with the rest of the market consisting of non-tobacco industry companies. Some products have also been introduced by the tobacco industry that could be referred to as 'hybrids' such that they use pre-filled nicotine cartridges but look like tank models. Additionally, a few EC that are similar to cigalikes in function are also sold that use cartridges that can be refilled, and some users will puncture holes/remove the ends of cigalike cartridges to refill them instead of buying new cartridges.

Studies have validated the ability of EC to deliver nicotine to the user. Blood plasma nicotine concentrations increase after inhalation of EC aerosol [6, 7], and cotinine, a biomarker for nicotine, has been detected in the saliva of EC users [8, 9]. Information about the overall and relative risks of EC in comparison with smoking has also been developing. Using a multi-criteria decision analysis (MCDA) model, the Independent Scientific Committee on Drugs selected experts from several different countries to compare a variety of nicotine products on variables of harm identified by the UK Advisory Council on the Misuse of Drugs [10]. EC were identified as having 4% of the relative harm of cigarettes overall (including social harm) and 5% of the harm to users, although it was acknowledged that there was a lack of hard evidence for the harms of most of the nicotine products on most of the criteria.

Structure of report

Following Chapter 2 on methodology, Chapter 3 assesses the current and future policy framework for EC. Chapters 4 and 5 assess trial and usage in England among adults and youth as well as different socioeconomic groups where evidence permits. Chapter 6 examines the evidence for the impact of EC on smoking behaviour including the use of EC in quit attempts as well as alongside smoking. Chapter 7 assesses reasons for trying and discontinuing EC and Chapter 8 perceptions of relative harms of EC and smoking. Chapter 9 discusses nicotine content and emissions of EC as well as nicotine uptake in users. Chapters 10 and 11 assess different aspects of safety drawing on recent published studies as well as national statistics. Chapter 12 examines international perspectives of EC policies and usage.

2. Methodology

For the present report we have included: (1) a synthesis of recent evidence (published since the two PHE 2014 EC reports) with the earlier evidence in the earlier PHE reports drawing on both national and international literature; and (2) *where feasible*, an analysis of any relevant national unpublished data available to PHE, KCL and partner organisations from England, Great Britain or the UK, including: i) Smoking Toolkit Study (UCL); ii) Action on Smoking and Health (ASH) Smokefree GB (adult and youth) surveys; iii) Internet Cohort GB survey; iv) Smokers' surveys 2014 commissioned by ASH from YouGov; and v) the International Tobacco Control (ITC) policy evaluation project.

For the evidence review (1) above, given the short timeframe for this report, a systematic review of the literature was not possible. However, we followed systematic review methods where possible and searched PubMed for studies from 2014 onwards using the following search terms: (("2014/01/01"[Date - Publication] : "3000"[Date - Publication])) AND (((((((e-cigarette) OR Electronic cigarettes) OR e-cig*) OR electronic cig*) OR ENDS) OR electronic nicotine delivery systems) OR electronic nicotine delivery system) OR ((Nicotine) AND Vap*)).

The term ENDS was used as some studies have referred to e-cigarettes as Electronic Nicotine Delivery Systems (ENDS). This search returned 3,452 records. The titles of all records were screened and 798 articles were identified as potentially relevant to the report. The full papers of abstracts considered relevant by two reviewers were retrieved and reviewed as identified in Appendix A.

We wanted to ensure we included the most up-to-date information on EC use and impact in England. In order to do this we used routine national data sources to retrieve measures of EC use prevalence, fires, poisoning and other adverse events. Specifically for (2) above, we assessed, in addition to published papers, unpublished national survey data relevant to this work, identifying where findings are peer reviewed/published. The methods of the surveys that we have accessed are as follows:

Smoking Toolkit Study (STS, University College London)

The STS consists of monthly **cross-sectional household interviews** of adults (aged 16 and over) in England that has been running since November 2006. Each month involves a **new nationally representative sample** of about 1,800 respondents. Since 2009, all respondents who smoked in the last year have been asked questions on EC; since November 2013 all respondents complete questions on EC. For more information, see www.smokinginengland.info

ASH Smokefree GB (adult and youth) surveys

Adult: ASH has conducted **cross-sectional internet surveys** of adults (aged 18 and over) in Great Britain (GB) since 2007. These surveys cover a wide range of tobacco control policies and smoking behaviour and are carried out on ~12,000 adults each year. Questions on EC were included first in 2010, with new EC questions added in each subsequent survey (2012, 2013, 2014, 2015).

Youth: ASH has conducted **cross-sectional surveys of British youth** (aged 11-18) three times to date (2013, 2014, 2015). **Younger** participants are recruited, **online,** through the adult YouGov participants with **older** participants contacted **directly**. It has been used to give a more contemporaneous and comprehensive snapshot of youth attitudes towards smoking and their behaviours (and includes a breakdown of trial and more prolonged use of EC) than UK Government national surveys have been able to.

Internet Cohort GB survey (King's College London, University College London)

A unique longitudinal internet survey of smokers and recent ex-smokers in GB (aged 16 and over) surveyed first in 2012 and then again in December 2013 and 2014. Of the 5,000 respondents in the initial sample, 1,031 respondents (20.7%) used EC at all at the time of the survey in 2012. The prevalence of past-year smoking in this baseline sample was similar to that identified through the STS (which, as stated above, recruited representative samples of the population in England), over a comparable period.

In 2013, 2,182 of the 5,000 were followed up and in 2014, 1,519 were followed up. EC use was 32.8% (n=717) in 2013 and 33.2% (n=505) in 2014. The study sample was recruited from an online panel managed by Ipsos MORI who were invited by email to participate in an online study and were screened for smoking status. The survey included questions on smoking and quitting behaviour and stress and general health as well as detailed questions on EC usage.

ASH GB Smokers' survey 2014

This is an online survey carried out by YouGov for ASH specifically to assess more detailed attitudinal measures concerning nicotine containing products. The 2014 survey involved 1,203 adult smokers and recent ex-smokers selected from the ASH Smokefree adult survey to have roughly equal numbers of smokers who had (n=510) and had not (n=470) tried EC and a smaller number of ex-smokers who had tried EC (n=223).

ITC Policy Evaluation project

A longitudinal cohort survey of smokers and recent ex-smokers (aged 18 and over), surveyed by telephone and internet. The ITC UK survey started in 2002 and surveys

have been conducted approximately annually since that time. Probability sampling methods are utilised through telephone surveys using random digit dialling, but in more recent survey waves participants could opt to complete surveys on the internet. The ITC UK study benefits from parallel cohort surveys in Australia, Canada and the United States, enabling comparisons across countries with different tobacco and EC policies. Each wave of the survey includes approximately 1,500 UK respondents. EC questions were added to the last three waves. Data from the last wave (in 2014) were not available for inclusion in this report, but published papers from earlier waves are included. More details of the methodology are available at www.itcproject.org

3. UK policy framework

E-cigarette regulations in England: current and proposed

Regulations have changed little in England since the previous PHE reports. Currently EC are governed by general product safety regulations (UK and EU) which do not require that the products be tested before being put on the market. However, manufacturers can apply for a medicinal licence through the Medicines and Healthcare products Regulatory Agency (MHRA) [11] and from next year any EC not licensed by the MHRA will be governed by the revised European Union Tobacco Products Directive (TPD)[12]. Both the MHRA licensing and the TPD regulatory routes are described below. The TPD regulations are extensive and will have a significant impact on the EC market.

One change from the previous PHE report, which was introduced by the Advertising Standards Authority in October 2014, is that until the TPD comes into force, advertising of EC is governed by a voluntary agreement. This agreement indicates, inter alia, that advertising must be socially responsible, not promote any design, imagery or logo that might be associated with a tobacco brand or show the use of a tobacco product in a positive light, make clear that the product is an EC and not a tobacco product, not undermine quit tobacco messaging, and must not contain health or medicinal claims unless the product is licensed. These guidelines will be reviewed in October 2015 and when more is known about the application of the TPD the role of the Code will be clarified.

A further recent change is the introduction of measures to protect children from EC: an age of sale lower limit of 18 years of age (in line with tobacco cigarettes) is being introduced and a ban on proxy purchasing of EC.

EU Tobacco Products Directive (TPD) route

The revised TPD will introduce new regulations for EC or refill containers (referred to below as products) which are not licensed by the MHRA. We have listed these in detail below because they are wide-ranging and will impose a significant step change for manufacturers, importers and Member State (MS) authorities:

- **notification**: Manufacturers must inform competent authorities of the MS six months before placing new products on the market. For those already on the market by 20 May 2016, the notification needs to be submitted within six months of this date. Each substantial modification of the product requires a new notification
- **reporting obligations** (for which manufacturers/importers might be charged) include:

    - details (including quantification) on all the ingredients contained in, and emissions resulting from the use of, the product, by brand name
    - toxicological data regarding ingredients and emissions, including when heated, with reference particularly to health of consumers when inhaled including any addictive effect
    - information on nicotine doses and uptake when consumed under normal or reasonably foreseeable conditions
    - description of the product components, including where appropriate opening and refill mechanisms of product or refill containers
    - description of the production process and declaration that it conforms with the TPD
    - declaration that manufacturer/importer bear full responsibility for the quality and safety of the product when placed on market and used under normal or reasonably foreseeable conditions
- **nicotine-containing liquid** restrictions:
    - EC must not contain more than 20 mg/ml of nicotine
    - nicotine-containing liquid must be in dedicated refill containers not exceeding 10ml volume, and cartridges or tanks do not exceed a volume of 2ml
    - additives are not prohibited but the nicotine-containing liquids cannot contain additives that are otherwise prohibited by the other Articles in the TPD
    - high purity ingredients must be used and substances other than those declared should only be present in trace quantities which are unavoidable during manufacture
    - ingredients must not pose a risk to health either when heated or not heated
    - nicotine doses must be delivered at consistent levels under normal conditions of use
- products are required to be child and tamper proof, protected against breakage and leakage and have a mechanism that ensures refilling without leakage
- products must include a **leaflet with information** on:
    - instructions for use and storage of the product, including a reference that the product is not recommended for use by young people and non-smokers
    - contra-indications
    - warnings for specific groups
    - possible adverse effects
    - addictiveness and toxicity
    - contact details of manufacturer/importer and a legal or natural contact person within the EU
- **outside packaging of products** must include:
    - list of all ingredients contained in the product in descending order of the weight
    - an indication of the nicotine content and delivery per dose
    - batch number
    - recommendation to keep the product out of reach of children

    - no promotional element or feature or such that suggests the product is harm reducing (or other features described in Article 13 of the Directive)
- **health warnings:**
    - One of the following must be shown:
        - 'This product contains nicotine which is a highly addictive substance. It is not recommended for use by non-smokers' or
        - 'This product contains nicotine which is a highly addictive substance'
    - Member States shall determine which health warning to use
    - health warnings must comply with regulations concerning specific provisions on position and size
- cross-border **advertising** and promotion, sponsorship etc of products will be prohibited (unless trade information)
- **cross-border sales** of products may be prohibited or subject to a registration scheme
- manufacturers/importers of products to submit an **annual submission** on their products to competent authorities in MS which should include:
    - comprehensive data on sales volumes, by brand name and product type
    - information on preferences of various consumer groups, including young people, non-smokers and the main types of current users
    - mode of sale of the products
    - executive summaries of any market surveys carried out in respect of the above, including an English translation thereof products
- MS shall monitor the market developments concerning products, including any evidence that their use is a gateway to nicotine addiction and ultimately traditional tobacco consumption among young people and non-smokers. This information to be made publicly available on a website although the need to protect trade secrets should be taken into account
- MS should on request, make all information relevant to this Article available to the Commission and other Member States who will respect confidential information
- MS shall require manufacturers, importers and distributors of products to establish and maintain a system for collecting information about all of the suspected adverse effects on human health
- **corrective action** should be taken immediately if economic operators consider or have reason to believe that products are not safe or of good quality or not conforming to the Directive, ensuring conformity or withdrawal or recall from the market. In such cases, operators are required to inform immediately market surveillance authorities of the MS giving details of risk to human health and safety, corrective action taken and results of such corrective action. MS may request additional information from the economic operators on safety and quality aspects or any adverse effect of products
- the Commission will submit a report to the European Parliament and the Council on potential risks to public health by 20 May 2016 and as appropriate thereafter

- where a competent authority believes specific products could pose a serious risk to human health it should take appropriate provisional measures, immediately inform Commission and competent authorities of other MS of measures taken and communicate any supporting data. The Commission will determine whether provisional measure is justified informing the MS concerned of its conclusions to enable appropriate follow-up measures to be taken
- the Commission can extend any prohibition to other MS if such an extension is justified and proportionate
- the Commission is empowered to adapt wording of health warnings and ensure factual
- the Commission will give a common format for notification and technical standard for the refill mechanism outlined above

The exact date of implementation in England is yet to be specified but full compliance is likely to be necessary by 2017. One UK company, Totally Wicked, has challenged the UK's intention to transpose the Directive into UK law. The case rests on whether the TPD was properly made and has been referred to the European Court of Justice for a preliminary ruling. This is expected in late 2015/early 2016.

During implementation, government will need to undertake an impact assessment for the UK market on the final proposals as set out in the Directive and this will be consulted upon. The TPD certainly raises the barrier for bringing EC products to market or continuing to market existing products, and will undoubtedly constrain the EC market. Understanding any unintended consequences of the EU TPD as well as intended ones will be important. For example, the cap on nicotine concentrations introduced by the TPD will take high nicotine EC and refill liquids off the market, potentially affecting heavier smokers seeking higher nicotine delivery products.

Medicines and Healthcare products Regulatory Agency (MHRA) licensing route

Following a consultation in 2010, the UK MHRA introduced a mechanism for the licensing of EC and other nicotine containing products as medicines requiring medicinal purity and delivery standards. Such a licence would be required for products to be prescribed on the NHS. As with other licensed nicotine containing products, advertising controls would be applied and VAT of 5% would be imposed.

The licensing process has been described by the MHRA [11]. This regulation was described initially as 'light touch' recognising a product that delivered nicotine could be effectively used for harm reduction or cessation purposes, thus implying a relatively speedy route to licensing. This was subsequently changed to 'right touch' as it was apparent that the process was more lengthy and costly than originally envisaged. We understand that the MHRA estimated costs for a one-off application of between £252K and £390K with an annually recurring cost of between £65K and £249K, for each

product. This does not include the costs of making manufacturing facilities and products MHRA compliant – estimated at several million pounds.

At the time of writing one non-EC nicotine inhaler product, Voke, developed by Kind Consumer, and to be marketed by British American Tobacco (BAT), had received a medicinal licence, although it is not yet being marketed in England. A further BAT product (an EC) is currently going through the application process. Other EC products are currently in the pipeline with the MHRA but it is not clear at what stage the applications are or what types of products, eg cigalikes or tank models, are involved.

The absence of a licensed product, five years after the MHRA's consultation took place, suggests that this route to market is not commercially attractive. The fact that the only product at the application stage is a BAT product suggests that the process is very resource intensive. As well as cost, other possible reasons include complexity, a lack of desire to engage with medicinal licensing or the MHRA, the entrepreneurial nature of the EC manufacturers and a possible lack of perceived benefits to acquiring a licence. This could be problematic when the EU TPD is implemented, which is likely to constrain the over-the-counter market. Additionally, having a diverse range of EC on prescription is likely to be beneficial (similar to nicotine replacement tobacco (NRT) products – when new products are introduced, evidence suggests that they do not cannibalise the existing NRT product market but instead expand the use of medications). This means that small manufacturers, particularly non-tobacco industry manufacturers, who may be producing a greater variety or more satisfying EC, will not compete with larger corporations such as the tobacco industry in the prescriptions market. There are several consequences of this which should be explored. These could include an inhibition of innovation and damage public health. Alternatively, given the demand for prescribed EC products is as yet unknown, particularly in the population groups where smoking prevalence is elevated, the medicinal route may not impact public health. The appeal of EC may rest in the fact that they are not medicines. A review of the MHRA licensing process for EC, and its likely impact, is recommended.

Summary of findings

The revised TPD will introduce new regulations for EC or refill containers which are not licensed by the MHRA. The cap on nicotine concentrations introduced by the TPD will take high nicotine EC and refill liquids off the market, potentially affecting heavier smokers seeking higher nicotine delivery products.

The fact that no licensed EC are yet on the market suggests that the licensing route to market is not commercially attractive. The absence of non-tobacco industry products going through the MHRA licensing process suggests that the process is inadvertently favouring larger manufacturers including the tobacco industry, which is likely to inhibit innovation in the prescription market.

Policy implications

- From May 2016, following the introduction of the revised TPD, ECs will be more strictly regulated. As detailed elsewhere in the report, the information we present does not indicate widespread problems as a result of EC. Hence, the current regulatory structure appears broadly to have worked well although protecting non-smoking children and ensuring the products on the market are as safe and effective as possible are clearly important goals. New regulations currently planned should be implemented to maximise the benefits of EC whilst minimising these risks.

- An assessment of the impact of the TPD regulations on the UK EC market will be integral to its implementation. This should include the degree to which the availability of safe and effective products might be restricted.

- Much of England's strategy of tobacco harm reduction is predicated on the availability of medicinally licensed products that smokers want to use. Licensed ECs are yet to appear. A review of the MHRA EC licensing process therefore seems appropriate, including manufacturers' costs, and potential impact. This could include a requirement for MHRA to adapt the processes and their costs to enable smaller manufacturers to apply, and to speed up the licensing process. The review could also assess potential demand for the EC prescription market and what types of products would be most appropriate to meet that demand.

4. Prevalence of e-cigarette use in England/Great Britain

This chapter assesses the use of EC by adults and young people in England by drawing on recent surveys carried out in England and Great Britain (GB). A later chapter discusses EC prevalence internationally.

Measures used

One of the main issues in measuring EC use is the lack of consistent and appropriate terminology, for example some studies equate ever having used EC with current use of EC which is clearly inappropriate. We recommend that definitions of usage categories should be standardised similar to those used in smoking surveys. Appendix B lists the different measures used in surveys focused on in this report, and gives definitions used in the other studies included in this review.

Use of e-cigarettes by adults

First, we assess e-cigarette use in the adult population in England. We summarise various data sources to provide an overview of EC use among the general population, and then specifically smokers, recent and long-term ex-smokers, and never-smokers. The two main surveys used in this chapter are the Smoking Toolkit Study (STS) and the ASH Smokefree GB surveys. However, in addition to these surveys, findings from the Office for National Statistics Opinions and Lifestyle Survey (ONS survey), a randomised probability sample omnibus survey in GB, have also been included in this section although the exact question used is not available [13]; preliminary released data from Q1 2014 are reported here in advance of the complete data due for publication later in 2015.

Population use of e-cigarettes

Of the available datasets, just two – the Smoking Toolkit Study (STS, England) and the ASH Smokefree GB adult surveys – provide information on population prevalence (Table 1). Using the STS, it is estimated that 5.5% of the adult population of England used EC in the first quarter of 2015 indicating a marked rise from 0.5% in 2011. The measure of use in the STS is compiled from four survey questions and assesses *current use for any reason* (Appendix B). A very similar estimate is obtained for GB using the 2015 ASH survey, with 5.4% of the population estimated to be current (defined as *tried EC and still use* them, see Appendix B) EC users. This translates to about 2.6 million EC users in GB in 2015 [14](for comparison there are about nine million tobacco

smokers in GB and as discussed later, most EC users are smokers or ex-smokers). The ASH survey also assessed trial and about 17% of the adult GB population was estimated to have tried EC.

Table 1: Adult EC current use[1]

Source (date of data collection)	Population Prevalence	Never smokers	Ex-smokers	Smokers ('Dual users')
ASH Smokefree GB adult survey *(2015 - March)*	5.4%	0.2%	6.7%	17.6%
Office for National Statistics *(2014 - Q1)*	N/A	0.1%	4.8%	11.8%
Smoking Toolkit Study *(2015 – Q1)*	5.5%	0.2%[2]	3.3%[2]	21.2%

[1]For definitions of current use please see Appendix B. The ONS question is unavailable.
[2]Figures for never and long-term ex-smokers are derived from n=22489 never and long-term ex-smokers surveyed between November 2013 and March 2015

Never smokers and long-term ex-smokers

All three surveys estimate *current* EC use among adult *never* smokers to be very rare at 0.2% or less, and between 3% and 7% among *ex*-smokers – the latter estimates may vary because in the STS recent ex-smokers (last-year) are not included in this category (Table 1). Prevalence of current EC use among recent ex-smokers in the STS was around 40% in the first quarter of 2015 [15].

The ASH survey estimated that around 1.5% of *never* smokers and 16% of *ex*-smokers had *ever tried* EC.

Smokers

Recent surveys estimate that *current* EC use among smokers, sometimes referred to as 'dual users' of cigarettes and e-cigarettes, is between 12 and 21% (Table 1). The prevalence of EC use among last-year smokers (defined as smokers and recent ex-smokers) using the STS in England is estimated at 22.9% for *any* use of EC and 14.9% for *daily* EC use. The ASH 2015 survey indicated that 17.6% of current smokers use EC currently (18% of occasional and 17% of daily smokers); the same survey indicated that a small majority of smokers (59%) have now tried EC.

The Q1 2014 ONS Survey data estimates for current use are considerably lower, suggesting that just under 12% of current smokers used EC in early 2014. The survey question/s used to determine this is/are not available to assess whether different ways of assessing use may be a reason for this discrepancy in findings.

The ASH survey indicates that about 60% of current EC users are current smokers, and about 40% are ex-smokers. The proportion of EC users among never smokers remains negligible.

Summary

Around one in 20 of the general adult population in England (and GB) use EC. Current EC users are almost exclusively smokers or ex-smokers. EC use among long-term ex-smokers is considerably lower than among recent ex-smokers.

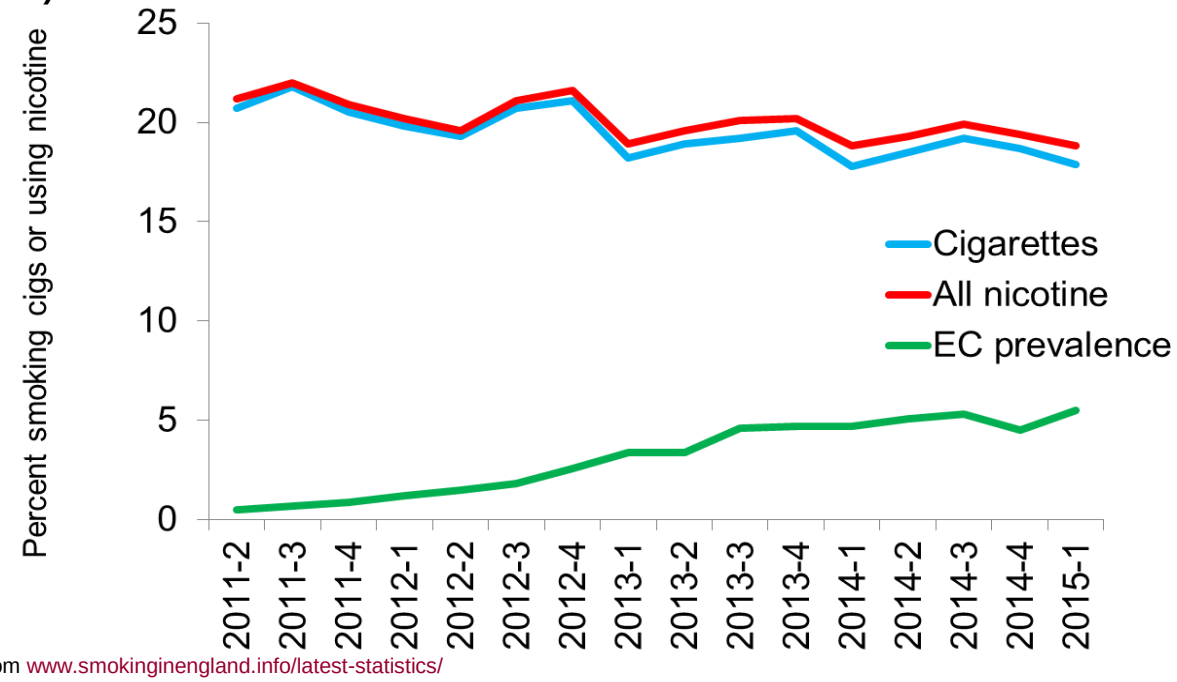
Trends in e-cigarette use among adults

Both the STS and ASH surveys demonstrate that there was a steady increase in EC use in the population from 2011 to 2013.

Smoking Toolkit Study (STS) data

The STS data indicate that this increase slowed down, even declining at the end of 2014 from 5.3% in Q3 to 4.5% in Q4 (Figure 1). However, as Q1 data from 2015 show a recent upswing to 5.5%, this decline may have been temporary. The STS data show that alongside the increase in EC use, smoking of tobacco cigarettes declined. Overall nicotine use, ie any consumption via cigarette smoking, NRT use or EC use, has also declined.

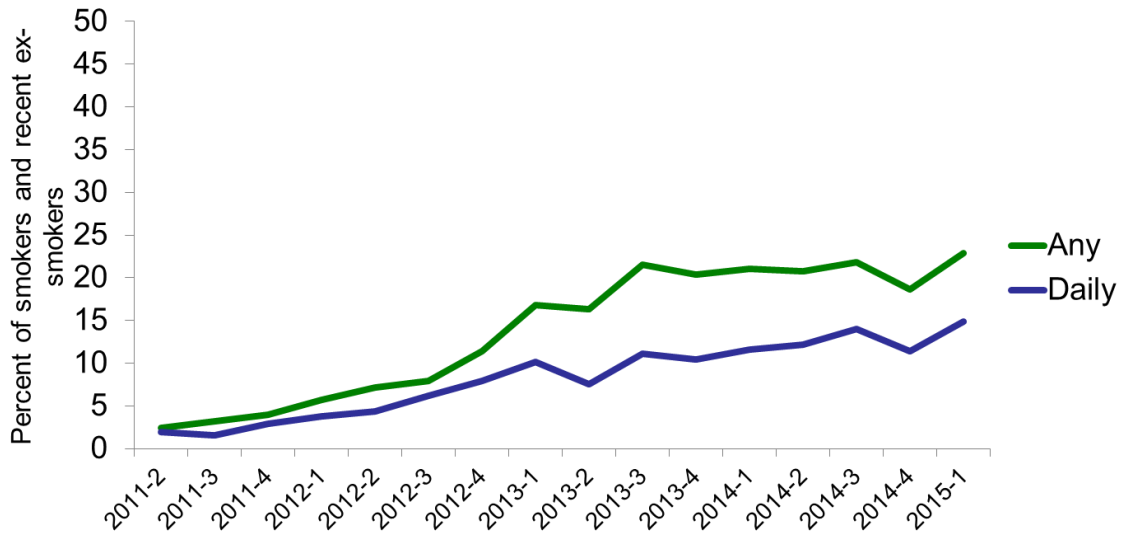
Figure 1: Prevalence of smoking and e-cigarette use among the adult English population (STS)



From www.smokinginengland.info/latest-statistics/

The overall pattern of EC use in the population is mirrored among last year smokers for whom EC prevalence increased from 2011, but declined from 22% for *any* use and 14% for *daily* use in Q3 2014, to 19% and 11% respectively in Q4 2014; however, any and daily use increased again to 23% and 15% respectively in Q1 2015 (Figure 2).

Figure 2: Prevalence of e-cigarette use among last year smokers (STS)



From www.smokinginengland.info/latest-statistics/

ASH Smokefree GB adult survey

The ASH surveys indicated a slowing down in the increase of EC use in the population between 2014 and 2015 and use among current smokers in 2015 remained at the 2014 level (17.6% of smokers in 2014 and 2015). Use among ex-smokers increased from 1.1% in 2012, to 4.5% in 2014 and 6.7% in 2015, whereas no increase in use was observed among never smokers over the last few years, remaining at 0.2% since 2013. **This means that the increase in EC use observed overall was accounted for by an increase in use by ex-smokers.** It is not clear to what extent this is due to smokers stopping smoking using EC or ex-smokers taking up ECs.

Summary

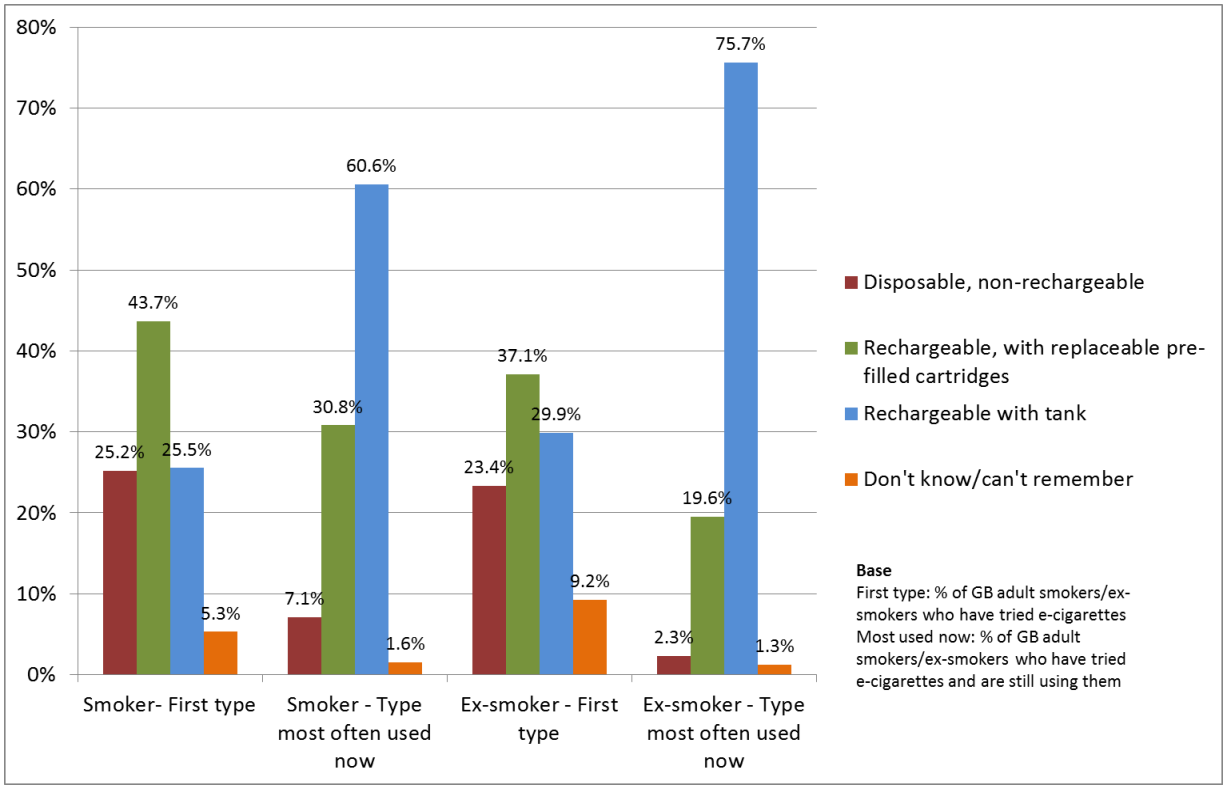
The prevalence of EC use among adults has plateaued. Most of the recent increase in use appears to be among ex-smokers. Cigarette smoking has declined over the period when EC use increased and overall nicotine use has also declined. These findings suggest that the advent of EC is not undermining and may be contributing to the long-term decline in cigarette smoking.

Types and flavours of e-cigarettes used among adults

When those who had tried EC in the 2015 ASH survey were asked about which EC *they used first*, 24% reported a disposable, 41% a rechargeable with replaceable pre-filled cartridges and 28% rechargeable with tank/reservoir filled with liquids (7% didn't know/couldn't remember). The different types were in the same order of popularity for first use regardless of smoking status (Figure 3).

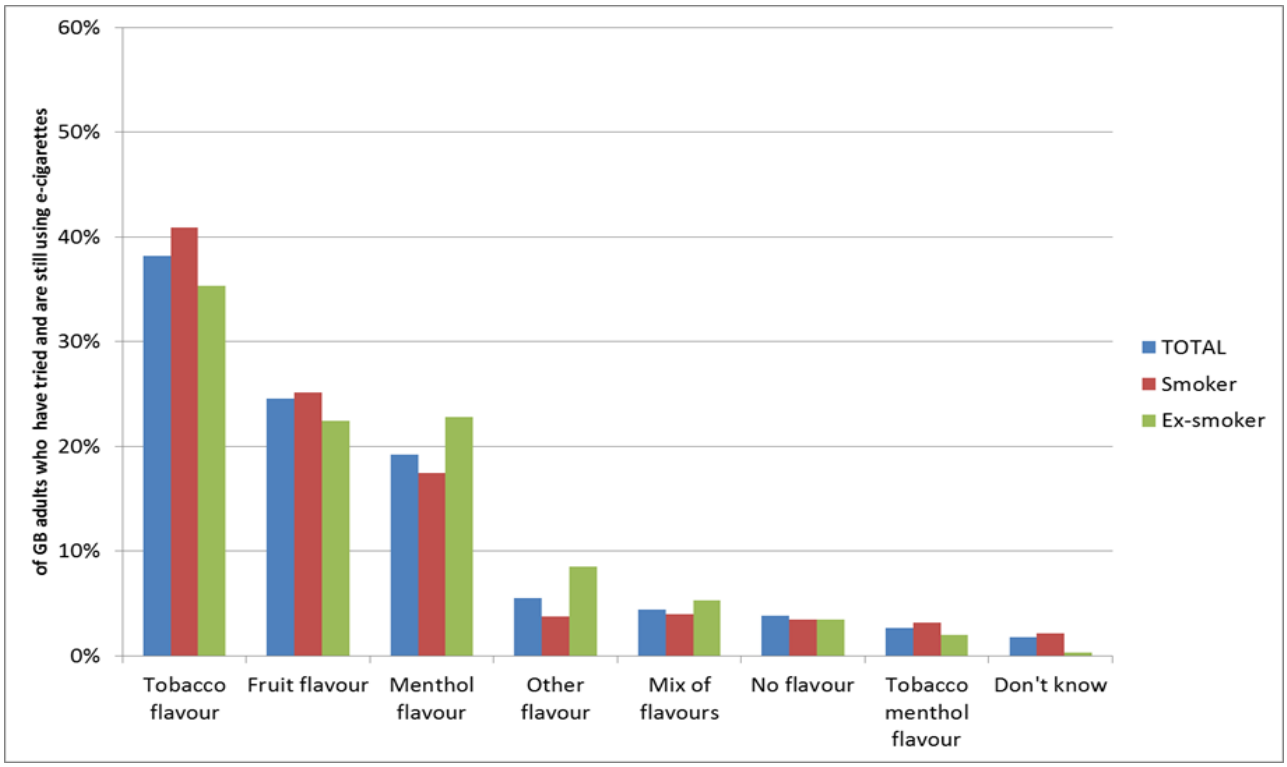
For those *still using EC* from the same survey, only 5% were *now mostly* using a disposable, 26% a rechargeable with replaceable pre-filled cartridges and 66% rechargeable with tank/reservoir filled with liquids (2% didn't know/couldn't remember). **This suggests that a considerable proportion of those who continue to use EC over time switch to the tank models.** Among EC users, ex-smokers were particularly likely to use tank models mostly and very few ex-smokers were using disposables (Figure 3). This is in agreement with findings reported in Chapter 6 of this report, where tank models were found to be associated with having quit smoking [16].

Figure 3: Type of e-cigarettes first used and currently used (ASH Smokefree GB data 2015)



The ASH Smokefree GB 2015 adult survey also shows that the most popular flavour was tobacco flavour, followed by fruit and menthol flavours (Figure 4).

Figure 4: Use of different flavoured e-cigarettes (ASH Smokefree GB data 2015)



Use of e-cigarettes among young people

The main source for estimating *smoking* prevalence in England among youth is the '*Smoking, drinking and drug use among young people'* surveys [17], however, EC use was first assessed in 2014 and these data are not yet available. This section therefore draws on the ASH Smokefree GB youth surveys to assess EC usage in young people, supplemented by a study in the North West of England, two cross-sectional national surveys in Wales and one national survey in Scotland. The measures used are detailed in Appendix B.

In 2015, the ASH survey found that 12.7% of 11 to 18-year olds reported *having tried EC;* of these, 80.9% had only used one once or twice (10.2% of all respondents). Current EC use was considerably lower: 0.7% had used an EC sometimes but not more than once a month; 1.2% more than once a month but not weekly; and 0.5% weekly (Table 2). **The prevalence of EC use (2.4% overall)** among people aged between 11 and 18 was therefore lower than among the general population. In comparison, 21% of all 11 to 18-year olds reported having tried cigarettes, of whom 54% only tried once (11.4% of all respondents). Current smoking was reported by a total of 6.7%; 2.7% smoked less than weekly and 4% at least weekly.

Experimentation increased with age: 2.9% of 11-year olds and 20.2% of 18-year olds had tried EC. In comparison, among 11-year olds, 3.9% had tried cigarettes (0.7% current smokers), whereas 40.9% of 18-year olds had tried cigarettes (14.3% current smokers).

Use of EC was very closely linked with smoking status. Among never smokers, 0.3% used EC monthly or more often, compared with 10.0% of ever smokers and 19.1% of current smokers. The majority of EC users had tried tobacco cigarettes first (Table 2).

Table 2: E-cigarette use among young people

Source	Ever tried	Use more than /at least once a month	Use more than once a week	Use (at least monthly) in *never* smokers	Those using e-cigarettes who had tried tobacco first
ASH Smokefree GB youth survey (11-18 years) [1] *(2015 – March)*	12.7%	1.9%	0.5%	0.1%	63.7%
Health Behaviour in School-aged Children, Wales (11-16 years) *(Nov 2013 – Feb 2014)* **[18]** [2]	12.3%	1.5%	Not reported	0.3%	Not reported
CHETS Wales survey (10—11 year olds)[19] 2014	5.8%	Not reported	Not reported	Not reported	Not reported
SALSUS Scotland survey (15 and 13 year olds)[20] 2013/2014	12%	0.4%	0%	0%	Not reported

[1]For question on e-cigarette categories please see Appendix B. Use more than/ at least once a month excludes those using more than once a week who are reported separately
[2] N=9055, use defined as at least monthly

Similar findings have been observed in Scotland. A national survey carried out in 283 schools across Scotland in late 2013/early 2014 involved more than 33,000 schoolchildren aged 13 and 15 years old [20]. Seven per cent of 13-year olds, and 17% of 15-year olds, had ever used an EC. Trial was associated with smoking status – 4% of never smokers had tried EC (3% trying them once and 1% having tried a few times) compared with 24% of ever smokers, 39% of ex-smokers, 46% of occasional smokers and 66% of regular smokers. Eleven per cent of regular smokers and 6% of occasional smokers reported using e-cigarettes at least monthly.

Very similar findings have been reported from a survey in Wales (Table 2). A survey of secondary schoolchildren was carried out under the auspices of the Health Behaviour of

School Children (HBSC) study and more than 9,000 participants aged 11–16 from 82 schools were included [18]. Overall, 12.3% had tried EC, 1.5% were monthly users, compared with 12.1% reporting ever having smoked and 5.4% current smokers (reported smoking less than once a week or more frequently). Whilst many *experimental* EC users had never smoked, most *regular* EC users had also smoked tobacco. The authors commented that *"the very low prevalence of regular use…suggests that e-cigarettes are unlikely to be making a significant direct contribution to adolescent nicotine addiction".*

Additionally, around 1,500 **10 to 11-year olds** were surveyed in Wales, from 75 schools in the CHETS Wales study [18, 19] (Table 2). Overall, 5.8% (n=87) had ever used an EC; most reported only using once (3.7%, n=55 overall) and only 2.1% (n=32) reported using them more than once. Again, EC use was associated with smoking. Just under half (47.6%) of those who reported having used tobacco had ever used an EC compared with 5.3% of never smokers. Controlling for other variables associated with EC use, parental use of EC and peer smoking remained significantly associated with having ever used an EC. Having ever used an EC was associated with weaker anti-smoking intentions. **Parental EC use was not associated with weakened anti-smoking intentions whereas parental smoking was [19].** This study, published prior to the one above, concluded that EC represented a new form of experimentation with nicotine that was more common than tobacco usage. It also commented that the findings added *"some tentative support for the hypothesis that use of e-cigarettes may increase children's susceptibility to smoking"*. However, as this was a cross-sectional survey, causal connections cannot be inferred. It is possible that children who had used EC would have smoked cigarettes in their absence and this could explain the relationship between intentions and EC usage (see below).

An additional survey of schoolchildren has been carried out in England. Trading Standards in the North West of England have been running biennial surveys of schoolchildren since 2005. The 2013 findings on EC, smoking and alcohol were published [21]. The survey was not designed to be representative (no compliance or completion rates were collected) but instead *"to provide a broad sample of students from a range of community types".* More than 100 schools participated and more than 16,000 participants aged 14–17 years of age were included in the analyses. It is important to acknowledge that the question about EC was "*Have you ever bought or tried electronic cigarettes?*", and this study cannot therefore add to knowledge on current usage. Around one in five of the sample had accessed EC, with access being higher in those who had experience of smoking. Around 5% of those who had *never* smoked cigarettes reported accessing EC; around half of *ex-smokers* and over two thirds of *regular smokers* had accessed them. Parental smoking and alcohol use were also associated with EC access.

Summary

Regular use of EC among youth is rare with around 2% using at least monthly and 0.5% weekly. A minority of British youth report having tried EC (national estimates suggest around 12%). Whilst there was some experimentation with EC among never smokers, **nearly all those using EC regularly were cigarette smokers.**

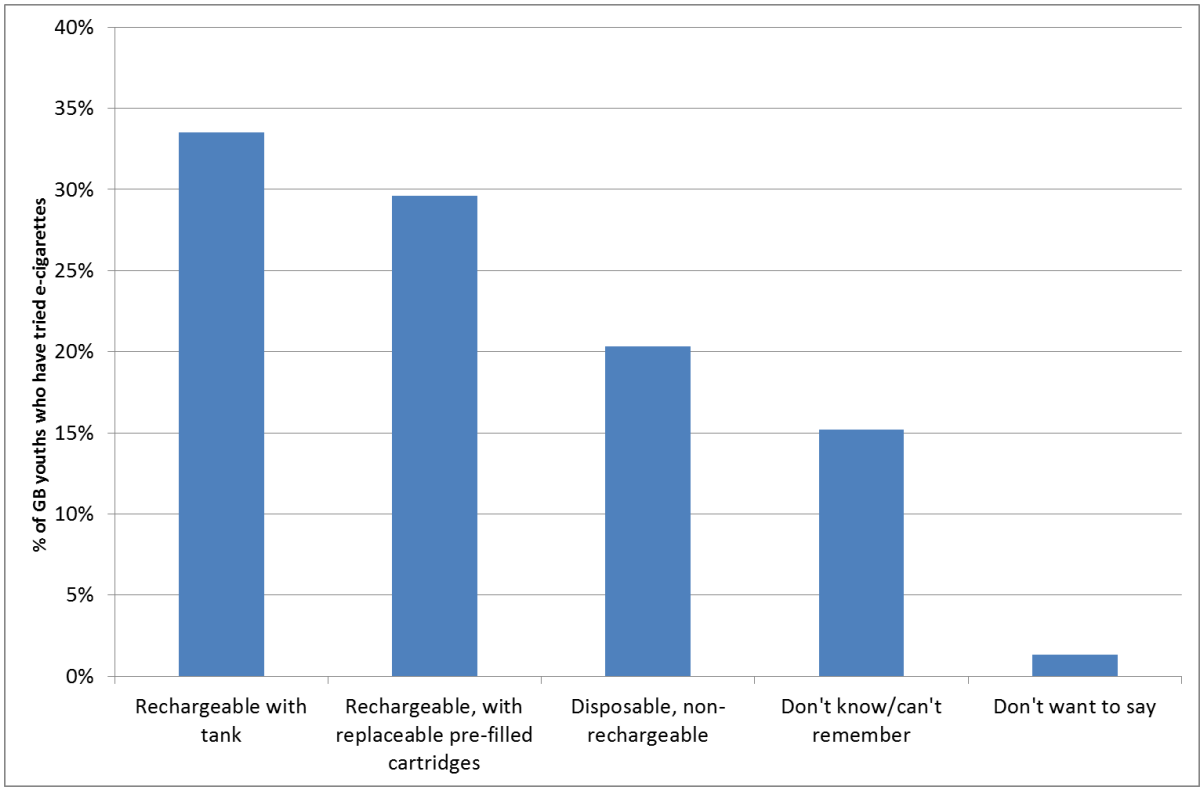
Trends in e-cigarette use among young people (ASH Smokefree GB youth)

The ASH Smokefree GB youth surveys indicate that awareness of EC has increased markedly, with the proportion of individuals who had *never heard* of EC falling from 33.1% in 2013 to 7.0% in 2015*. Ever having tried* EC also increased, from 4.5% in 2013, to 8.1% in 2014, and to 12.7% in 2015. However, the proportion using an EC monthly or more frequently remained virtually unchanged from 2014 (1.6%) to 2015 (1.7%). Over the same period, the proportion of regular smokers (at least weekly) remained at around 4% (2013: 4%, 2014: 3.6%, 2015: 4%).

Type and flavour among youth

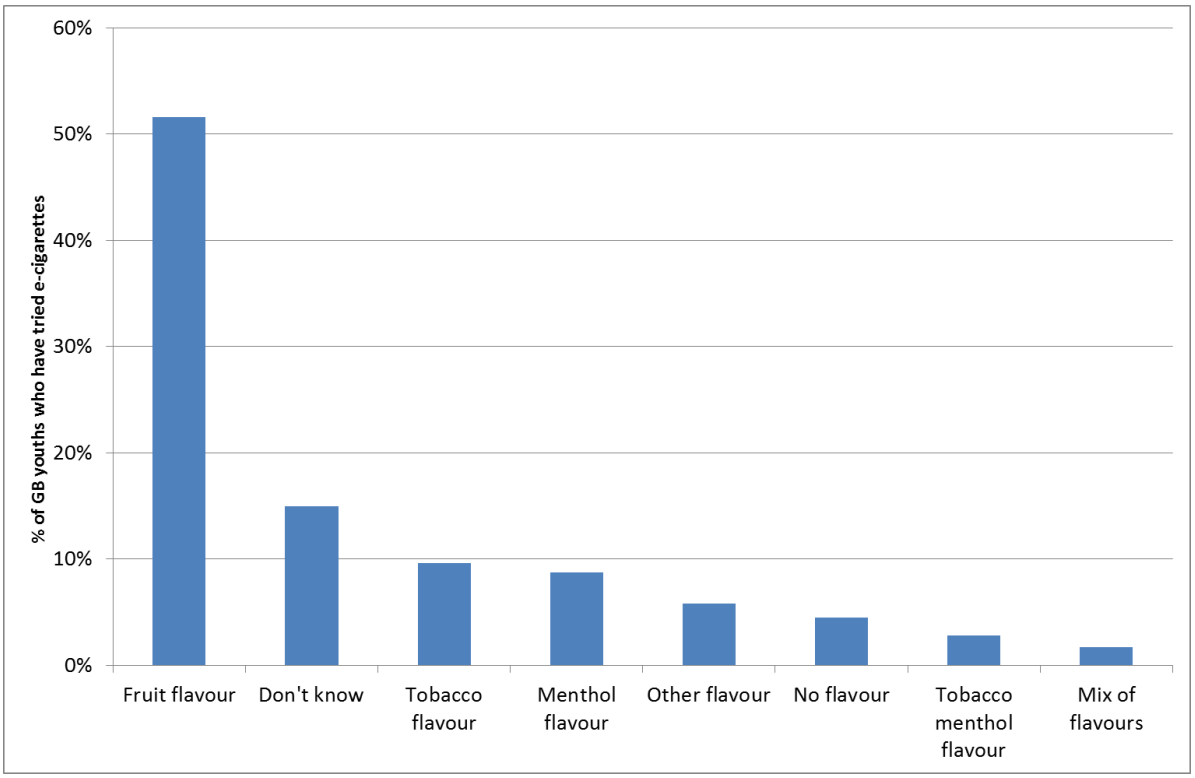
The proportion of youth reporting current use was too small to assess the most frequently used types or flavours in current users, so Figures 5 and 6 include everyone *who had tried* an EC. One third had first used a tank model and the most popular flavours among triers by far were fruit flavours. The responses for adults and youth are not directly comparable given flavours were assessed for adult current EC users, but in the latter group, fruit flavours were less popular than tobacco flavours.

Figure 5: First type of e-cigarette tried by youth, ASH Smokefree GB youth survey, 2015



Note: The proportion of youth reporting current use was too small to assess the most frequently used types.

Figure 6: Last flavour tried by youth, ASH Smokefree GB youth survey, 2015



Note: The proportion of youth reporting current use was too small to assess flavours in current users.

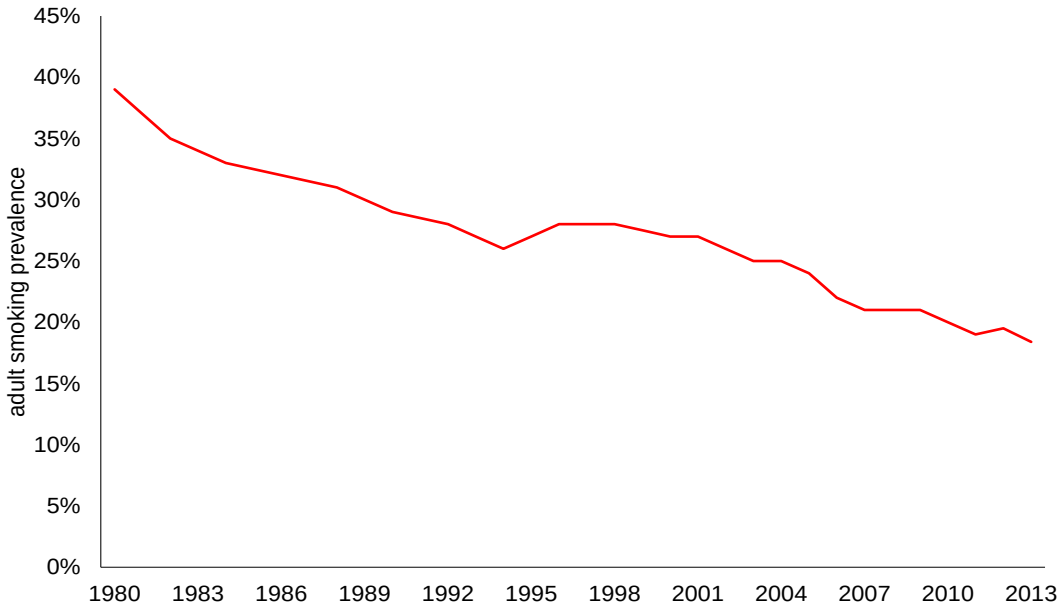
Concerns about impact of e-cigarette use on smoking

Three main concerns raised about EC use are that they might 1) renormalise smoking 2) reduce quitting and 3) act as a 'gateway' to smoking or nicotine uptake. An ultimate test for the first concern, and to some extent all three concerns, is the impact of EC use on smoking prevalence nationally which is explored first below. Evidence for effectiveness of EC on quitting smoking is explored in more detail in Chapter 6. Whilst other concerns have been raised such as renormalising the tobacco industry, we are only able to comment on issues pertaining to the objectives of our report.

Recent trends in smoking prevalence

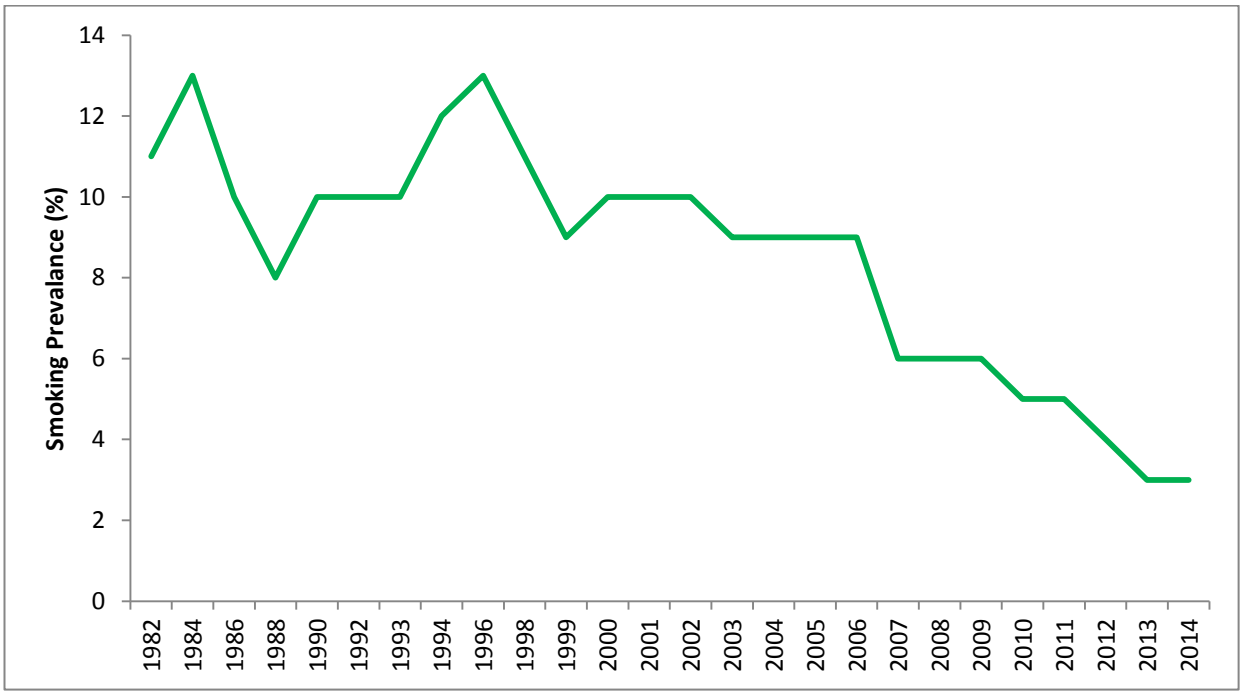
Since EC arrived on the market in England, smoking prevalence has continued to decline among both adults and youth (Figures 1, 7 and 8). Evidence to date therefore conflicts with any suggestion that EC are renormalising smoking. Whilst other factors may be contributing to the decline in smoking, it is feasible that EC may be contributing to reductions in smoking over and above any underlying decline.

Figure 7: Adult smoking prevalence in England 1980–2013[1]



[1] General Lifestyle Survey aged 16+(1980-2010); Integrated Household Survey aged 18+ (2011). Diagram courtesy of ASH.

Figure 8: Prevalence of regular smoking among 11–15 year olds in England 1980–2014[2]



Please note: decimal places were not used in the published data.

Gateway

The gateway theory or hypothesis is commonly invoked in addiction discourse, broadly to suggest that the use of one drug (sometimes a legal one such as tobacco or alcohol) leads to the use of another drug (sometimes an illegal one) but its definition is contested. No clear provenance exists and its origin appears to derive from lay, academic and political models [22]. It is apparent that discussions about the natural progression of drug use observed in longitudinal studies of young people appear to have morphed into implicit conclusions on causality without any evidential backing. Some have argued that the effect could be causal if the use of one drug, biochemically or pharmacologically, sensitises the brains of users to the rewarding effects of other drugs [23] making the dependent use of these other drugs more likely. However, there are many plausible competing hypotheses for such a progression [24] including i) shared networks and opportunities to purchase the drugs; and ii) individual characteristics such as genetic predispositions or shared problematic environment. Academic experts have stated that the gateway concept "*has been one of the most controversial hypotheses…in part because proponents and opponents of the hypothesis have not always been clear about what the hypothesis means and what policies it entails*" [24]. Indeed, a recent analysis of gateway concluded *"Although the concept of*

[2] Smoking drinking and drug use among young people in England surveys. Health and Social Care Information Centre, 2014.

the gateway theory is often treated as a straightforward scientific theory, its emergence is rather more complicated. In effect, it is a hybrid of popular, academic and media accounts – a construct retroactively assembled rather than one initially articulated as a coherent theory" [22].

Despite these serious and fatal flaws in the arguments, the use of the term 'gateway' is commonplace both in the academic literature and the lay press, particularly in relation to EC use and whether EC are a gateway to smoking. Some have suggested that if EC use increases at the same time as smoking increases then EC are acting as a gateway to smoking. Similarly, it's been argued that if someone uses an EC first and then initiates smoking, EC are a gateway. These arguments are clearly erroneous. To give one example of the misuse of the gateway concept, a BMJ news item on the Moore et al., 2014 [18] *cross-sectional* study discussed above commented that "[EC} *could be a gateway into smoking*" [25].

Kandel recently argued that evidence from mice offers a biological basis for the sequence of nicotine to cocaine use in people [26], but there is limited evidence for this. In reality, the gateway theory is extremely difficult to test in humans. For example, a clean test of the gateway hypothesis in relation to EC and smoking would require randomising people to an environment with EC and one without, and then following them up over a number of years to assess uptake of EC and smoking.

We strongly suggest that use of the gateway terminology be abandoned until it is clear how the theory can be tested in this field. Nevertheless, the use of EC and smoking requires careful surveillance in young people. The preferred option is that young people do not use EC but it would be preferable for a young person to use an EC instead of smoking, given the known relative risks of the EC and smoking cigarettes [10].

Summary

Since EC were introduced to the market, smoking prevalence among adults and youth has declined. Hence there is no evidence to date that EC are renormalising smoking, instead it's possible that their presence has contributed to further declines in smoking, or denormalisation of smoking. The gateway theory is ill defined and we suggest its use be abandoned until it is clear how it can be tested in this field. Whilst never smokers are experimenting with EC, the vast majority of youth who regularly use EC are smokers. Regular EC use in youth is rare.

Summary of findings

Adults: Around one in 20 adults in England (and Great Britain) use EC. Current EC users are almost exclusively smokers (~60%) or ex-smokers (~40%), that is smokers

who now use EC and have stopped smoking altogether. EC use among long-term ex-smokers is considerably lower than among recent ex-smokers. Current EC use among never smokers is very low, estimated to be 0.2%. The prevalence of EC use plateaued between 2013-14, but appeared to be increasing again in 2015.

Youth: Regular EC use among youth is rare with around 2% using at least monthly and 0.5% weekly. EC use among young people remains lower than among adults: a minority of British youth report having tried EC (~13%). Whilst there was some experimentation with EC among never smoking youth, prevalence of use (at least monthly) among never smokers is 0.3% or less.

Overall, the adult and youth data suggest that, despite some experimentation with EC among never smokers, EC are attracting few people who have never smoked into regular use.

Trends in EC use and smoking: Since EC were introduced to the market, cigarette smoking among adults and youth has declined. In adults, overall nicotine use has also declined (not assessed for youth). These findings, to date, suggest that the advent of EC is not undermining, and may even be contributing to, the long-term decline in cigarette smoking.

Policy implications

- Trends in EC use among youth and adults should continue to be monitored using standardised definitions of use.
- Given that around two-thirds of EC users also smoke, data are needed on the natural trajectory of ‘dual use’, ie whether dual use is more likely to lead to smoking cessation later or to sustain smoking (see also Chapter 6).
- As per existing NICE guidance, all smokers should be supported to stop smoking completely, including ‘dual users’ who smoke and use EC.

5. Smoking, e-cigarettes and inequalities

Smoking and inequalities

Whilst smoking prevalence overall has been declining over the past 50 years, smoking has become increasingly concentrated in more disadvantaged groups in society. Over the last decade, the gap between smoking in the different social groups has not narrowed (Figure 9) and some of the most disadvantaged groups in society (such as people with serious mental illness or prisoners) have shown no change in smoking prevalence over time (e.g. Figure 10). Furthermore, among smokers, the level of nicotine dependence increases systematically as deprivation increases [2]. A key challenge in tobacco control is therefore how to encourage smokers from disadvantaged groups to stop smoking.

Whilst quitting cigarettes and all nicotine use should remain the main goal across all social groups, EC are of interest because, as with other cleaner nicotine delivery systems, they potentially offer a wide reach, low-cost, intervention to reduce smoking and improve health in these more deprived groups in society where smoking is elevated [2]. It is therefore important to examine the potential impact of EC on inequalities.

Figure 9: Smoking trends by socioeconomic group status (GHS data)

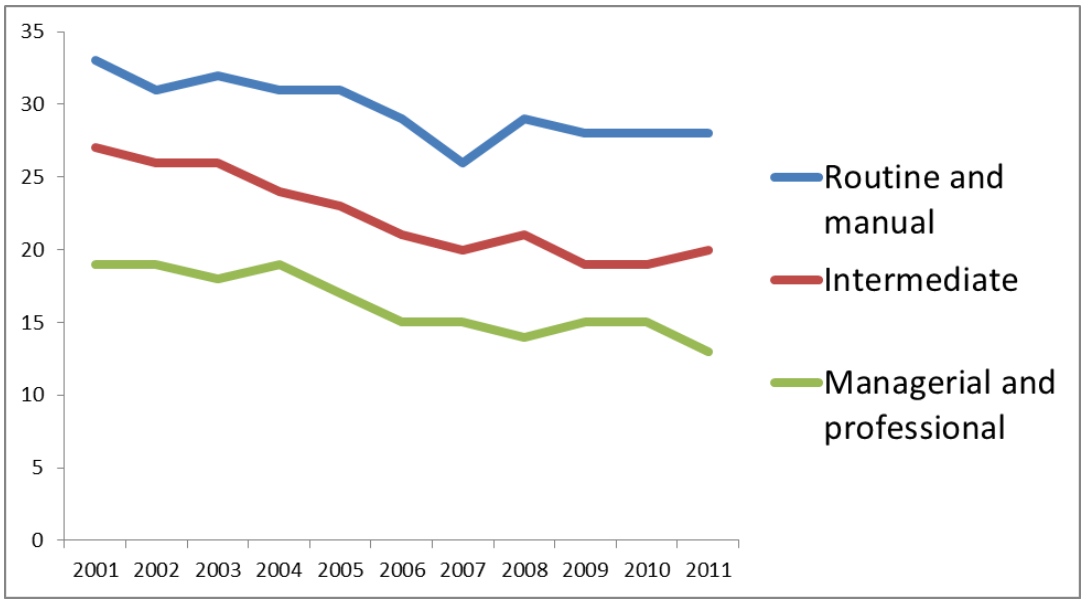
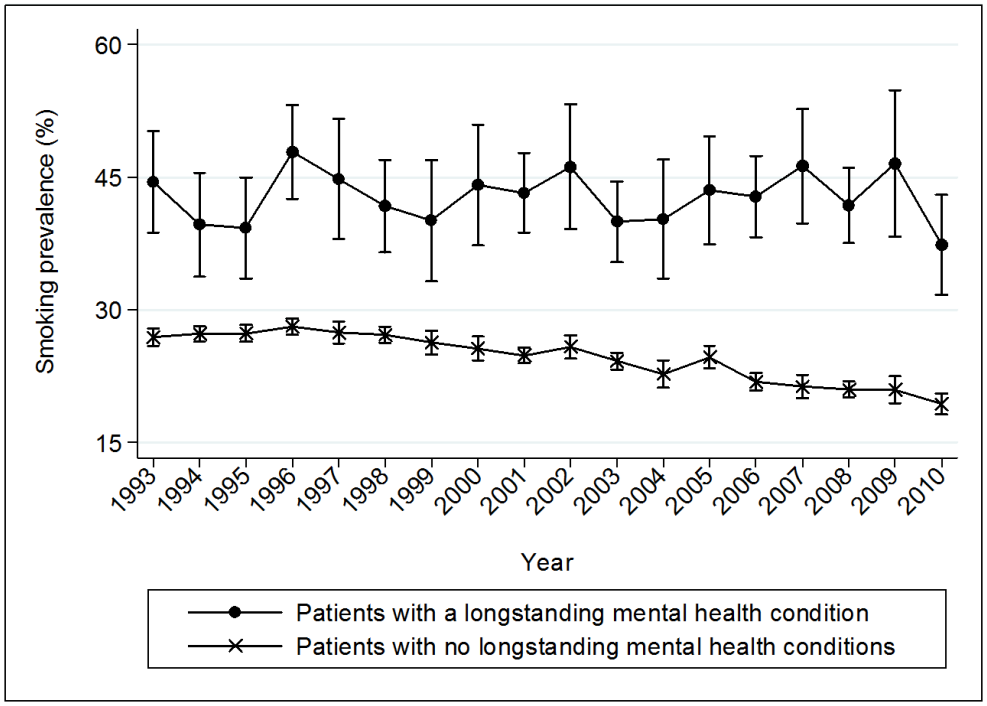


Figure 10: Smoking trends and mental health [27]

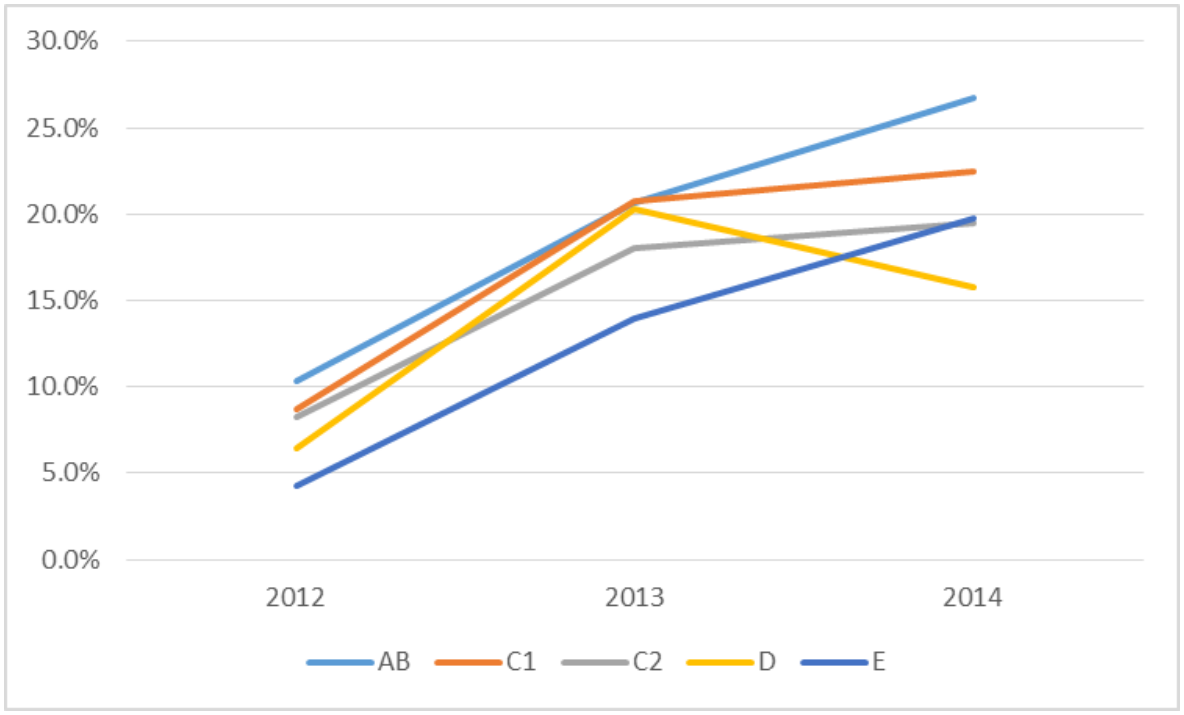


E-cigarette use and different social groups

Earlier surveys in GB and internationally suggested a social gradient in the use of EC, with smokers of higher income and education being more likely to have used and tried [28, 29]. However, the 2015 ASH Smokefree GB adult 2015 survey indicated only small differences across groups, with lower socioeconomic groups slightly more likely to have tried and be using EC. At the population level, 14.4% of ABC1 groups ('non-manual' occupational groups) had tried EC compared with 19.4% in C2DE groups ('manual' occupational groups); 4.6% of ABC1 were still using EC compared with 6.3% of C2DE groups. Nevertheless, given the higher prevalence of smoking in C2DE groups, when examined within the smoker population by social class, 20.0% of ABC1 smokers compared with 16.0% of C2DE smokers were EC current users.

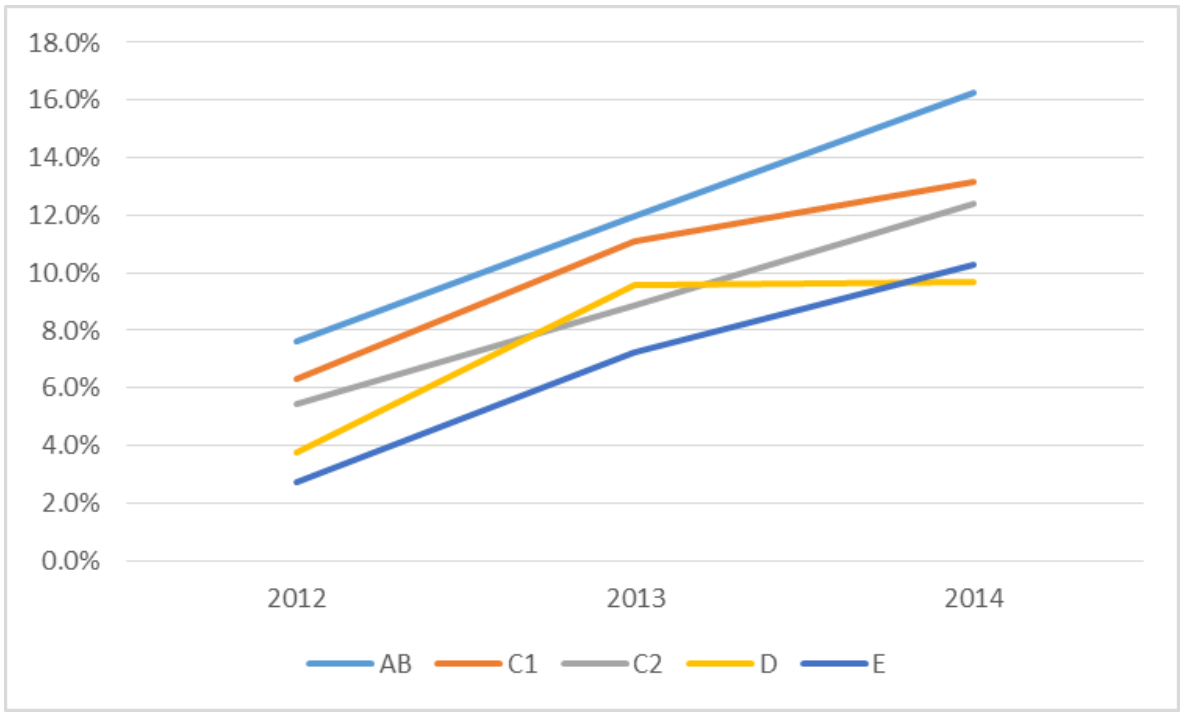
The STS data surveys show an increase in EC use in all social groups between 2012 and 2014 (Figures 11 and 12) but at a relatively similar rate such that socioeconomic differences are still apparent both for current and daily use of EC.

Figure 11: *Current* use of e-cigarettes by social class among last year smokers (STS data)



From www.smokinginengland.info/latest-statistics/

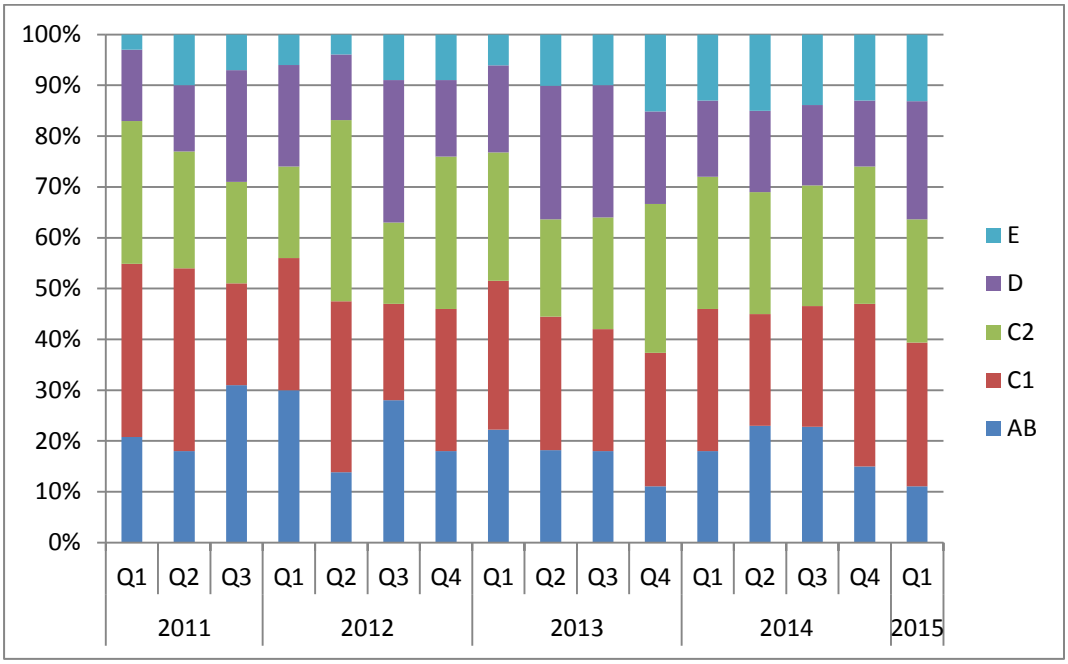
Figure 12: *Daily* use of e-cigarettes by social class among last year smokers (STS data)



From www.smokinginengland.info/latest-statistics/

Nevertheless, EC are penetrating the lower socioeconomic groups. Figure 13 shows the social class breakdown of EC users by quarter over time, also derived from STS data.

Figure 13: E-cigarette use by social class over time (STS data)



From www.smokinginengland.info/latest-statistics/

E-cigarette use in other disadvantaged groups

There are no GB data, to our knowledge, on EC use among groups where smoking prevalence is known to be very high, such as offenders and people with serious mental illness. There is emerging evidence on the effectiveness of EC in people with mental illness (see Chapter 6). However, to some extent, usage among these groups will be dependent on EC policies being introduced in prisons and mental health settings.

Recent NICE guidance on smoking cessation in secondary care settings [30] recommended the implementation of smokefree policies in these settings, alongside advice to stop smoking and nicotine dependence treatment. Trusts are now implementing this guidance but many prohibit EC usage as well as cigarettes. The rationale for such prohibition is unclear.

The South London and Maudsley NHS Foundation Trust (SLaM) was the second NHS mental health trust to go comprehensively smoke free in England. It has developed an EC policy alongside the smokefree policy which allows EC to be used in private spaces or grounds, although EC are not to be offered as first line treatment or replace tobacco cigarette smoking and can only be used as part of a care treatment pathway [31]. Currently, the use of disposable products or rechargeable models with cartridges is allowed (the latter only under supervision), but tanks are prohibited because of fears

that they might be used for new psychoactive substances (sometimes also known as ‘legal highs’). The basis for this fear is being assessed and the use of tank models may be assessed in a restricted pilot shortly. During the first six months of the policy, the EC policy has been implemented smoothly.

A more general concern has been raised that EC can be used as a vehicle for other drugs. This concern needs exploring and is not something that should be promoted. Nevertheless, if true, EC are likely to offer a less harmful delivery route for the drugs than smoking which could be the subject of research.

Prisons are likely to introduce comprehensive smokefree policies over the next few years [32]. Similar to mental health trusts, it would seem inappropriate to prohibit EC and disposable EC are currently being piloted in at least three prisons [33]. Consideration should also be given to the use of other models of EC in pilots. The use of EC in prisons has been considered in other jurisdictions which should also be informative [34].

Summary of findings

Smoking is increasingly concentrated in disadvantaged groups who tend to be more dependent. EC potentially offer a wide reach, low-cost, intervention to reduce smoking and improve health in disadvantaged groups.

Some health trusts and prisons have banned the use of EC which may disproportionately affect more disadvantaged smokers.

Policy implications

- Consideration could be given to a proactive strategy to encourage disadvantaged smokers to quit smoking as quickly as possible including the use of EC, where appropriate, to help reduce health inequalities caused by smoking.

- EC should not routinely be treated in the same way as smoking. It is not appropriate to prohibit EC use in health trusts and prisons as part of smokefree policies unless there is a strong rationale to do so.

6. E-cigarettes and smoking behaviour

Introduction

Studies examining the relationship between EC use and smoking behaviour have focused on two main questions to date: (1) do EC help people to quit when used on a quit attempt, and, (2) what is the effect of using EC while smoking, on reductions in smoke intake, cigarettes per day, quit attempts, and stopping smoking? Because EC use is a relatively new phenomenon and the products are constantly changing with technological innovation, the studies examining these questions to date are heterogeneous. As mentioned earlier, studies vary in their definitions of EC use, including ever use, which could include one puff, to studies that discriminate between daily and non-daily use. Additionally, it is evident that many of the studies were not originally designed to study the effects of EC use on smoking behaviour due to the absence of rigour and omitted/unmeasured variables.

Current recommendations for use of e-cigarettes to quit

The National Centre for Smoking Cessation and Training (NCSCT) has published current recommendations for practice regarding the use of EC for stopping smoking [35]. The NCSCT recommends that practitioners be open to EC use among smokers trying to quit, particularly if they have tried other methods of quitting and failed. The NCSCT also provides more detailed guidelines for smokers wanting to use EC to quit, including differences in puffing on EC versus regular cigarettes, the need to try different types of EC to find one that works for them, and that multi-sessional behavioural support is likely to improve their success of quitting. Some services have welcomed smokers who wish to stop with the help of EC [36].

The NICE guidelines for tobacco harm reduction cover recommendations for the use of *licensed* EC for quitting, cutting down (reduction in cigarettes per day), and temporary abstinence [1], similar to NRT. Use for both cutting down and temporary abstinence have been shown to be precursors to quitting among smokers using NRT. As discussed in Chapter 3, no licensed EC are currently available.

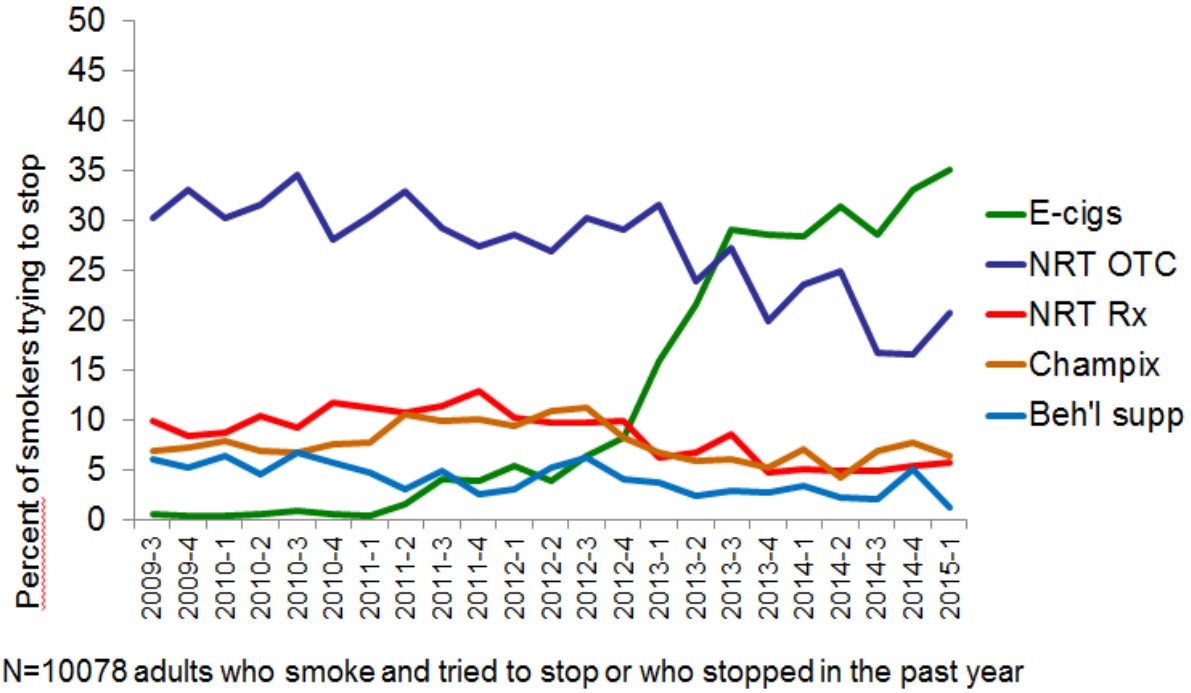
Use of e-cigarettes for stopping smoking

STS data have shown that EC have quickly become the most common aid that smokers in England use to help them stop smoking (Figure 14). The rise in the use of EC as a stop smoking aid is occurring despite the fact that no licensed EC are available. Although the most effective way for stopping smoking, currently supported by the research literature [37, 38] is a combination of behavioural support (NHS in Figure 14)

and medication (NRT on prescription or Champix), the problem is that few smokers access these services, limiting their impact on population health.

This section reviews the evidence regarding the use of EC for stopping smoking that has been published since the Cochrane Review [39] on the use of EC for smoking cessation and reduction (cutting down). The Cochrane Review is briefly summarised below.

Figure 14: Support used in quit attempts



From: smokinginengland.info/latest-statistics

Randomised controlled trials

To date, two randomised controlled trials (RCTs) have tested the efficacy of EC for stopping smoking, one among smokers wanting to stop and the other among smokers not intending to quit within the next month [40, 41]. Both were among highly dependent smokers. A recent Cochrane Review of these RCTs [39] concluded that they demonstrated that EC with nicotine help smokers reduce their cigarette consumption and stop smoking compared with no nicotine EC (placebo). However, the authors cautioned that there was uncertainty in the findings, and gave their findings a 'low' confidence rating using GRADE standards. The Cochrane Review also considered observational studies of EC use and cessation. They concluded that these observational studies were generally consistent with the findings of RCTs. Since the Cochrane Review, one RCT[41], and a secondary analysis of one of the RCTs in the Cochrane Review[42] have been published and are discussed below.

O'Brien et al., 2015 [42] conducted a secondary analysis of the RCT data from Bullen et al., 2013 [43] to examine the effectiveness of EC with and without nicotine compared to the nicotine patch among individuals with mental illness (MI). They identified 86 participants among the original 657 participants (all motivated to quit) using secondary data from the trial on reported use of any medications associated with MI. Overall, when compared to participants without MI, there were no significant differences for those with MI on the primary outcomes of smoking reduction and smoking cessation. One exception was that the six-month quit rate was higher among participants with MI in the patch condition compared to those without MI. Although not a primary outcome, there was evidence of a greater rate of relapse among participants with MI. In the analysis that only included participants with MI, there were no significant differences in quit rates across the three conditions, however participants allocated to 16mg EC showed greater smoking reduction than those allocated to patch. **The authors concluded that EC appear to be equally effective for smoking cessation among individuals with and without MI**, building on other promising research involving EC and people with MI.

Adriaens et al., 2014 [41] conducted an eight-week RCT in Belgium with control where they randomised 48 smokers **who did not want to quit** to one of two conditions: (1) use of tank model EC, and training on how to use, with no encouragement to quit, and (2) no use of EC. Both groups attended similar periodic lab sessions over an eight-week period where measurements of craving, withdrawal, saliva cotinine, and expired-air CO levels were taken. Adriaens found that after eight weeks of use 34% of those given EC had quit smoking compared to 0% of those not given EC, the EC group also showed substantially greater cigarette reduction. After eight weeks, the group which did not receive EC at baseline was given EC, but no training on how to use the products. At the final eight-month follow-up, 19% of the original EC group and 25% of the control group (given EC at week eight) had quit smoking. Significant reductions in cigarette consumption were also found.

Population studies

One problem with RCTs is that because of the time taken to set up and implement trials, the EC used in the trials are often no longer available for sale by the time the research is published. This is problematic because many new EC enter onto the market and it is possible they may be more effective at delivering nicotine than the products used in the trial, and possibly more effective for smoking cessation. Additionally, the controlled environment of RCTs is unable to provide evidence of the effectiveness of EC in the real world where use is much more subject to external forces, such as availability, price and social norms around use. RCTs also reveal little about the attractiveness of the products and thus likely uptake of the products used and what happens after a successful or failed attempt to stop smoking with an EC in the long-term.

Observational and natural history studies are therefore important. Only one population-based survey has examined the effectiveness of EC used during quit attempts. A large cross-sectional study of 5,863 English smokers who attempted to quit in the past year without using professional support [29] found that those who used EC on their last quit attempt were more likely to quit than those who used over the counter NRT – (the most common help sought by smokers after EC, see Figure 14), or no quit aid, controlling for factors related to quitting. This study was, however, unable to explore prospective predictors of quitting, including pre-quit nicotine dependence. Still, this study offers some of the best evidence to date on the effectiveness of EC for use in quit attempts.

Other recent population studies [16, 44, 45] have also examined the association between EC use and quitting. However, because these studies (1) included smokers who were already using EC at baseline, and (2) did not examine the use of EC during a specific quit attempt, we discuss them below in the section on use of EC while smoking.

Pilot studies

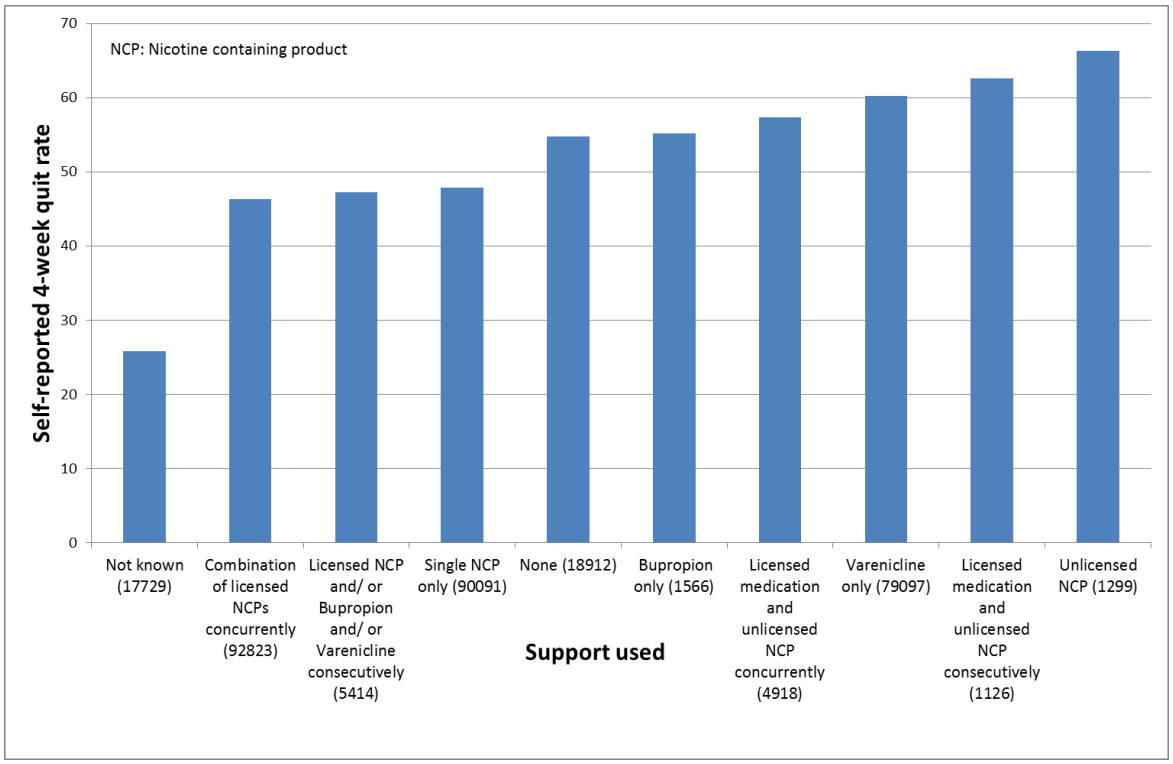
Polosa et al., 2014 [46] conducted a six-month pilot study of tank-type EC users with no control group among 72 smokers **who did not want to quit (smokers were enrolled after rejecting participation in smoking cessation program at a hospital)**. At six months, they found significant 50% and 80% reductions in cigarette consumption, and a quit rate of 36% [46]. Another study by Polosa et al., 2014 [47] followed 71 vape shop customers (seven different shops) after their first visit to the shop. The first visit included instructions on how to use EC and encouragement to use their EC of choice to reduce their smoking, along with a telephone number they could call for help. At six and twelve months after their initial visit they found that the smokers reported significant 50% and 80% reductions in cigarettes per day at six and twelve months, and that at six and twelve months, 42.2% and 40.8% had quit smoking.

E-cigarettes and stop smoking services

Some English stop smoking services and practitioners support the use of EC in quit attempts [48], and provide behavioural support for EC users trying to quit smoking. The most recent monitoring data from the stop smoking services show the self-reported success rates for different medications and nicotine-containing products used (Figure 15). Data are not given by validated success rates but overall, 69% of those who self-report stopping smoking are carbon-monoxide validated [49]. Hence, there are limitations with these data as they are self-reported success rates and it is possible that they may vary by treatment used. Additionally, the data are not adjusted for other factors, such as dependence, known to influence success rates, and it is likely that they emanate from a limited number of services who record unlicensed nicotine-containing products and who might therefore be more supportive of their use. Nevertheless, the

evidence is consistent with evidence from trials and other observational data that e-cigarettes are likely to support successful quitting.

Figure 15: Support used and stop smoking service self-reported quit rates[3]



Note: Figures in brackets represent the number of quit attempts in which each type of support was used. The number of clients with recorded e-cigarette use is very small in comparison to those recorded to have used other types of support.

Use of e-cigarettes while smoking

Population studies

Two studies using data drawn from a longitudinal population sample of more than 1,500 smokers in GB recently examined the impact of EC use on quitting, considering the effects of frequency of EC used and type of EC. Brose et al., 2015 [45] found that respondents who used EC daily at baseline were more likely to make a quit attempt one year later, but were no more or less likely to quit than those who did not use EC. Daily EC use at follow-up was found to be associated with reduced cigarette consumption since baseline. No effects of non-daily EC use on quit attempts, quitting, or reduction in consumption were found. Using data from the same Internet Cohort GB study, Hitchman et al., 2015 [16] found differences in quitting between baseline and follow-up

[3] Taken from Health and Social Care Information Centre. Statistics on NHS Stop Smoking Services in England - April 2014 to December 2014.Publication date: April 23, 2015 Source: Ref 47. http://www.hscic.gov.uk/catalogue/PUB17302

depending on the type and frequency of EC used at follow-up: compared to no EC use, non-daily cigalike users were less likely to have quit smoking since baseline, daily cigalike or non-daily tank users were no more or less likely to have quit, and daily tank users were more likely to have quit. Overall, the two studies showed that daily use of EC does not lead to lower cessation, and is associated with making quit attempts, cigarette reduction, and if tank-type EC is used, is associated with smoking cessation. Non-daily use of EC is not associated with quit-related outcomes, and may, if cigalike-type EC are used, be associated with lower cessation.

Supporting these findings, using data from a longitudinal population study of smokers in two metropolitan areas in the US, Biener et al., 2015 [44] measured use and intensity of EC use at *follow-up* in a longitudinal sample of smokers at baseline from two US cities. Biener also found that it was only intensive EC users (used daily for at least one month) that were more likely to quit, less intensive EC users were no more likely to quit than those not using EC.

There are limitations with these studies. For example, an unavoidable methodological problem is that only people who currently smoke are included in these studies meaning that smokers who switched completely to EC and stopped smoking are excluded. The efficacy of EC is thus invariably underestimated.

A longitudinal telephone survey reported by Al-Delaimy et al., 2015 [50] among a sample of 368 current smokers from California at baseline (2011) investigated the relation between '*ever have used*' versus *'never will use'* EC, and making a quit attempt, a 20% reduction in cigarettes per month, and quitting for more than one month at follow-up (2012). Al-Delaimy included smokers at baseline who at both baseline and follow-up reported the same EC status: never will use EC at both baseline and follow-up OR ever have used EC at both baseline and follow-up, excluding anyone who gave different responses. Also excluded were respondents who said they might use EC in the future at baseline or follow-up, and respondents who had never heard of EC, reducing sample size from n=980 to n=368. Al-Delaimy concluded that compared to smokers who reported they never will use EC, respondents who had ever used EC were significantly less likely to have reduced their cigarette consumption and quit at follow-up, with no differences reported of quit attempts at follow-up. This study has serious methodological problems that make its conclusions uninterpretable, first, the measure of EC use is 'ever use', which could include even a puff on an EC and second, they applied several exclusion criteria that are not clearly justified.

Studies of smokers enrolled in smoking cessation programs

Two recent studies have examined the use of EC among smokers enrolled in smoking cessation programmes in longitudinal studies [51, 52]. Pearson et al., 2015 [51] examined the relation between reporting using an EC for quitting at follow-up and

smoking cessation (30-day abstinence) in a sample of smokers enrolled in a web-based cessation programme in the US with three-month follow-up. Pearson illustrated how the relation between using EC to quit and successful smoking cessation depended on the factors that were adjusted for and how the data were analysed, finding that under some conditions EC use was related to being less likely to quit and in others there was no relationship. The authors concluded that caution needs to be exerted when interpreting observational studies of the effects of EC use on smoking cessation.

Borderud et al., 2014 [52] examined whether any use of EC in the past 30 days was related to smoking cessation outcomes in a group of cancer patients enrolled in a smoking cessation programme in the US. When treating all smokers who dropped out of the study as smoking cessation failures, the authors found that any use of EC in the last 30 days was related to being less likely to quit; however, this treatment of the data may have been problematic because more EC users than non-users dropped out of the study. No relationship between EC use in the last 30 days and smoking cessation was observed when drop-outs were excluded from the analyses. One potential problem with this study is the measure of any EC use in the last 30 days, as this could range from using an EC once in the last 30 days to using an EC daily for the past 30 days. As illustrated [16, 44, 45] and discussed in previous studies [51], measurements of EC use that do not fully capture frequency of use may influence the relation between EC use and smoking cessation. As with studies in the previous section, the Borderud study started with smokers who had tried EC but did not stop smoking. This, of course, seriously reduces the chance of detecting a positive effect.

Summary of findings

Recent studies support the Cochrane Review findings that EC can help people to quit smoking and reduce their cigarette consumption. There is also evidence that EC can encourage quitting or cigarette consumption reduction even among those not intending to quit or rejecting other support. It is not known whether current EC products are more or less effective than licensed stop-smoking medications, but they are much more popular, thereby providing an opportunity to expand the number of smokers stopping successfully. Some English stop smoking services and practitioners support the use of EC in quit attempts and provide behavioural support for EC users trying to quit smoking; *self-reported* quit rates are at least comparable to other treatments. The evidence on EC used *alongside smoking* on subsequent quitting of smoking is mixed.

Policy implications

- Smokers who have tried other methods of quitting without success could be encouraged to try EC to stop smoking and stop smoking services should support smokers using EC to quit by offering them behavioural support.

- Research should be commissioned in this area including:
  - longitudinal research on the use of EC, including smokers who have not used EC at the beginning of the study
  - the effects of using EC while smoking (temporary abstinence, cutting down) on quitting, and the effects of EC use among ex-smokers on relapse
  - research to clarify the factors that i) help smokers using EC to quit smoking and ii) deter smokers using EC from quitting smoking, including different EC products/types and frequency of use and the addition of behavioural support, and how EC compare with other methods of quitting which have a strong evidence base

- It would be helpful if emerging evidence on EC (including different types of EC) and how to use EC safely and effectively could be communicated to users and health professionals to maximise chances of successfully quitting smoking.

7. Reasons for use and discontinuation

Reasons for using e-cigarettes

Reasons for using EC have been assessed for adult smokers and ex-smokers in a number of different ways. Across different populations, help to quit smoking and harm reduction were the top reasons endorsed for using EC [44, 53-57].

In the Internet Cohort GB survey, the list of possible reasons for using EC was extended after the first year (the survey was carried out in 2012, 2013 and 2014). Nevertheless, the most frequently endorsed reasons were health, to cut down and to quit smoking. These were endorsed by approximately 80% of current users at all three time points. The biggest change over time was recorded for '*they are cheaper'* which appeared to be more popular in 2014 than 2013 (Table 3). Because of the way the question is phrased, a user endorsing a reason does not indicate that current use is for this particular reason, for example, 80% of current users agree that e-cigarettes may help you quit, but this does not mean that 80% of all users were using them in a quit attempt.

Table 3: Internet cohort GB survey, reasons for using e-cigarettes (in order of frequency of endorsement in 2014)

Which of the following were reasons for your using electronic cigarettes? (multiple responses possible)	2012 (n=1031)	2013 (n=717)	2014 (n=505)
They may make it easier for you to cut down the number of cigarettes you smoke	81.0	78.1	79.4
They may not be as bad for your health	81.7	79.8	79.2
They might help you quit	81.8	79.9	79.0
No tobacco smoke	not asked	70.9	71.3
They are cheaper	not asked	36.1	65.5
The smell or cleanliness	not asked	65.4	65
So you can use them in places where smoking regular cigarettes is banned	67.2	66.5	61
They may be more socially acceptable	not asked	55.8	54.3
Because I enjoy it	not asked	38.6	48.7
They taste better	28.5	26.1	34.1
Friends or family use them	not asked	37.0	33.3
The technology	not asked	34.2	30.3
A health professional advised you to do so	not asked	16.7	16.4

The ASH Smokefree GB survey similarly found that EC users who were ex-smokers most frequently endorsed that they used or had used EC to help them stop smoking entirely (Table 4). Among smokers, this was the second most frequently endorsed reason, with curiosity being the most frequent reason. Smokers also often reported use to help them cut down on smoked tobacco, which was rarely reported by ex-smokers.

Table 4: Reasons for use, ASH Smokefree GB adult survey, 2015 (weighted)

I use/used electronic cigarettes…	Smokers	Ex-smokers
Just to give it a try	35%	29%
To help me stop smoking tobacco entirely	30%	44%
To help me reduce the amount of tobacco I smoke, but not stop completely	29%	9%
Because I had made an attempt to quit smoking already and I wanted an aid to help me keep off tobacco	27%	35%
To save money compared with smoking tobacco	24%	22%
Because I felt I was addicted to smoking tobacco and could not stop using it even though I wanted to	16%	17%
Because I want to continue to smoke tobacco and I needed something to help deal with situations where I cannot smoke (e.g. workplaces, bars or restaurants)	15%	8%
To avoid putting those around me at risk due to second-hand tobacco smoke	12%	13%
Other	1%	3%

A smaller number of surveys specifically assessed reasons for trial and gave the option of selecting curiosity, which was frequently endorsed as an important reason for experimentation in US adults from the general population as well as in a sample of opioid-dependent smokers [58-60].

In youth, reasons for use has rarely been surveyed; one survey on reasons for experimentation among 1,175 students (middle school, high school and college) who had ever tried EC reported that the top three reasons for e-cigarette experimentation were curiosity (54.4%), the availability of appealing flavours (43.8%) and friends' influence (31.6%). Compared with never smokers, however, ever cigarette smokers (OR=37.5, 95% CI: 5.0 to 283.3) and current cigarette smokers (OR=102.2, 95% CI: 13.8 to 755.9) were many times more likely to say they tried EC to stop smoking [61].

A national survey in New Zealand of 3,127 year 10 students (mostly aged 14 to 15) also showed that the most frequently given reason for first trying EC was curiosity, irrespective of smoking status (64.5% overall) [62].

Reasons *not* to use EC are rarely assessed. The ASH Smokers' survey 2014 asked current and ex-smokers about advantages and disadvantages of EC. Among those who had never used EC, the three most important disadvantages were "*They might be too expensive*" (46%), "*They might not be safe enough as a product*" (39%) and "*They might not satisfy my desire to smoke enough*" (31%).

Reasons why trial does not become use

The rates of ever having tried an EC in the ASH GB Smokefree adult survey are more than three times those of current use; in the ASH GB Smokefree youth survey, about five times as many respondents had tried an EC as were currently using an EC, indicating that **most of those who try EC do not progress to current use**. A small number of surveys assessed why respondents who had tried an EC did not continue use.

In a national sample of 3,878 US adults who reported ever trying EC, two-thirds did not continue to use them and this was linked to the main reason for trying them. Trial turned into continued use for only a minority (19%) of those who did not know their main reason for trying them or whose main reasons were curiosity, friends or family members or advertising. Continued use was more common for those whose main reasons for trial included help to quit smoking or reduce harm. Those who did not continue use were asked for their reasons for stopping. The reason most often given was that they were just experimenting (49%) [58].

In the survey by Kong et al., reported previously, it appears that 98.5% of experimenting students did not continue use. Reasons for discontinuation were assessed but unfortunately the most commonly chosen response was 'other' (23.6%, open-ended responses included "I don't like it", "I just tried once") followed by "uncool" (16.3%) and health risks (12.1%) [61].

Some surveys can be used to assess why smokers may not continue to use EC. The ASH Smokers' survey in 2014 indicates that disappointment with the help EC provide in reducing smoking urges may be an important reason. Among smokers who had tried EC but did not continue using them, 44% said that a disadvantage of the products was that "*They might not satisfy my desire to smoke enough*". No other reason got a higher rate of agreement in this group. A high proportion of smokers who were currently using EC also stated this reason (37%), but the proportion was significantly ($p<0.05$) lower in ex-smokers who had used (32%) or were currently using EC (7%), suggesting that satisfaction with the device/s may be a correlate of stopping smoking.

Of concern is that data suggest that some smokers may not continue to use EC instead of smoking because of a misguided belief that EC would be harmful to their health. In the ASH Smokers' survey 2014, the second most frequently endorsed disadvantage was "*They might not be safe enough as a product*" (35%) among smokers who had tried an EC but were not using one anymore. Similarly, in a survey of US respondents, among 227 respondents who had tried EC in the past, were no longer using them but were still smoking cigarettes [44], the most frequently endorsed reason was that EC didn't feel enough like smoking cigarettes, followed by dislike of the taste and that they were bad for health. It would appear therefore that these respondents stopped EC use in favour of continuing to smoke more deadly cigarettes.

Summary of findings

A number of surveys in different populations provide evidence that reducing the harm from smoking (such as through cutting down on their cigarette consumption or helping with withdrawal during temporary abstinence) and the desire to quit smoking cigarettes are the most important reasons for using EC. Curiosity appears to play a major role in experimentation. Most trial of EC does not lead to regular use and while there is less evidence on why trial does not become regular use, it appears that trial due to curiosity is less likely to lead to regular use than trial for reasons such as stopping smoking or reducing harm. Dissatisfaction with products and safety concerns may deter continued EC use.

Policy implications

- Smokers frequently state that they are using EC to give up smoking. They should therefore be provided with advice and support to encourage them to quit smoking completely.

- Other reasons for use include reducing the harm from smoking and such efforts should be supported but with a long-term goal of stopping smoking completely.

8. Harm perceptions

Perceptions of the harmfulness of EC are frequently assessed in surveys, most commonly relative to conventional tobacco cigarettes. However, a recent Eurobarometer survey [63] asked smokers in absolute terms whether EC were harmful to the health of those using them. Overall in Europe, 40.6% perceived EC as not harmful (UK: 48.6%), 28.5% as harmful (UK: 14.6%) and 30.9% did not know if they were or were not harmful (UK: 36.8%).

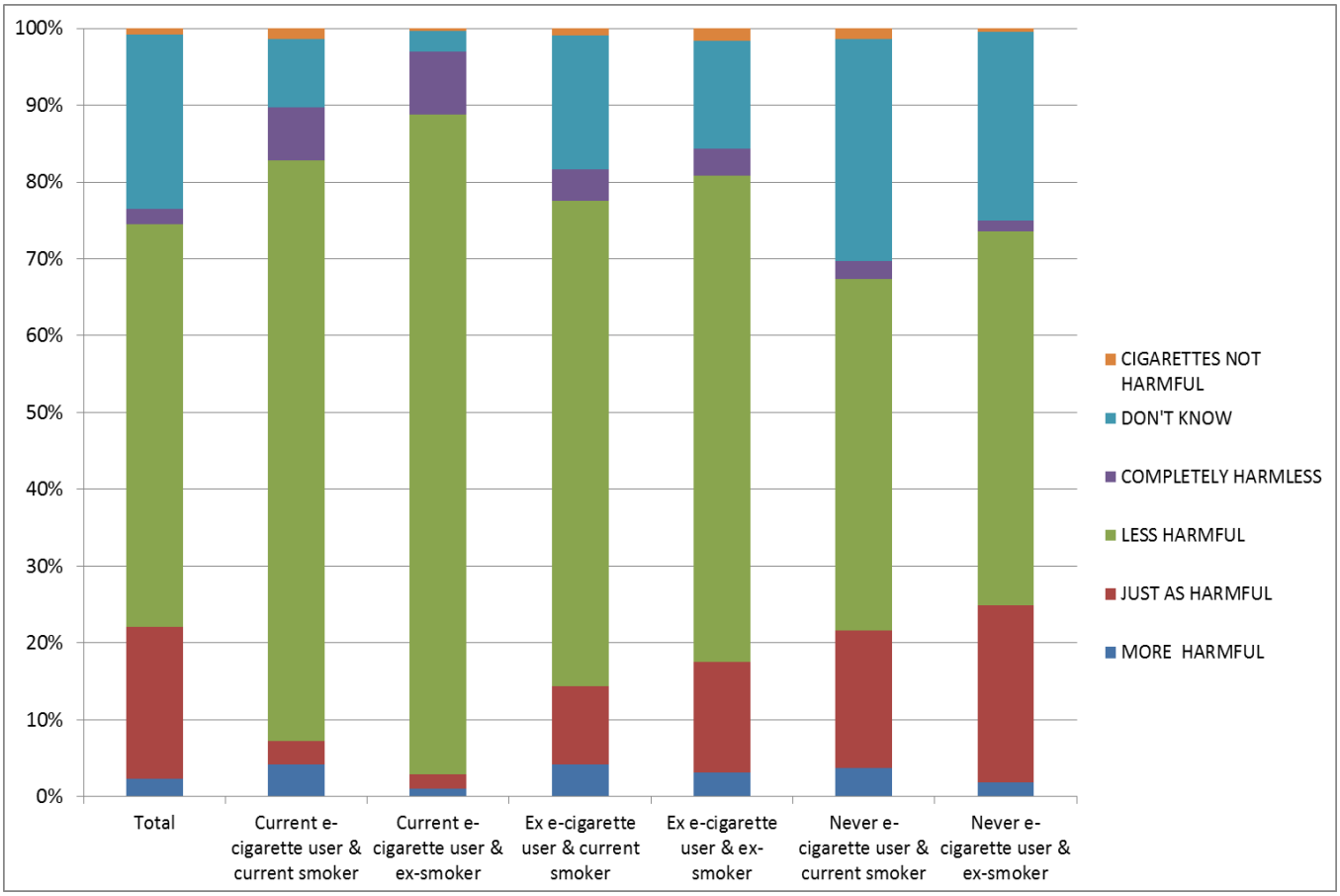
Harm perception relative to cigarettes

In GB, the ASH surveys and the Internet Cohort survey have included questions on the perceived relative harm of EC. These surveys consistently show that compared with conventional tobacco products, EC were perceived as less harmful by a small majority of respondents, **but with a sizeable minority inaccurately judging them to be more harmful, about as harmful or being unsure about their relative risks**. For example, in the 2015 ASH Smokefree GB adult survey, 2% thought that EC were more harmful than cigarettes, 20% equally harmful, 52% less harmful, 2% completely harmless and 23% did not know.

Harm perception differed by smoking status ($\chi 2=104.05$, $p<0.001$) and by EC use status ($\chi^2=453.4$, $p<0.001$) (Figure 15). Overall, smokers were more likely to judge EC to be less harmful compared with cigarettes (63.7%, including 'completely harmless') than ex-smokers (55.6%), whereas never-smokers were least likely to judge EC as less harmful (51.2%, all $p<0.05$). A higher proportion of current EC users (87.4%) thought that they were less harmful compared with cigarettes than those who had tried but were not using (68.8%) or never-users (50.4%), among whom the proportion was lowest (all differences $p<0.05$). Perceptions among youth were similar to adults. For example, in the 2015 ASH Smokefree GB youth survey, 2% thought that EC were more harmful than cigarettes, 21% equally harmful, 67% less harmful and 10% did not know.

In the STS, the proportion believing EC to be less harmful appears to be even lower. Only 44.1% of current smokers in England between November 2014 and March 2015 believed that EC were less harmful than cigarettes [15].

Figure 15: Perceptions of relative harmfulness of e-cigarettes in comparison with tobacco cigarettes by e-cigarette use and smoking status. ASH Smokefree GB adult surveys (weighted)



Trends in harm perceptions relative to cigarettes over time

Since 2013, perceptions of the relative harmfulness of EC have become less accurate. Significantly larger proportions perceived EC to be at least as harmful as cigarettes in 2014 than in 2013 both in the Internet Cohort GB surveys (Figure 16) and in the ASH youth surveys (Figure 17 [64]). In the Internet Cohort GB survey, there was no significant change from 2012 to 2013, but from 2013 to 2014 the proportion thinking that EC were less harmful decreased in favour of equally or more harmful ($p<0.001$). For youth, between 2013 and 2014, the decrease in the proportion endorsing 'less harmful' and the increase in the proportion endorsing 'equally harmful' were significant ($p<0.01$). There were no significant changes in the proportion endorsing 'more harmful' or 'don't know'.

In the ASH adult surveys, data on harm perception are available for 2013 to 2015 (Figure 17). In line with the other GB surveys, this survey found a steep increase in the proportion perceiving EC to be equally harmful as cigarettes ($p<0.001$).

Figure 16: Perceptions of relative harmfulness of e-cigarettes in comparison with tobacco cigarettes. Internet Cohort GB surveys (N=1,209 respondents with data at all three time points)

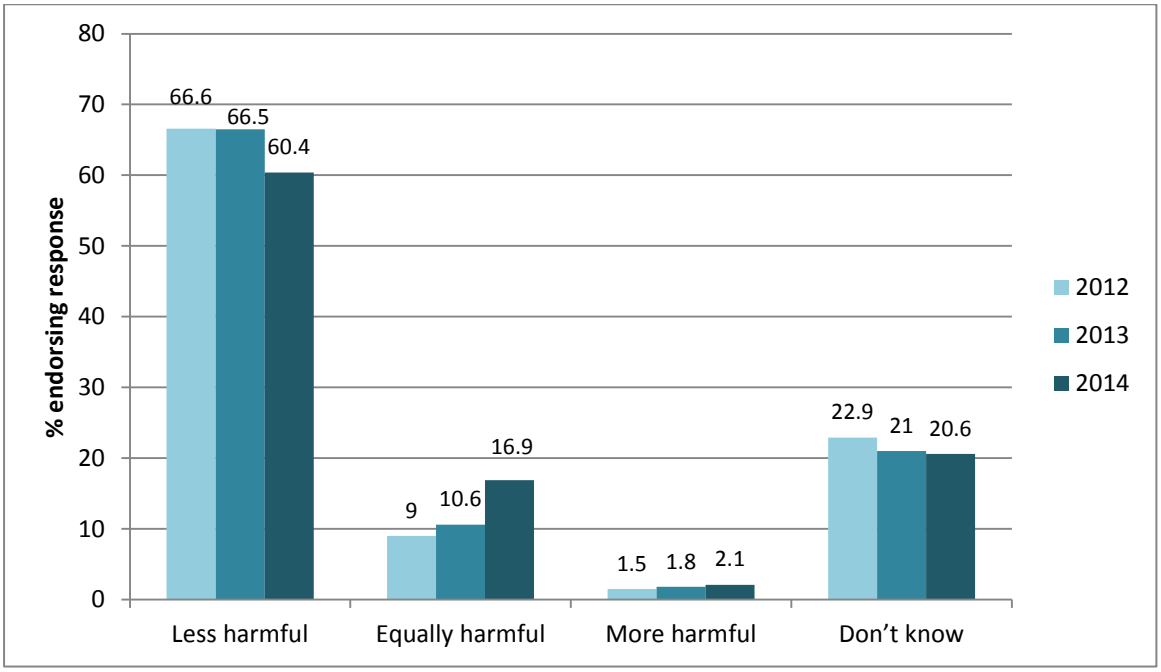
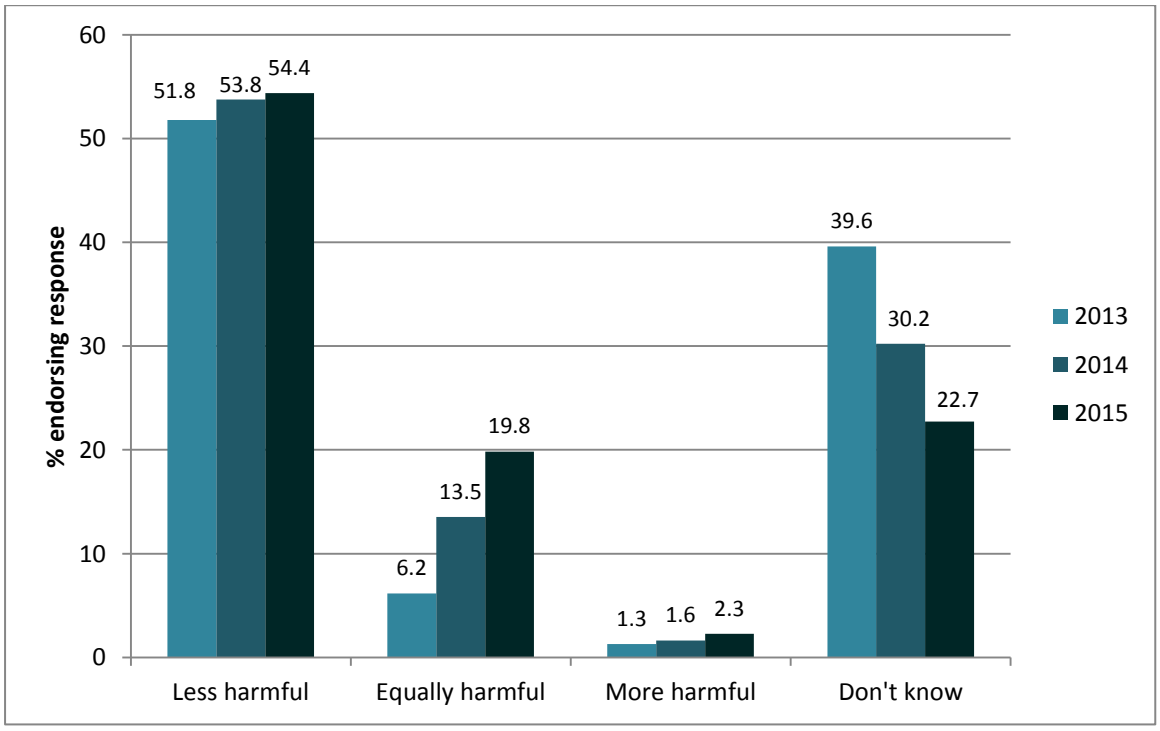
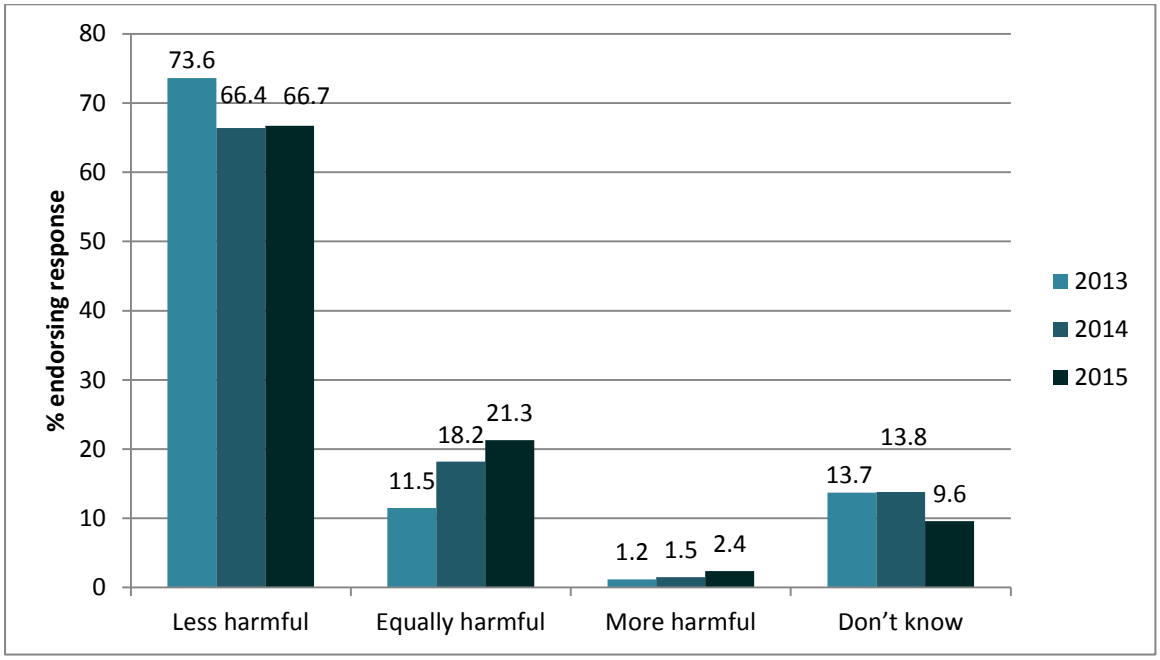


Figure 17: Perceptions of relative harmfulness of e-cigarettes in comparison with tobacco cigarettes. ASH Smokefree GB adult surveys (weighted)



Notes: "Less harmful" includes those saying "Electronic cigarettes are completely harmless". "Not applicable – I do not think regular cigarettes are harmful" not shown (2013: 1.2%, 2014: 0.9%, 2015: 0.8%)

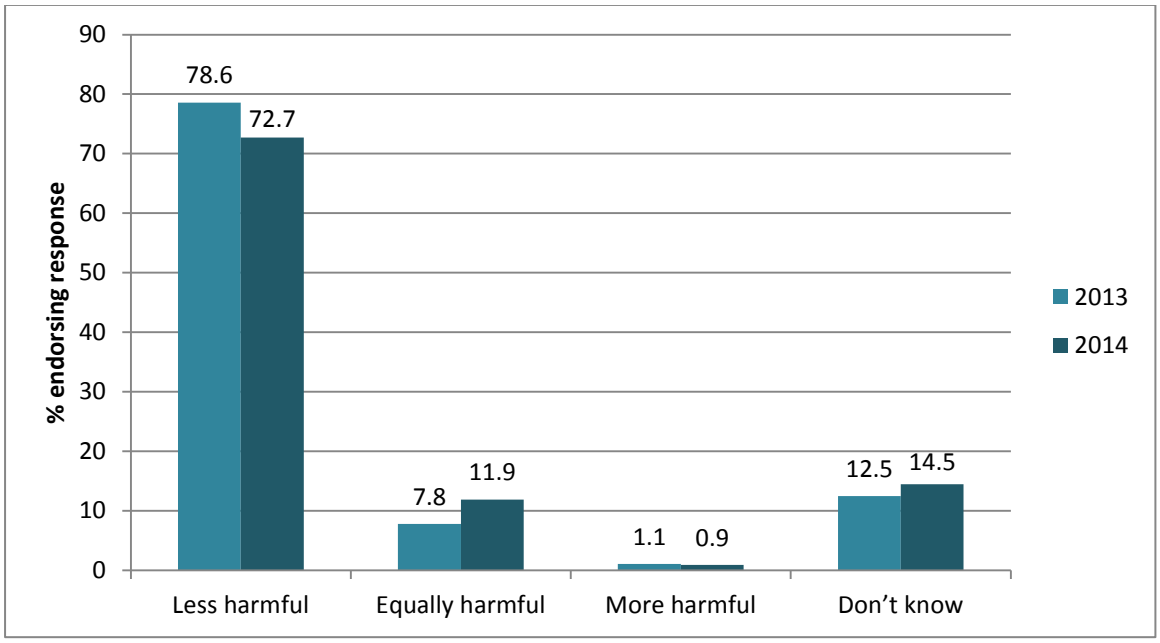
Figure 18: Perceptions of relative harmfulness of e-cigarettes in comparison with tobacco cigarettes. ASH Smokefree GB youth surveys (2013 and 2014) taken from Eastwood et al., in press[64].



Surveys from the US also suggest that from 2010 to 2013, the proportion of current smokers aware of EC who believed that EC were less harmful than smoking cigarettes declined considerably [65]. Youth in the US appear to have a less realistic perception of the relative harm of EC compared with cigarettes than UK youth. In the 2012 National Youth Tobacco Survey, of those who were aware of EC, around one-third perceived them to be less harmful than cigarettes and around half were unsure [66, 67].

The ASH Smokefree GB youth survey in 2013 and 2014 further included a question on the harm of EC to persons around a user. Again, the proportion who thought them less harmful than traditional cigarettes decreased from 2013 to 2014 ($p<0.05$), and the proportion who thought they caused similar levels of harm increased ($p<0.01$) (Figure 19).

Figure 19: Perceptions of relative harmfulness of e-cigarettes to people around the user. ASH Smokefree GB youth surveys



Harm perception relative to nicotine replacement therapy (NRT)

The ASH Smokers' survey in 2014 asked respondents about their perception of EC compared with NRT (Table 20). The largest group of respondents thought EC were about as safe. Notably, a higher proportion thought that EC were safer than NRT than believed that NRT was safer than EC. This was particularly pronounced in current EC users.

Table 5: Relative harm perception by e-cigarette use status ASH Smokers' survey 2014

	E-cigarette use status			
	Never	**Current**	**Ex**	**Total**
	39.10%	**21.30%**	**39.70%**	
	(n=470)	**(n=256)**	**(n=477)**	**(n=1203)**
Compared to NRT				
Safer	14 (66)	28.1 (72)	22 (105)	**20.2 (243)**
About as safe	28.1 (132)	44.1 (113)	35.6 (170)	**34.5 (415)**
Less safe	16.2 (76)	6.3 (16)	13 (62)	**12.8 (154)**
Don't know	41.7 (196)	21.5 (55)	29.4 (140)	**32.5 (391)**

One US survey of 1,400 current and former smokers also assessed expected outcomes of using EC compared with NRT [68]. EC were perceived to be less risky, cost less, cause fewer negative physical feelings, taste better, provide more satisfaction, and be better at reducing craving, negative affect, and stress.

Summary of findings

Although the majority of adults and youth still correctly perceive EC to be less harmful than tobacco cigarettes, there has been an overall shift towards the inaccurate perception of EC being at least as harmful as cigarettes over the last year, for both groups. Intriguingly, there is also some evidence that people believe EC to be less harmful than medicinal nicotine replacement therapy (NRT).

Policy implications

- Clear and accurate information on relative harm of nicotine, EC and tobacco cigarettes is needed urgently (see also Chapter 10).
- Research is needed to explore how health perceptions of EC are developed, in relation to tobacco cigarettes and NRT, and how they can be influenced.

9. E-cigarettes, nicotine content and delivery

Background

We have undertaken a review of available evidence concerning nicotine released by EC. The review is divided into four parts, covering nicotine that EC use (vaping) releases into ambient air, nicotine content of e-liquid, nicotine content in e-vapour, and nicotine delivery to EC users (vapers). The main concern with nicotine in EC relates to the question of whether EC use exposes users or bystanders to the risk of nicotine poisoning. For this reason, we start with a short introductory review of this topic.

Toxicity of nicotine

Nicotine in the form of tobacco and more recently NRT has been available to thousands of millions of people and large numbers of them, including small children, have ingested considerable doses of nicotine. Fatal nicotine poisoning, however, is extremely rare. This fact strongly contradicts the often-repeated claim that an ingestion of 30-60mg of nicotine is fatal. The source of this claim proved difficult to locate – textbooks just cite older textbooks. Eventually, the assertion was found to be based on dubious self-experiments conducted in the 1890s [69].

We are aware of one unconfirmed newspaper report of a fatal poisoning of a two-year old child [70] and of three published case studies of small children who drank e-liquid. A two-year old was admitted to hospital with vomiting, ataxia, and lethargy, and was discharged after 24 hours of observation [71]. In the second report, an 18-month old girl drank 24mg nicotine in e-liquid, vomited and was irritable, and recovered fully within an hour or so [72]. The third article presented a case of a 30-month old child suspected to have ingested e-liquid. The quantity of e-liquid was uncertain and the child was asymptomatic with all clinical observations reported to be normal [73].

With the increase in EC use, there has been an increase in calls to poison centres following accidental exposures but these remain lower than calls following such exposure from tobacco and none resulted in any serious harm [74] (see next chapter for UK data). Serious nicotine poisoning seems normally prevented by the fact that relatively low doses of nicotine cause nausea and vomiting, which stops users from further intake.

Apart from accidental poisoning, nicotine has also been used in suicide attempts. Suicide attempts with large amounts of pesticides containing nicotine sulphate often succeed [75] but completed suicides using e-liquids are extremely rare. Where adults

drank up to 1,500mg of nicotine in e-liquid, the result was vomiting and recovery within a few hours [76]. One fatal outcome was recorded with 3,950mg of nicotine found in gastric content. The victim seems to have drunk three vials of e-liquid totalling over 10,000mg of nicotine[76]. An intravenous injection of unknown quantity of e-liquid also resulted in death [77].

E-liquid normally comes in 10ml bottles containing up to 360mg of nicotine (see below). This poses no risk to vapers if used as intended. The liquid however should be in 'childproof' packaging to prevent small children, who may find the flavouring appealing, from drinking it. This seems to have been widely accepted by the EC industry. All e-liquids we have seen so far in the UK and globally were sold in child-resistant packaging.

Review methods

We searched the US National Library of Medicine (Pubmed) using the following search terms: ((cotinine OR nicotine) AND (blood OR plasma OR urine OR saliva OR liquid OR aerosol OR pharmacokinetic$)) AND (electronic cigarette$ OR e-cig$ OR ENDS). This search returned 161 records. The abstracts of all records were screened.

Papers were included if they were peer-reviewed and presented data regarding nicotine in e-liquid, aerosol, or body fluids (blood, saliva or urine). Studies that reported data on blood, salivary, or urine cotinine were also included.

A total of 112 records were excluded as they did not contain any relevant information, leaving 49 records. The full papers of these records were retrieved and reviewed.

From the full text review, 25 studies provided data regarding nicotine content of ambient air, e-liquid and vapour, and 16 provided data on nicotine delivery to users. The remaining eight papers did not contain any relevant information. Three further relevant papers were published during the writing of this report and were also included.

Nicotine in ambient air, e-liquid and e-vapour

We identified five studies of nicotine in ambient air, 14 studies of nicotine in e-liquid and nine studies of nicotine vapour. The results are summarised below. We tabulate the results where appropriate and provide a narrative summary where there are only a few studies available. Each section is concluded with a brief summary.

Passive vaping: Nicotine from e-cigarette use in ambient air

Four studies examined nicotine exposure from passive vaping. Long et al., 2014 measured nicotine content of EC exhalations. EC exhalations contained eight times less

nicotine than cigarette exhalations [78]. Estimating environmental nicotine exposure, however, has to take into account the fact that side-stream smoke (ie the smoke from the lighted end of the cigarette, which is produced regardless of whether the smoker is puffing or not) accounts for some 85% of passive smoking and there is no side-stream EC vapour. A study measuring nicotine residue on surfaces in houses of smokers and vapers reported only negligible levels from vaping, 169 times lower than from smoking [79].

Colard et al., 2015 describe a model for estimating environmental workplace exposure [80]. The model predicts much lower nicotine exposure from vaping than from smoking, at levels negligible in health terms.

Goniewicz and Lee 2014 found that nicotine from EC vapour gets deposited on surfaces, but at very low levels [81]. This poses no concerns regarding exposure to bystanders. At the highest concentration recorded (550 µg/m^2), an infant would need to lick over 30 square metres of exposed surface to obtain 1mg of nicotine.

Ballbe et al., 2014 provide the most informative data collected to date as this study measured the actual levels of airborne nicotine in homes of ex-smokers who live either with smokers (N=25) or with vapers (N=5) and also in 24 control homes [82]. The study also measured salivary and urinary cotinine in partners of smokers and vapers. As expected, there was little nicotine in non-smokers' homes. The air in the homes of vapers contained six times less nicotine than the air in the homes of smokers. There was less of a difference between cotinine levels of partners of vapers and smokers (1.4 to 2 fold difference), most likely due to some 'ex-smokers' still occasionally smoking, but even with this possible contamination, the nicotine levels absorbed via passive vaping were negligible. Partners of vapers had mean cotinine concentrations of 0.19 ng/ml in saliva and 1.75 ng/ml in urine, which is about 1,000 times less than the concentrations seen in smokers and similar to levels generated by eating a tomato [83].

Summary

EC release negligible levels of nicotine into ambient air with no identified health risks to bystanders.

Nicotine in e-liquids

Fourteen studies tested more than 400 different e-liquids, mainly to check the accuracy of product labelling. Their results are summarised in Table 6, updated from an earlier review by Cheng et al., 2014 [84].

Table 6: Nicotine in refill solutions, cartridges and aerosols of e-cigarette products
(Adjusted from Cheng et al. 2014)

Study	Matrix	Units	Nicotine level	Maximum deviation from label*
Westenberger [85]	Cartridge	mg/cartridge	0.00 to 6.76	N.A.
	Aerosol	µg/100mLpuff	0.35 to 43.2	N.A.
	Refill solution	µg/mL	N.D. to 25.6	N.A.
	Cartridge	mg/cartridge	0.00 to 6.76	N.A.
Cobb *et al* [86]	Cartridge	mg/cartridge	3.23±0.5 to 4.07±0.54	–80 to –77%†
	Aerosol	µg/35 mL puff	0.3 for puffs 11 to 50 to 1 for puffs 1 to 10	N.A.
Trehy *et al* [87]	Refill solutions	mg/mL	0 to 25.6	–100 to 100%†
	Cartridge	mg/cartridge	0 to 21.8	–100 to 100%†
	Aerosol	µg/100 mL puff	0 to 43.2	N.A.
Cheah *et al* [88]	Cartridge	mg/cartridge	0.00 to 15.3	–89 to 105%†
Pellegrino *et al* [89]	Cartridge	% W/W	<0.001 to 0.25	N.A.
	Aerosol	mg/m^3	<0.01 to 6.21	N.A.
McAuley *et al* [90]	Indoor air	ng/L	538 to 8770	N.A.
Goniewicz *et al* [91]	Refill solution	mg	0±0.0 to 25±1.1	–75 to 28%
	Cartridge	mg	0±0.0 to 19±0.5	–89 to 25%
	Aerosol	mg/150 puffs	0.3±0.2 to 8.7±1.0	N.A.
Etter *et al* [92]	Refill solution	mg/mL	N.D. to 29.0	–15 to 21%†
Kirschner *et al* [93]	Refill solution	mg/mL	14.8±0.2 to 87.2±2.7	–50 to 40%†
Cameron *et al* [94]	Refill solution	mg/mL	8.5±0.16 to 22.2±0.62	–66 to 42%†
Goniewicz *et al* [95]	Liquids	mg/mL	N.D. to 36.6 (150.3 'pure nicotine')	-92 to 104%
Geiss *et al* [96]	Liquids	mg/mL	N.D. to 20.8	-0 to 16%
Kavvalakis *et al* [97]	Liquids	%w/v	1.01 to 1.62	-17 to +6%
Farsalinos *et al* [98]	Liquids	mg/ml	Labelled 12-18	-21 to +22%

*Deviation from label = (measured value – labelled value) * 100/labelled value.

†Calculation performed by this analysis based on reported data in each study.

N.A. = not available; N.D. = none detected.

A range of analytical methods was used, which may have contributed some variation. There is no established standard and different studies use different approaches. Cheah et al., used gas chromatography coupled with flame ionization detector [88]; Etter et al., gas chromatography coupled with mass spectrometry and ultra high-performance liquid chromatography coupled with diode array detector [92]; McAuley et al., gas chromatography coupled with nitrogen-phosphorus detector [90]; Goniewicz et al., gas chromatography coupled with thermionic specific detector [95]; Trehy et al., high-performance liquid chromatography coupled with diode array detector [87]; Westenberger high-performance liquid chromatography coupled with ultraviolet/ visible spectroscopic detector [85]; Kubica et al., liquid chromatography coupled with tandem mass spectrometry [99]; and Kirschner et al., liquid chromatography coupled with time-of-flight mass spectrometry [93].

The data generated so far provide answers to three questions:

Do e-liquids pose a poisoning hazard?

The vast majority of vapers use ‘ready-made’ liquids in 10ml bottles, but some aficionados, primarily in the US, buy high concentration nicotine solutions in larger quantities for DIY dilution. An e-liquid was identified labelled as containing 210mg/ml which in fact contained only 150mg/ml [95] but even this may pose risk if ingested in larger volume. DIY liquids are rarely used in Europe, but for spurious reasons, Europe is poised to prohibit sales of products with nicotine concentrations above 20mg/ml. When this happens, the popularity of DIY e-liquids among dependent vapers, who now cannot access the products they need but can mix them themselves at home at low cost, may increase.

‘Ready-made’ e-liquids come in strengths of up to 36mg/ml nicotine, with the highest concentration recorded of 36.6mg/ml. This poses no risk of nicotine poisoning if used as intended. An overenthusiastic vaper, like someone who is over-smoking, receives a reliable warning via nausea. If the 10ml bottle of e-liquid was drunk, it would cause nausea and vomiting but would be unlikely to inflict serious harm. To protect young children from accidental exposure though, e-liquids should be in ‘childproof’ packaging.

How accurate is product labelling?

The real content exceeded markedly the labelled concentration only in samples where the declared content was very low (6mg/ml) and the real concentrations ranged up to 12mg/ml (ie still low levels). The most striking examples of inaccurate labelling concerned much lower nicotine levels than those declared in e-liquids confiscated in Singapore where EC are banned, for example, a liquid labelled as containing 24mg of nicotine contained only 3mg [88]. This however was most likely due to samples being several years old. Market competition seems to have led to improved standards as

poorly labelled products are now less common and overall the labelling accuracy has improved. For instance in the latest study which sampled 263 liquids from 13 manufacturers, the correlation between the declared and measured concentrations was r=0.94 with the samples ranging from -17% to +6% of the declared value [85]. In another study testing the five most popular EC brands, the consistency of nicotine content across different batches of nicotine cartridges of the same products was found to be within the accuracy required from medicinal nebulisers [100]. Given the generally adequate labelling accuracy and the fact that the actual nicotine intake by vapers is dictated by a host of other factors discussed below, the accuracy of labelling of common e-liquids poses no major concerns.

Is there is a risk from e-liquids inaccurately labelled as containing 0 nicotine?

All samples labelled as containing 0 nicotine were nicotine free in the newer studies, but three early studies found nicotine in some samples of '0 nicotine' e-liquids. One sample reported in 2011 was clearly mislabelled [87] but in all other cases, only trace contamination was detected (below 1mg/ml). This would have no central effect on users.

Summary

Poorly labelled e-liquid and e-cartridges mostly contained less nicotine than declared and so posed no risk to users. The accuracy of product labelling currently raises no major concerns.

Nicotine in e-vapour

A number of studies evaluated nicotine in EC vapour generated by puffing machines. A recent experiment [101] has shown that parameters of puffing topography, especially puff duration and puff frequency, have a major influence on nicotine delivery. This poses a serious problem in interpreting the existing studies. The key parameters used by puffing machines differ widely across studies, and may not correspond well or at all with vapers' behaviour generally and especially with the way individual EC products are used. To illustrate the point, Table 7 below, from Cheng et al. 2014 [84], shows the wide range of settings used in different studies. (Table 7 includes some unpublished studies).

Table 7. Settings of EC puffing parameters. From Cheng et al 2014 [84].

Study	Puff volume (mL)	Puff interval (s)	Puff duration (s)	Puffs/session	Smoking machine
Goniewicz *et al [100]*	70	10	1.8	15	Palaczbot*
Pellegrino *et al [89]*	498	8	3	16	Aspiration

Ingebrethsen [102]	55	30	2 to 4	10	Lab-built device
McAuley *et al [90]*	50	30	4	50	SCSM
Trehy *et al [87]*	100	60	2	30	Lab-built device
Williams & Talbot [103]	N.A.	60	2.2	10/11	Lab-built device
Cobb *et al[86]*	35	60	2	≥50	Machine ISO
Trtchounian *et al [104]*	N.A.	60	2.2	10	Lab-built Puff box
Uchiyama *et al [105]*	N.A.	N.A.	N.A.	N.A.	Premium Smoker
Westenberger [85]	100	60	N.A.	N.A.	Lab-built device
Laugesen [106]	38, 58	N.A.	N.A.	N.A.	Syringe

N.A., not available.

For instance, the average puff duration in experienced vapers is 2.8 seconds [101], but some studies used puffs lasting for up to 4 seconds. This can overheat the e-liquid and provide unrealistically high readings (see Chapter 11).

Although it would be feasible to establish some empirical standards, eg of puff duration and frequency, by observing vapers, any general standard would have to average values across different products. As different products, and especially products from different ‘generations’, are used differently, such a blanket regimen would still provide inaccurate and potentially misleading information.

A recent study discovered another serious problem with trying to make sense of nicotine content in e-vapour. Across five common e-liquids with middle ranges of strength, the actual nicotine concentration in the e-liquid had almost no relationship with the nicotine content in vapour when the devices were puffed on by a machine at a standard rate [100]. The e-liquid of course had to contain a certain minimal level of nicotine as with little or no nicotine in e-liquid, there would be little or no nicotine in vapour. This finding concerning machine testing also does not mean that nicotine levels in e-liquids are irrelevant for EC users. Although EC technology is developing to maximise nicotine delivery, a vaper seeking high blood nicotine levels is likely to struggle to achieve them with a weak e-liquid. The reason for the low correlation between nicotine in e-liquid and in e-vapour is that the battery output, type of wicks, ventilation holes and other mechanical characteristics of each individual EC product determine how much vapour and nicotine is released – before the individual puffing style and preferences generate yet another key determinant of nicotine delivery to users.

These findings have an important implication. Above the necessary minimum level of nicotine, nicotine concentrations in e-liquid and even the concentrations in vapour, if measured by standard puffing schedules, are of limited relevance. For light smokers, 18mg/ml ‘mild’ e-liquid may be sufficient, but they may also prefer a stronger liquid and take shorter and less frequent puffs. A heavy smoker who would be expected to prefer a 28mg/ml ‘strong’ liquid may in fact chose a ‘moderate’ strength if they favour long and frequent puffs.

In real-life use, vapers have no way of knowing in advance what liquid strength and product characteristics they will prefer. As with other consumer products of this type, such as cigarettes, coffee and soft drinks, vapers have to try several EC models and different e-liquids before settling on a preferred product that matches their preferences.

For practical purposes, general labelling of the strength of e-liquid, along the lines used for indicating coffee strength, may provide sufficient information for consumers. The current vapers’ preferences suggest as a rough rule of thumb that ‘mild’ equates to 16–20mg/ml, ‘medium’ to 21–26mg/ml and ‘strong’ to 27–36mg/ml.

Translating these findings into regulatory recommendations, it would seem that regulation to enforce standard nicotine delivery may not be needed because nicotine delivery is influenced by a host of factors, including user puffing preferences, and because consumer preferences differ. EC products will hopefully continue to evolve guided by differential market success, with the result that more smokers find EC helpful and switch to them.

Summary

Across the middle range of nicotine levels, nicotine delivery to vapour is determined primarily by mechanical and electrical characteristics of EC products and by the duration and frequency of puffs. General labelling of the strength of e-liquids, along the lines used for indicating coffee strength (eg mild, medium and strong), is likely to provide sufficient information for consumers.

Nicotine delivery to e-cigarette users

To assess nicotine intake from EC, a number of studies took blood samples from smokers during and after vaping. Table 8 summarises data from 17 studies that investigated nicotine delivery from EC in humans. The narrative description of the studies and additional details concerning their findings are presented in Appendix C.

The two key questions in this field are:

a) How much nicotine EC deliver compared to cigarettes, and
b) How fast EC deliver nicotine compared to cigarettes.

As in every new field, methodological problems limit the usefulness of some of the data collected so far. Two problems in particular are prominent.

1) Almost all studies used prescribed puffing regimes, sometimes derived from observations of smokers rather than vapers. We described above the evidence that puffing schedules have a major influence on nicotine delivery to vapour. Puffing schedules that do not correspond with vapers' behaviour are thus unlikely to provide realistic nicotine delivery data. Only three studies allowed vapers to puff ad-lib on first use.

2) Regarding the question of the speed of nicotine delivery, all existing studies started blood sampling only after five minutes of vaping. Cigarettes provide peak nicotine plasma levels very quickly (eg peak arterial nicotine concentrations of around 20ng/ml nicotine are reached within 20 seconds of starting to puff on an cigarette [107]). Data collected so far do not allow an appraisal of whether EC are approaching cigarettes in this key parameter.

Despite these limitations, the studies above have generated several strands of useful information on how much nicotine vapers obtain over time and how this compares with nicotine intake from cigarettes.

Cotinine is a metabolite of nicotine with a long half-life which shows nicotine exposure over time. Cotinine data are thus not influenced by the laboratory puffing schedules. Some studies suggest that experienced vapers can, over time, reach nicotine levels comparable to those obtained from smoking [108-110], although others have found plasma or salivary cotinine levels that are still lower than those observed in daily smokers [111-113].

Cigalike EC deliver lower levels of nicotine than cigarettes [114-116], especially to novice users [117-119]. Vapers obtain slightly more nicotine from them with practice, but nicotine delivery is comparatively low and slow [115]. Experienced users can obtain a rise in blood nicotine concentration of between 8 and 16ng/ml [120, 121]. Tank systems deliver nicotine more efficiently than cigalikes and somewhat faster [120, 122, 123].

Overall, the data indicate that within five minutes of use of a cigalike EC, blood nicotine levels can rise by approximately 5ng/ml. For comparison, after chewing a piece of 2mg nicotine chewing gum, peak plasma concentrations of 3–5ng/ml are observed within approximately 30 minutes [124, 125]. For experienced users of tank systems the increase in blood nicotine concentration within five minutes of use can be 3–4 times higher.

Speed of nicotine delivery seems important for smokers' satisfaction. Cigarettes deliver nicotine very fast via the lungs. It is likely that to out-compete cigarettes, EC will need to provide nicotine via the lungs as well. Although some EC products may already provide a degree of lung absorption, most nicotine is probably delivered via a much slower route through buccal mucosa and upper airways, in a way that is closer to the delivery from nicotine replacement medications than to the delivery from cigarettes.

This tallies with two other observations. Vapers feel they are less dependent on EC than they were on cigarettes [126]; and non-smokers experimenting with EC do not find them attractive and almost none progress to daily vaping [127]. This contrasts with the fact that about half of adolescents who experiment with cigarettes progress to daily smoking [128].

In addition to mechanical characteristics of EC and user puffing behaviour discussed in previous sections, the composition of the chemicals used to produce the vapour, typically vegetable glycerol and/or propylene glycol (PG), may also influence nicotine delivery. E-liquid with a mix of vegetable glycerol/PG was associated with better nicotine delivery than a vegetable glycerol-only e-liquid with the same concentration of nicotine [129]. The presumed effect is that PG vaporises at a faster rate than vegetable glycerol when heated in the EC and so is able to carry more nicotine to the user.

If EC continue to improve in the speed of nicotine delivery, they are likely to appeal to more smokers, making the switch from smoking to vaping easier. It may be important in this context to note that if the smoking-associated risk is removed, nicotine use by itself, outside pregnancy, carries little health risk and in fact conveys some benefits.

Table 8: Studies examining nicotine intake in vapers

Study	Participants	EC Device	Methods	Results
Vansickel et al 2012 [119]	20 smokers naïve to EC	Vapor King (cigalike), 18mg/ml nicotine	Overnight abstinence, baseline blood sample, after 5 mins 10 puffs, 30 sec inter-puff interval, 5 mins after last puff blood sample. Repeated 5x, 30 mins in between	At end of last puffing bout plasma nicotine increased from 2.2 ng/ml at baseline to 7.4 ng/ml.
Vansickel & Eissenberg 2012 [121]	8 vapers using EC for average of 12 months	Own EC 1 used 9 mg/ml 6 used 18 mg/ml 1 used 24 mg/ml	Overnight abstinence, Baseline blood, after 5 mins 10 EC puffs at 30 sec intervals, 5 and 15 mins after first puff blood sample, 60 min ad-lib vaping	Increase in plasma nicotine from 2.0 ng/ml to 10.3 ng/ml in 5 mins. Cmax = 16.3 ng/ml at end of ad lib period
Yan & D'Ruiz 2014 [129]	23 smokers	4 types of Blu (cigalike) EC (1.6% to 2.4%) Marlboro cigarette	Randomised 6 sessions 7-days get used to EC, 36 h abstinence. EC = 50x5 sec puffs, 30 sec	During controlled puffing Cmax (ng/ml): EC 10.3 to 18.9; cig 15.8

Study	Participants	EC Device	Methods	Results
		(cig)	intervals. Cig ad lib puff duration at 30 sec intervals. Then ad lib use for 60 mins. Blood: 10 mins pre, 5, 10, 15, 20, 25, 30, 45, 60, 75, 90 mins post start of controlled puffing.	Tmax: 30mins for EC and 5 mins for cig During ad lib use -Cmax (ng/ml): EC 13.7 to 22.42; cig 29.3
Vansickel et al 2010 [118]	32 smokers)	Own brand cig NJOY EC (18mg) Crown 7 EC (16mg) Sham (unlit cig) EC were cigalike	Randomised crossover, overnight abstinence. Baseline blood, EC – 10 puffs at 30 sec intervals, blood at 5, 15, 30, 45, 60 mins	Only cig produced significant rise in nicotine (18.8 ng/ml at 5 mins)
Van Staden et al 2013 [113]	13 smokers	Twisp eGo (18mg/ml nicotine)	Provided with EC and asked to use this and stop smoking for two weeks	Cotinine ng/ml Baseline: 287, at 2 weeks 97 (p=0.0011)
Spindle et al 2015 [120]	13 vapers > 3 months, e-liquid ≥12mg/ml	Own EC (all tank systems) 1 x 12 mg/ml 3 x 18 mg/ml 9 x 24 mg/ml	Overnight abstinence, two sessions. Baseline blood, EC – 10 puffs at 30 sec interval. Blood at 5 and 15 min.	Plasma nicotine at Baseline: 2.4 ng/ml 5 mins: 19.2 ng/ml 10 mins: 10.2 ng/ml
Bullen et al 2010 [117]	8 smokers	Ruyan V8 (cigalike) 16mg/ml (puff for 5 mins) Inhalator 10mg (puff for 20 mins) Own brand cig (puff for 5 mins)	Randomised crossover, overnight abstinence. Baseline blood, product use, blood at 5, 10, 15, 30, and 60 mins.	Cmax (ng/nl): EC=1.3; Inh=2.1; Cig=13.4 Tmax (mins): EC=19.6; Inh=32.0; Cig=14.3
Flouris et al 2013 [130]	15 smokers	Giant (cigalike) 11mg/ml	Smoked 2 cigs, puffed EC to match smoking. Cotinine immediately and 1 h after puffing	No difference between products
Capon-netto et al 2013 [40]	Sample size not stated	Categoria (cigalike) 7.2mg for 12 weeks 7.2mg/5.4mg for 12 weeks	RCT – 12 weeks of EC use	Salivary cotinine 6 weeks: 42 ng/ml; 12 weeks: 91 ng/ml 6 weeks: 68 ng/ml; 12 weeks: 70 ng/ml
Etter & Bullen 2011 [110]	30 vapers Mean EC use 94 days	Own brand EC Mean nicotine content 18mg/ml	Ad libitum use	Salivary cotinine 322 ng/ml
Dawkins & Corcoran 2014 [114]	14 vapers, 7 dual users,	Skycig (cigalike) 18mg/ml	10 puffs in 5 mins, then 1 hour ad lib	After 10 mins: 0.74 – 6.77 ng/ml After ad lib: 4.35-25.6 ng/ml

Study	Participants	EC Device	Methods	Results
	Used EC for 4.7 months			
Nides et al 2014 [116]	29 smokers, 55% used EC in past	NJOY®King Bold (cigalike) 26mg	EC ad lib 1 week, 12 h abstinence. 2x10 puffs (30 sec inter-puff interval) 60 mins apart Blood before and 5, 10, 15, 30 minutes after	N=16 had no baseline plasma nicotine Rise 5 min after first puffs: 3.5 ng/ml; after second puffs: 5.1 ng/ml
Norton et al 2014 [112]	16 smokers	Smoke 51 TRIO (cigalike) 11 mg/ml	Day 1: own brand, saliva sample Given EC and stopped smoking. Saliva at day 5. Analysis of 16 who abstained from smoking for 72 hours	Significant decrease in saliva cotinine between baseline (338.0 ng/ml) and day 5 (178.4 ng/ml), p<0.001
Hecht et al 2014 [111]	28 vapers (median 9 months), 96% daily users	Average nicotine 12.5 +/- 7.0 mg/ml All tank system EC	Measured toxicants, carcinogens, nicotine and cotinine in urine	Nicotine: 869 ng/ml Cotinine: 1880 Smokers normally Nicotine: 1380 ng/ml, cotinine: 3930 ng/ml
Hajek et al 2014 [115]	40 smokers,	Greensmoke (cigalike) EC (2.4% nicotine)	Overnight abstinence Baseline blood, first EC use ad-lib 5 mins, blood at 5, 10, 15, 20, 30 and 60 mins. Repeated after 4-weeks of ad lib use	***Baseline:*** Cmax: 4.6, Tmax: 5, AUC: 96 ***4-weeks:*** Cmax: 5.7, Tmax: 5, AUC: 142
Farsalinos et al 2014 [122]	N=23 vapers (19 months use)	A: V2 (cigalike) B: Tank system EVIC at 9 watts, EVOD Same 18mg/ml liquid	Abstained for 8 hrs Blood baseline and after 10 puffs over 5 mins, 1 h ad lib, blood every 15 mins	A:5 mins: 4.9 ng/ml 1h: 15.8 ng/ml B: 5 mins: 6.6 ng/ml 1h: 23.5 ng/ml
Oncken et al 2015 [123]	N=20 smokers given EC for 2 weeks	Menthol or non-menthol tank system with 18mg/ml liquid	Blood baseline, 5 min ad lib vaping, blood at 5,10,15,20,30 min	At 5 min nicotine increased by 4-5 ng/ml

Summary of findings

The accuracy of labelling of nicotine content currently raises no major concerns. Poorly labelled e-liquid and e-cartridges mostly contained less nicotine than declared. EC used as intended poses no risk of nicotine poisoning to users. However, e-liquids should be in ‘childproof’ packaging.

Duration and frequency of puffs and mechanical characteristics of EC play a major role in determining nicotine content in vapour. Across the middle range of nicotine levels, in machine tests using a standard puffing schedule, nicotine content of e-liquid is related to nicotine content in vapour only weakly. EC use releases negligible levels of nicotine into ambient air with no identified health risks to bystanders. Use of a cigalike EC can increase blood nicotine levels by around 5ng/ml within five minutes of use. This is comparable to delivery from oral NRT. Experienced EC users using the tank EC can achieve much higher blood nicotine levels over a longer duration, similar to those associated with smoking. The speed of nicotine absorption is generally slower than from cigarettes but faster than from NRT.

Policy implications

- General labelling of the strength of e-liquids, along the lines used for example indicating coffee strength, provides sufficient guidance to consumers.

- Regulatory interventions should ensure optimal product safety but make sure EC are not regulated more strictly than cigarettes and can continue to evolve and improve their competitiveness against cigarettes.

10. Safety of e-cigarettes in the light of new evidence

Introduction

PHE commissioned a review of EC in 2014, which covered EC safety [131]. The review found that the hazard associated with use of EC products currently on the market "is likely to be extremely low, and certainly much lower than smoking" and "the health risks of passive exposure to electronic cigarette vapour are likely to be extremely low".

These conclusions tally with a review by an international team of experts, which estimated the risks of vaping at less than 5% of the risks of smoking [10] and a comprehensive review of relevant literature by another international team which concluded that "EC aerosol can contain some of the toxicants present in tobacco smoke, but at levels which are much lower. Long-term health effects of EC use are unknown but compared with cigarettes, EC are likely to be much less, if at all, harmful to users or bystanders" [132].

Over the past few months, however, several reports have suggested that EC may pose more risks than previously thought [133-137].

We were asked to review these studies to see if in the light of this new evidence, the conclusions of the PHE 2014 review need to be adjusted. We present below the details of these studies together with any additional data that may assist with their interpretation.

Aldehydes in vapour from e-cigarettes

Two recent reports raised a possibility that under certain conditions, EC may release high levels of aldehydes. Aldehydes, including formaldehyde, acrolein and acetaldehyde, are released in tobacco smoke and contribute to its toxicity. Aldehydes are also released with thermal degradation of propylene glycol and glycerol in e-liquids. Previous studies detected the presence of aldehydes, especially formaldehyde, in the vapour from some EC, but at levels much lower than in cigarette smoke [138]. Across brands, EC released 1/50th of the level of formaldehyde released by cigarettes. The highest level detected was six times lower than the level in cigarette smoke [138].

In November 2014, following a press release from Japan [136], major media around the world reported variations of a headline: "E-cigarettes contain 10 times the carcinogens of regular tobacco". This was based on a Japanese researcher reporting at a press conference that during tests on a number of EC brands, one product was identified

which released 10 times more formaldehyde than cigarettes. The press release states that the formaldehyde was released when the e-liquid was over-heated. The study has not been published yet and so no further details are available, but the two experiments described below provide the explanation for this finding.

In January 2015, a similar report was published as a research letter to the *New England Journal of Medicine* (NEJM) [133]. In this study, negligible levels of formaldehyde were released at lower EC settings, but when a third generation EC (EC with variable power settings) was set to the maximum power and the apparatus was set to take puffs lasting 3–4 seconds, this generated levels of formaldehyde that, if inhaled in this way throughout the day, would exceed formaldehyde levels in cigarette smoke between five and 15 times.

The EC was puffed by the puffing machine at a higher power and longer puff duration than vapers normally use. It is therefore possible that the e-liquid was overheated to the extent that it was releasing novel thermal degradation chemicals. Such overheating can happen during vaping when the e-liquid level is low or the power too high for a given EC coil or puff duration. Vapers call this phenomenon ‘dry puff’ and it is instantly detected due to a distinctive harsh and acrid taste (it is detected by vapers, but not by puffing machines) [139]. This poses no danger to either experienced or novice vapers, because dry puffs are aversive and are avoided rather than inhaled.

A study has just been published testing the hypothesis that the NEJM report used dry puffs [140]. An equivalent EC product was set to the same or normal settings and used by seven vapers. The vapers found it usable at normal settings, but all received dry puffs and could not use the device at the settings used in the NEJM report [133]. The product was then machine tested. At the dry puff setting, formaldehyde was released at levels reported in the NEJM letter and the Japanese press release. At normal settings, there was no or negligible formaldehyde release.

We are aware of two studies that examined aldehyde levels in vapers. In a cross-sectional study, vapers had much lower levels of acrolein and crotonaldehyde in urine than smokers [111]. The other study, funded by the Medicines and Healthcare products Regulatory Agency (MHRA), examined changes in acrolein levels in smokers who switched to exclusive EC use and in those who continued to smoke while also using EC. As both EC and cigarettes release acrolein, there was a concern that ‘dual users’ may increase their acrolein intake compared to smoking only. The results showed a substantial decrease in acrolein intake in smokers who switched to EC, but it also found a significant decrease in acrolein intake in dual users (ie people that were both smoking and vaping). This was because they reduced their smoke intake as indexed by exhaled CO levels. Normal vaping generated negligible aldehyde levels [141].

Although e-liquid can be heated to a temperature which leads to a release of aldehydes, the resulting aerosol is aversive to vapers and so poses no health risk.

Summary

There is no indication that EC users are exposed to dangerous levels of aldehydes.

Effects of e-cigarette vapour on mice lungs

A paper published in February 2015 [135] generated worldwide media coverage with claims that it linked EC to lung inflammation, lung infection, and even lung cancer.

Groups of mice were put in a small container exposing them to vapour from six EC ('Menthol Bold' 1.8% nicotine) puffed on a rotating wheel at six puffs per minute for 1.5 hours, twice daily, over two weeks. The control mice were not exposed to this treatment.

Animals were infected with either streptococcus pneumonia via intranasal instillation and killed 24 hours later, or with tissue culture influenza virus and monitored for weight loss, mortality, and lung and airways inflammation. Compared to the control group, the experimental animals had an increase in pro-inflammatory cytokines, diminished lung glutathione levels, higher viral titre, and were more likely to lose weight and die. The study identified free radicals in EC vapour as the potential culprit.

There are several problems with the study and with the way its results have been interpreted.

EC vapour is inhaled as a replacement for tobacco smoke, but the study attempted no comparison of the effects on the lungs from smoke and vapour exposures. This makes a meaningful interpretation of the results difficult. A comparison was made, however, of the levels of free radicals. Even at the very high vapour density generated by the study procedure, the level of free radicals identified in vapour was "several orders of magnitude lower than in cigarette smoke".

In addition to this, the mice in the experimental group were exposed to a much higher level of stress than the control group, and stress affects bacterial and viral response. Long and repeated containment in the small and crowded smoke chamber emitting an overpowering smell is a stressor in itself, but the animals also suffered repeated nicotine poisoning. The mice showed an average cotinine concentration of 267ng/ml. Cotinine is the primary metabolite of nicotine and in humans the amount of nicotine needed to give similar cotinine levels are tolerated by heavy smokers, but highly aversive to non-smokers, who would be expected to feel sick and vomit at this level of exposure. Mice are much more sensitive to nicotine than humans (LD50 in mice is 3mg/kg, in humans

6.5–13mg/kg [69]). Accelerated weight loss, reduced immunity and early death in the experimental group were much more likely the result of protracted stress and nicotine poisoning than the result of exposure to free radicals (which were in any case 1,000 times lower than from cigarettes).

A similar study from 2015 [134] reported oxidant reactivity (which is linked to free radicals) of e-liquid and cytokine release in exposed lung tissue and in mice exposed to EC vapour. Again, no comparison with exposure to smoke was reported.

Human studies do not corroborate any of the findings reported here. A case study of lipoid pneumonia, which could have been caused by EC flavouring, received worldwide attention in 2012 [142] but despite extensive interest in the phenomenon, no further cases were published. Adverse effects of vaping are primarily local irritation and dry mouth [132]. A study that monitored asthma patients who switched from smoking to vaping found significant improvements in symptoms and in respiratory function [143]. The recent Cochrane Review found no significant adverse effects associated with EC use for up to 1.5 years [39].

Summary

The mice model has little relevance for estimating human risk and it does not raise any new safety concerns.

Particles in e-cigarette vapour

For completeness we are including information on another recent report which was interpreted as showing that EC may be dangerous to bystanders. At an EC Summit conference in London in November 2014, Harrison and McFiggans reported on particles present in EC vapour. Their presentation was reported in the British Medical Journal under the title “E-cigarette vapour could damage health of non-smokers” [137]. McFiggans and Harrison requested a retraction of the piece because their findings did not concern any health risks. It is the content of the particles rather than their presence or size which has health implications [144].

Impact of media reports that e-cigarettes are dangerous

Together with previous health scares, the articles reviewed here may be having a significant impact on public perception of EC safety. In the US, 82% of responders believed that vaping is safer than smoking in 2010, but the figure has shrunk to 51% in 2014 [65]. A perception that EC pose as much risk as smoking is the most likely explanation of the recent decline in adoption of EC by smokers [145].

Summary of findings

Two recent worldwide media headlines asserted that EC use is dangerous. These were based on misinterpreted research findings. A high level of formaldehyde was found when e-liquid was over-heated to levels unpalatable to EC users, but there is no indication that EC users are exposed to dangerous levels of aldehydes; stressed mice poisoned with very high levels of nicotine twice daily for two weeks were more likely to lose weight and die when exposed to bacteria and viruses, but this has no relevance for human EC users. The ongoing negative media campaigns are a plausible explanation for the change in the perception of EC safety (see Chapter 8).

None of the studies reviewed above alter the conclusion of Professor Britton's 2014 review for PHE. While vaping may not be 100% safe, most of the chemicals causing smoking-related disease are absent and the chemicals that are present pose limited danger. It had previously been estimated that EC are around 95% safer than smoking [10, 146]. This appears to remain a reasonable estimate.

Policy implications

- There is a need to publicise the current best estimate that using EC is around 95% safer than smoking.

- Encouraging smokers who cannot or do not want to stop smoking to switch to EC could be adopted as one of the key strategies to reduce smoking related disease and death.

11. Other health and safety concerns

There have been a number of newspaper reports about the hazards of EC use including e-liquid ingestion/poisonings, fires, battery explosions etc [147-149]. In this chapter we review available national data on these issues to endeavour to quantify the risk.

Poison reports

Data on e-liquid exposures in the UK are available from the National Poisons Information Service (NPIS)[150]. The NPIS provides information about poisoning to NHS staff and publishes data based on enquiries made by phone, using their online database TOXBASE, and by consultant referrals. The NPIS report for 2013/14 [150] details 204 enquiries related to the liquid content of EC and their refills, most of which reported accidental exposure, however 21 enquiries were related to intentional overdoses using e-liquids. Most incidences concerned ingestion of the liquid in EC or their refills (n=182) although small numbers of inhalation (n=17), eye contact (n=13) and skin contact (n=12) enquiries were also reported. The NPIS further reported that the number of enquiries about e-liquids has increased since 2007 (Figure 20) broadly reflecting the increasing popularity of EC.

A large proportion of exposures to e-liquids were in children under five years old (Figure 21), a finding that is replicated in a US study on calls to poison centres [151]. However, the concentration of events concerning children is not unique to e-liquids. Children under five years old appear to be more vulnerable than adults to accidental poisoning in general (Figure 22).

Figure 20: Number of telephone enquiries to National Poisons Information Service (NPIS) about e-cigarettes over time

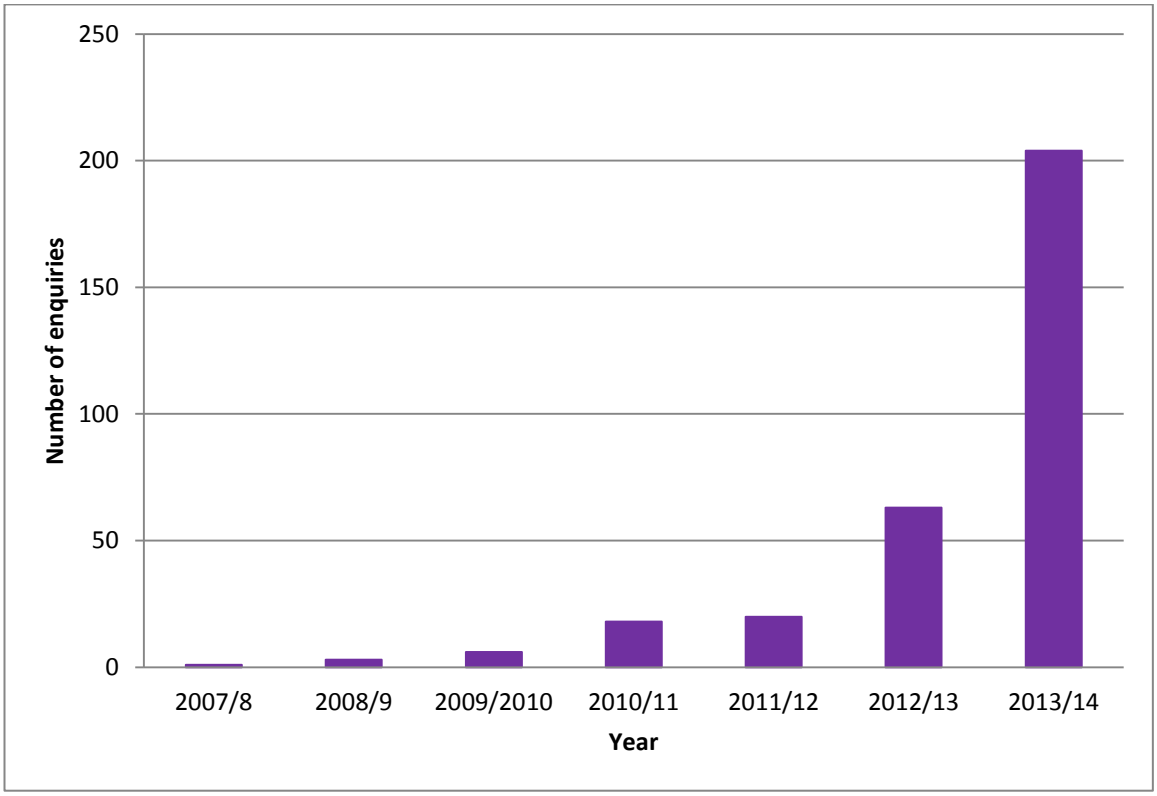


Figure 21: Number of enquiries about e-cigarettes to NPIS by age

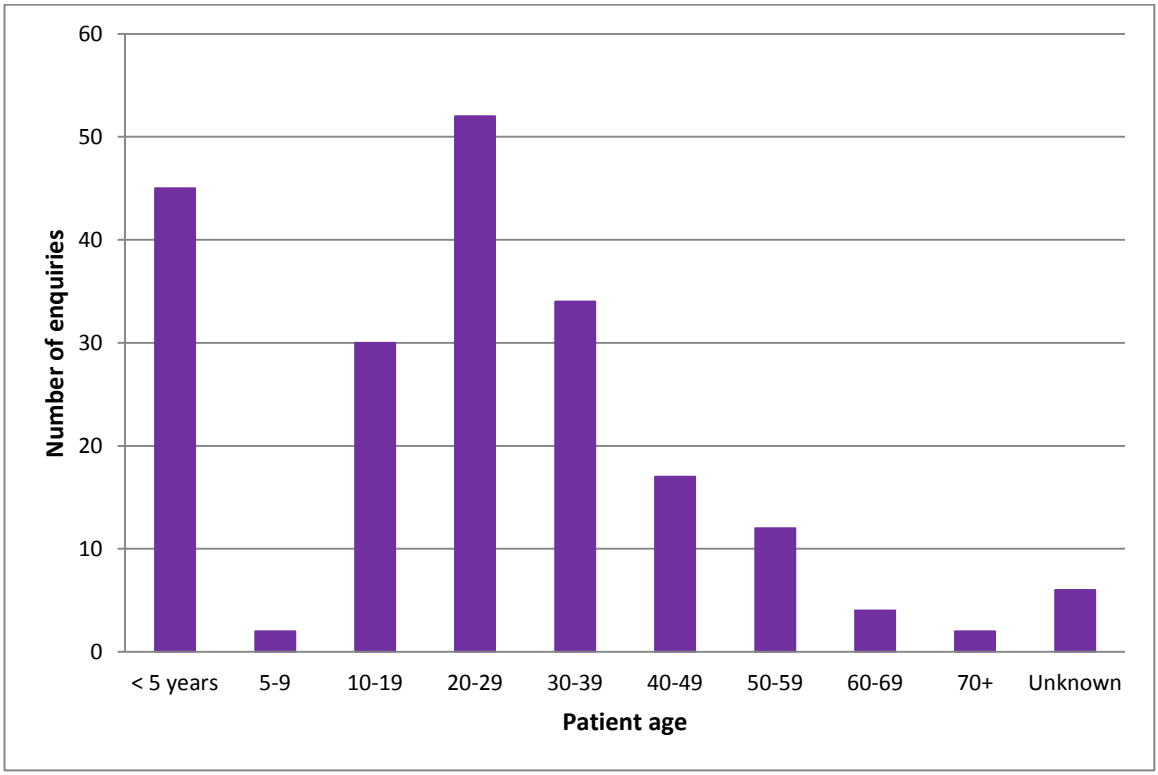
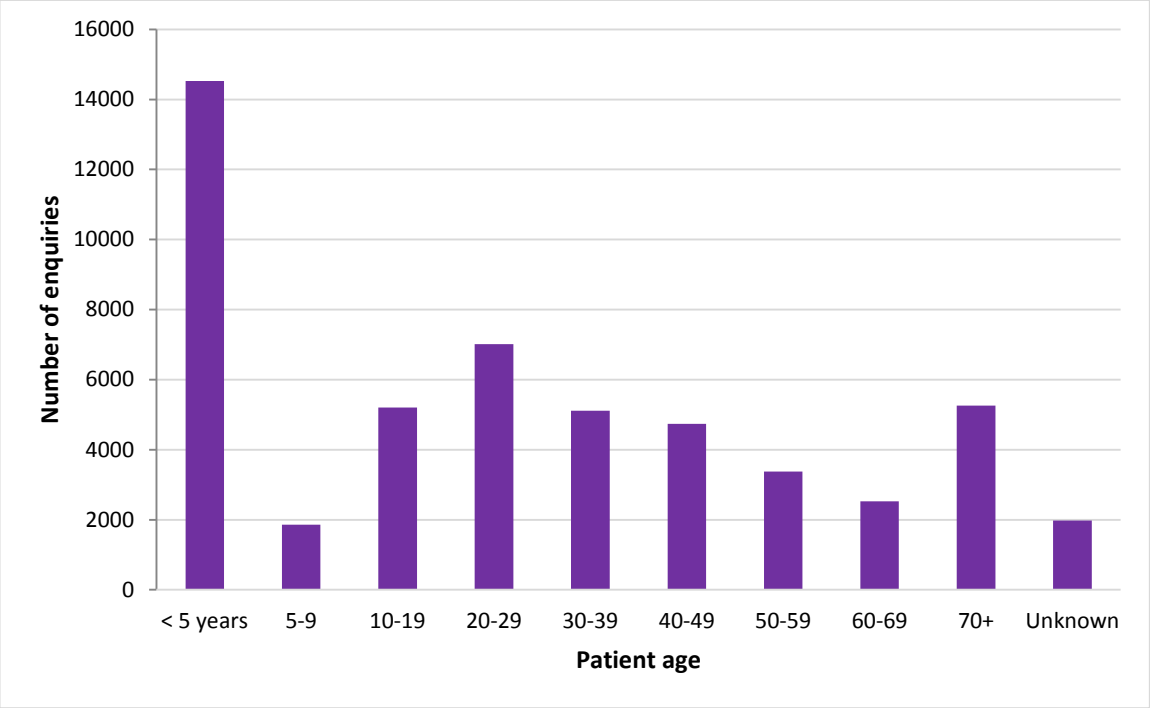


Figure 22: Age of poisoned patients overall reported in telephone enquiries to NPIS 2013/4



Exposures to poisonous liquid among children are of concern; however they should be taken in context. The same report from the NPIS recorded 208 exposures to liquid in reed diffusers, 1,168 exposures to pesticides and more than 600 to paracetamol. E-liquids seem to contribute towards domestic poisoning incidents but regulations, such as child safety caps, could limit this risk.

The clinical outcomes of exposures to e-liquids, as detailed in the NPIS report, were predominantly either ‘no toxicity’ or ‘mild toxicity’. There were two reported cases of ‘moderate toxicity’ and one ‘severe’ case that required treatment in an intensive care unit. Toxicity symptoms included conjunctivitis, irritation of the oral cavity, anxiety, vomiting, hyperventilation and changes in heart rate.

Fire

A number of news articles report the risk of fire and explosions from EC [147, 149, 152]. These reports suggest that faulty or incompatible chargers are the main causes of EC related fires along with faults relating to lithium batteries [152]. In order to assess the risks of fire we used the two data sources below:

1) In 2014, the BBC made Freedom of Information requests to UK fire services [153] and reported that there were 43 recorded call outs for fires related to EC in 2013 and 62 between 1 January 2014 and 15 November 2014. They added that call outs to EC related fires were rising in frequency. This report was based on responses from 43 out of 46 fire services in the UK [153, 154]

2) The official reporting statistics for the UK [155] do not specifically report EC as a cause of fire. There were 2,360 accidental fires between April 2013 and March 2014 where the source of ignition was “smokers’ materials” causing 80 fatalities and 673 non-fatal casualties. Additionally, there were 3,700 fires from faulty appliances and electrical leads causing 19 fatalities and 820 non-fatal casualties. It is not clear what proportion of these were caused by EC.

Regulations covering chargers and quality standards of production could help reduce the risk of fire and explosion in EC. An unpublished Department for Business, Innovation and Skills (BIS) funded market surveillance exercise in 2013/14 found that six out of 17 EC had no instructions for charging, and that eight out of 17 EC did not have a charging cut-off device and therefore did not meet the requirements of BS EN 62133:2013 'Safety requirements for portable sealed secondary cells and batteries for use in portable devices'[4]. It seems likely that the risk of fire and electrical fault is similar to other domestic electrical products, indicating that EC should be subject to the same guidelines and safety mechanisms.

Summary of findings

There is a risk of fire from the electrical elements of EC and a risk of poisoning from ingestion of e-liquids. These risks appear to be comparable to similar electrical goods and potentially poisonous household substances.

Policy implications

- The risks from fire or poisoning could be controlled through standard regulations for similar types of products, such as childproof containers (contained within the TPD but which are now emerging as an industry standard) and instructions about the importance of using the correct charger.
- Current products should comply with current British Standard operating standards.
- Records of EC incidents could be systematically recorded by fire services.

[4] BIS Funded Market Surveillance Exercise 2013/14. The Electrical Safety of Electronic Cigarettes and the Labelling of E-liquids. Lancashire County Council. Unpublished report.

12. International perspectives

Overview

Internationally, countries have taken a wide variety of approaches to regulating EC [156]. Current approaches range from complete bans on the sale of any EC, to applying existing laws on other products to EC (poison, nicotine, and/or tobacco laws), to allowing EC to be sold under general consumer product regulations. Similarly, within countries, different laws have also been applied at the state/provincial level, along with municipal by-laws, extending into areas including taxes on EC, and bans on use in places where smoking is banned. Furthermore, several nuances in laws exist, making it difficult to make broad statements about the regulations in a given country. This section focuses on presenting (1) studies that have compared the use of EC internationally across countries using representative samples and comparable methods, (2) a brief review of adolescent surveys internationally, and (3) the cases of Australia and Canada, two countries that have very similar tobacco control policies to the UK but very different policies relating to EC.

Use of e-cigarettes among adults internationally

Three studies have compared the use of EC internationally: (1) International Tobacco Control Project (described in the Methodology section), (2) Eurobarometer study and (3) Global Adult Tobacco Survey.

The International Tobacco Control Project compared EC use (use defined as less than monthly or more often) among smokers and ex-smokers across 10 countries [157]. Gravely et al., 2014 found significant variability in use across countries, but data were gathered across different years. Gravely et al., 2014 concluded that the study provided evidence of the rapid progression of EC use globally, and that variability was due partly to the year the survey was conducted, but also market factors, including different regulations on EC. Notably, EC use was highest in Malaysia at 14%, where a ban on EC was in place.

Two studies using secondary data from the 2012 Eurobarometer 385 survey have examined EC use. Vardavas, et al., 2014 [158] examined ever use (tried once or twice) of EC among smokers, ex-smokers and never smokers aged 15 years and over across 27 EU countries. The study found wide variation in ever EC use among smokers and non-smokers, with ever use varying from 20.3% among smokers, 4.4% among ex-smokers, and 1.1% among never smokers. Of those who had tried, 69.9% reported using EC once or twice, and 21.1% and 9% reported ever using or currently using occasionally or regularly (use or used regularly or occasionally). It is important to note that the question asked about ever using or currently using occasionally or regularly,

and thus would overestimate actual current use. Overall, being a smoker was the strongest predictor of ever using an EC, younger age was also predictive. Respondents who were uncertain about the harmfulness of EC were less likely to have tried an EC. Among current smokers, those who had a made a quit attempt in the past year were most likely to have ever used EC, along with heavier smokers. With regards to use as a smoking cessation aid, 7.1% of smokers who had ever made a quit attempt reported having used EC, compared to 65.7% who used no help, 22.5% who used nicotine replacement therapy, and 7.3% who received behavioural counselling. Geographical differences in EC use noted by the authors included higher ever use in Northern and Eastern Europe compared to Western Europe. The study did not go into detail on occasional or regular users of EC because the numbers were too low for any detailed analyses.

A 2012 study using the same Eurobarometer 385 survey data gave further detail on ever having used or currently using EC occasionally or regularly among smokers and non-smokers [63]. The study found that regular/occasional use was highest in Denmark at 4.2% and lowest in Lithuania and Portugal at 0.6%, and 2.5% in the UK [63].

The Global Adult Tobacco Survey [159] published findings on EC use in Indonesia (2011), Malaysia (2011), Qatar (2013) and Greece (2013) among smokers and non-smokers, the first countries with available data. Of those respondents who were aware of EC, they asked, “Do you currently use e-cigarettes on a daily basis, less than daily, or not at all?” and considered those who said they used ‘less than daily’ or ‘daily’ to be current EC users.

Overall, awareness of EC was highest in Greece (88.5%), followed by Qatar (49%), Malaysia (21%), and Indonesia (10.9%). Use of EC among smokers was highest in Malaysia (10.4%), followed by Qatar (7.6%), Indonesia (4.2%) and Greece (3.4%). Use of EC among non-smokers was highest in Greece (1.3%), followed by the other three countries, Malaysia (0.4%), Indonesia (0.4%) and Qatar (0.4%). Similar to findings from the ITC Project, these numbers are likely influenced by timing of the survey, due to the rapid progression of use of EC globally, and other market factors. Together with the findings from Gravely et al., 2014 [157] they show the rapid global progression of EC use across both high income and lower middle income countries.

Use of e-cigarettes among youth internationally

Whilst there are very few international or European studies which use consistent methodology, there is a rapidly growing body of research on the prevalence of EC use in young people at the country level, as well as reviews in this area [eg [160]]. However, much of this literature on EC use among adolescents is incomparable because of inconsistent measurements of use (confusing ever use, trial, current use), and different age ranges involved. In addition, many of the studies have been poorly reported. For

example, much has been made of the increase in EC observed in the US using the cross-sectional Centers for Disease Control & Prevention (CDC) National Youth Tobacco Surveys [161-163].These reports and press coverage have been heavily criticised [164-166]. The most important feature of the NYTS data was the fall in smoking prevalence over the same period (as observed in the UK, France [167] and elsewhere).

The CDC findings indicated that past 30-day use of EC increased among middle and high school students. For example, the 2014 data indicated that among high school students use increased from 4.5% to 13.4% between 2013 and 2014. Among middle school students, current EC use increased from 1.1% in 2013 to 3.9% in 2014. However, cigarette smoking had continued to decline during this period (high school students: 15.8% to 9.2%; middle school students: 4.7 % to 2.5%) such that smoking was at a 22-year low in the US. These findings strongly suggest that EC use is not encouraging uptake of cigarette smoking.

Whilst most of the recent studies examining youth EC use emanated from North America, the common pattern emerging worldwide is of a very high awareness of EC and an increase in trial of these products among young people [168-178]. Nevertheless, estimates of prevalence of current use of EC vary widely with the highest being reported in Poland at around 30% [174] and Hawaii (29% tried, 18% current) [178]. Most other estimates indicate that a very small minority of youth, less than 3%, currently or recently used EC. Whilst EC experimentation is increasing, regular or current use of EC appears to be largely concentrated in those already smoking conventional cigarettes. The most recent Europe-wide data indicated that 1.1% of never-smokers aged 15 and above had ever tried an EC [158]. Yet little research has focused on how EC are being used among young people, with limited qualitative research studies in this area [179, 180]. Other findings relate to the influence of parents who smoke on EC experimentation in youth [eg [170] and associations between EC experimentation and other substance use [eg [170, 181]. Several studies have also found an association between EC use and openness to cigarette smoking [eg [182] or intentions to smoke cigarettes [eg [168].

The cases of Australia and Canada

Australia has applied existing laws on poisons, therapeutic goods, and tobacco products to EC. Very broadly speaking, the current laws in Australia have resulted in a ban on the sale and importation of EC with nicotine (although there is a mechanism for legal import as an unapproved medicine with a doctor’s prescription). There are no national level prevalence data on EC use in Australia available at this time. One study comparing trends in awareness, trial, and use of EC among nationally representative samples of smokers and ex-smokers (use defined as less than monthly or more often) in Australia and the UK in 2010 and 2013 found reported EC use in Australia in 2013 at 6.6% and use in the UK at 18.8% [183]. Although the use of EC was found to be

significantly lower in Australia than in the UK in 2013, the use of EC increased at the same rate in Australia and the UK between 2010 and 2013 [183].

Canada took a similar approach to regulating EC as Australia by prohibiting the sale of EC with nicotine through existing laws. However, a recent House of Commons report stated that the current regulatory approach was not working to restrict access to EC with nicotine [184]. Canada has now put forward recommendations to develop a new legislative framework for EC that would most likely allow the sale of EC with nicotine [184]. There has been only one population-level survey of EC use in Canada. The 2013 Canadian Tobacco, Alcohol and Drugs Survey (CTADS) of Canadians 15 years and older found that 9% had ever tried an EC, with trial being higher among young people aged 15–19 years at 20% [185]. Use in the past 30 days was lower at 2%, with past 30 day use being higher among young people aged 15–19 years at 3%. Of those who tried an EC, 55% stated the EC did not contain nicotine, while 26% reported it did contain nicotine, with 19% reporting uncertainty. Whether the EC they tried contained nicotine is uncertain given (1) the ban on the sale of EC with nicotine, and (2) reports that many EC sold and bought in Canada are labelled as not containing nicotine but actually contain nicotine [184]. Although it is difficult to make comparisons due to different survey methods and questions, the percentage of young people (15–19 years) who have tried EC in Canada (20%) is roughly similar to the percentage who have tried EC in GB in 2014 (reported at 8%, 15%, 18%, and 19%, for ages 15 to 18, respectively).

Summary of findings

Although EC use may be lower in countries with more restrictions, these restrictions have not prevented EC use. Overall, use is highest among current smokers, with low numbers of non-smokers reporting ever use. Current use of EC in other countries is associated with being a smoker or ex-smoker, similar to the findings in the UK. EC use is frequently misreported, with experimentation presented as regular use. Increases in youth EC trial and use are associated with decreases in smoking prevalence in all countries, with the exception of one study from Poland.

Policy implications

- Future research should continue to monitor and evaluate whether different EC policies across countries are related to EC use and to smoking cessation and smoking prevalence.

- Consistent and agreed measures of trial, occasional and regular EC use among youth and adults are urgently needed to aid comparability.

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Declaration of interests

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Professor Peter Hajek is director of Health and Lifestyle Research Unit at Wolfson Institute of Preventive Medicine, Queen Mary University of London (QMUL). He provided consultancy to and received research funding from manufacturers of stop-smoking medications including Pfizer, GSK and Johnston and Johnston. His research into safety and effects of e-cigarettes was funded by MHRA and NIHR. He has no links with any tobacco or e-cigarette manufacturers.

Dr Hayden McRobbie is a researcher at QMUL and Director of the Dragon Institute for Innovation (New Zealand), which has no links with any tobacco or e-cigarette manufacturers. He contributed to educational sessions sponsored by Pfizer and Johnson & Johnson, manufacturers of stop-smoking medications, and received investigator-led research funding from Pfizer. He was an investigator on a study of e-cigarettes (EC) produced by Ruyan Group, Beijing and Hong Kong. Ruyan sponsored Health New Zealand Ltd. who provided funding to the University of Auckland to conduct the trial, independently of Ruyan. He was also an investigator on an EC trial funded by the Health Research Council of New Zealand that used EC supplied at no charge by PGM international, a retailer of EC.

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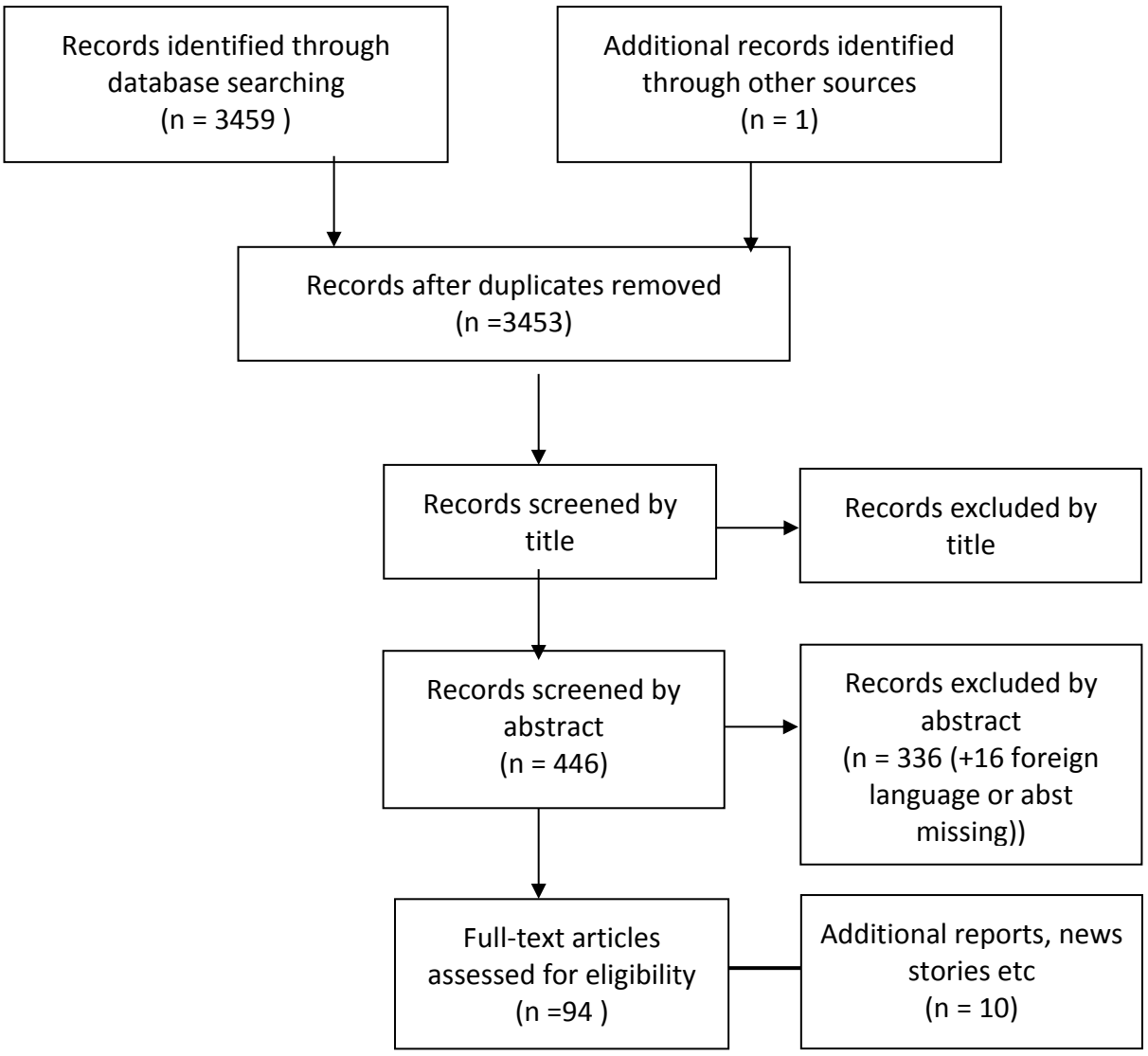
Appendices

APPENDIX A: PRISM Flow Diagram[5]



[5] Please note that we did not carry out a full systematic review for this report but followed systematic review methods. We assessed 94 papers and 9 additional reports included those that were relevant to our objective of describing the **use** of e-cigarettes and how they **impact smoking behaviour,** with a particular focus on the UK.

APPENDIX B: Measures of e-cigarette use

Measures of EC use in studies referenced, in most cases respondents were only asked about EC use if they first answered yes to ever trying an EC/had heard of EC.

Surveys

These questions in all surveys below may have been slightly altered from year to year as the EC market evolved and awareness grew.

Smoking Toolkit Study (STS)

The following four questions are used to assess current use of e-cigarettes: (if already responded they are cutting down)

Q632e37. Which, if any, of the following are you currently using to help you cut down the amount you smoke?
Nicotine gum
Nicotine replacement lozenges\tablets
Nicotine replacement inhaler
Nicotine replacement nasal spray
Nicotine patch
Electronic cigarette
Nicotine mouthspray
Other (specify)

Q632e1. Do you regularly use any of the following in situations when you are not allowed to smoke?
Nicotine gum
Nicotine lozenge
Nicotine patch
Nicotine inhaler\inhalator
Another nicotine product
Electronic cigarette
Nicotine mouthspray
Other (specify)

NEWW53a. Can I check, are you using any of the following either to help you stop smoking, to help you cut down or for any other reason at all?

Nicotine gum
Nicotine lozenge

Nicotine patch
Nicotine inhaler\inhalator
Another nicotine product
Electronic cigarette
Nicotine mouthspray
Other (specify)

QIMW86_1. Can I check, are you using any of the following?
PROBE FULLY: Which others? PROBE UNTIL RESPONDENT SAYS 'NO OTHERS'
PLEASE TYPE IN OTHER ANSWERS CAREFULLY AND USE CAPITAL LETTERS
Nicotine gum
Nicotine lozenge
Nicotine patch
Nicotine inhaler\inhalator
Another nicotine product
Electronic cigarette
Nicotine mouthspray
Other (specify)

ASH Smokefree GB adult survey

Which of the following statements BEST applies to you?

- I have heard of e-cigarettes and have never tried them
- I have heard of e-cigarettes but have never tried them
- I have tried e-cigarettes but do not use them (anymore)
- I have tried e-cigarettes and still use them
- Don't know

The fourth option constitutes 'current use'

ASH Smokefree GB youth survey

An e-cigarette is a tube that looks like a normal cigarette, has a glowing tip and puffs a vaour that looks like smoke but unlike normal cigarettes, they don't burn tobacco.
Have you ever heard of e-cigarettes?

- Yes, I have
- No, I haven't

All those who have heard of e-cigarettes: Which one of the following is closest to describing your experience of e-cigarettes?

- I have never used them
- I have tried them once or twice
- I use them sometimes (more than once a month)

- I use them often (more than once a week)
- Don't want to say

Internet cohort survey

Have you ever heard of electronic cigarettes or e-cigarettes? These are electronic devices that contain nicotine in a vapour and are designed to look like cigarettes, but contain no tobacco.
Yes/No/Don't know

If Yes, Have you ever tried an electronic cigarettes?
Yes/No/Don't know

If Yes, How often if at all, do you currently use an electronic cigarette? (PLEASE SELECT ONE OPTION)

1. Daily
2. Less than daily, but at least once a week
3. Less than weekly, but at least once a month
4. Less than monthly
5. Not at all
6. Don't know

Other studies

Amrock et al., 2015 (US)

Which of the following tobacco products have you ever tried, even just one time?" to which they could select, "electronic cigarettes or e-cigarettes, such as Ruyan or NJOY" alongside other tobacco products. A related question asked if students used e-cigarettes on at least one of the past 30 days.

Biener & Hargraves, 2014 (US)

At baseline, three questions were asked about e-cigarettes: whether the respondent had "ever heard of electronic cigarettes, also known as e-cigarettes"; if so, whether he/she had ever used an e-cigarette even one time, and if so, on how many of the past 30 days the respondent had used an e-cigarette. To assess how intensively and for how long the respondent had used e-cigarettes during the period between interviews, the follow-up interviews included questions to describe e-cigarette usage. Those who were not aware of e-cigarettes at baseline were asked if they had heard of them at follow-up. Those who had not tried e-cigarettes at baseline were asked if they had done so by follow-up. All respondents who reported ever trying them by follow-up were asked

whether they currently used e-cigarettes every day, some days or not at all. If not at all, they were asked if they ever used e-cigarettes “fairly regularly.” If not, whether they had used only once or twice or more often than that. All who had used more than once or twice, were asked a series of questions about their patterns of use: for how long they had used e-cigarettes (less than a month, 1–6 months, more than 6 months); whether they had ever used e-cigarettes daily for at least one week; if so for how long they had used e-cigarettes daily. From these variables, a 3-level measure of intensity of e-cigarette usage was computed: 3 = intensive (used daily for at least 1 month); 2 = intermittent (more than once or twice but not daily for a month or more); 1 = non-use or at most once or twice.

Borderud et al., 2014 (US)

Patients were asked if they had used E-cigarettes within the past 30 days, with the response options being yes or no.

Brose et al, 2015 and Hitchman et al., 2015 (GB)

How often, if at all, do you currently use an electronic cigarette? [Asked of respondents who had ever heard of e-cigarettes and had ever tried one.]

1. Daily
2. Less than daily, but at least once a week
3. Less than weekly, but at least once a month
4. Less than monthly
5. Not at all
6. Don't know

What electronic cigarette equipment do you currently use the most?

1. A disposable electronic cigarette (non-rechargeable)
2. A commercial electronic cigarette kit which is refillable with pre-filled cartridges
3. A commercial electronic cigarette kit which is refillable with liquids
4. A modular system (I use my own combination of separate devices: batteries, atomizers, etc.)
5. Don’t know

Brown et al., 2014 (England)

Which, if any, of the following did you try to help you stop smoking during the most recent serious quit attempt?

1. E-cigarettes
2. NRT bought over-the-counter
3. No aid

Canadian Tobacco, Alcohol and Drugs Survey 2013 (CTADS)

Trial

Have you ever tried an electronic cigarette, also known as an e-cigarette?

1. Yes
2. No
3. Refused
4. Don't know

Last 30 day use

In the past 30 days did you use an electronic cigarette, also known as an e-cigarette?

1. Yes
2. No
3. Refused
4. Don't know

CDC/NYTS and Dutra and Glantz

During the past 30 days, on how many days did you use electronic cigarettes or e-cigarettes such as Blu, 21st Century Smoke, or NJOY?

Gravely et al., 2014 (Republic of Korea, US, UK, Canada, Australia, and Malaysia); Yong et al., 2014 (UK and Australia)

How often, if at all, do you currently use an electronic cigarette? (dichotomised into current use and non-current by combining any use responses vs. not at all)

1. Daily, Less than daily but at least once a week
2. Less than weekly but at least once a month
3. Less than monthly
4. Not at all

Gravely et al., 2014 (Netherlands)

How often do you currently use an electronic cigarette? (dichotomised into current use and non-current by combining any use responses vs. have you stopped altogether)

1. Daily
2. Less than daily, but at least once a week
3. Less than weekly, but at least once a month
4. Less than monthly versus, or
5. Have you stopped altogether?

Gravely et al., 2014 (China)

Are you currently using an electronic cigarette at least weekly? (Yes vs. No)

1. Yes
2. No

Hughes et al., 2014 (Trading Standards NW Study)

"Have you ever bought or tried electronic cigarettes?"

Hummel et al., 2014 (Netherlands)

Respondents who had ever tried e-cigarettes were asked how often they currently used an e-cigarette (daily, at least once a week, at least once a month, less than monthly, or stopped altogether

Lee et al., 2014 (US)

E-cigarette use questions were:

Have you ever used e-cigarettes?

1. yes
2. no

Have you used e-cigarettes in the past 30 days?

1. yes
2. no

Moore et al., 2014 (Welsh study 10-11 year olds)

"Have you heard of e-cigarettes before this survey?"
'Have you ever used an e-cigarette? with response options of 'no', 'yes, once' or' yes, more than once'

Moore et al., 2015 (Welsh study HBSC)

Asked whether they had ever used an e-cigarette with response options of:

- I have never used or tried e-cigarettes
- I have used e-cigarettes on a few occasions (1-5 times);
- I regularly use e-cigarettes (at least once a month)'.

Palipudi et al., 2015 (Global Adult Tobacco Survey)

“Do you currently use e-cigarettes on a
1. Daily basis,
2. Less than daily,
3. Or, not at all?”

Pearson et al., 2014 (US)

Participants were asked which methods they had used to quit in the past 3 months and were presented a list of common quit methods. Participants were considered e-cigarette users if they selected “e-cigarettes” in response to this question or if they entered terms like “vapors,” “vaping,” “vape,” or “ecigs” in the “other quit methods” open-ended response option.

Pepper et al., 2014 (US)

Have you ever used an e-cigarette, even one puff?
Do you now use e-cigarettes every day, some days, or not at all?

Richardson et al., 2014 (US)

Please indicate whether you have ever heard of these products, if you have ever tried them and if you have ever purchased them. Products included ENDS; dissolvables; chew, dip, or snuff (assessed in 1 question); and snus, each presented with brand names to increase validity of responses. Respondents could choose multiple options from the following choices: (1) heard of; (2) tried; (3) purchased; (4) never heard of, tried, or purchased (for those to whom options 1, 2, and 3 were not applicable); (5) refused; and (6) don’t know.

Rutten et al., 2014 (US)

Do you now use e-cigarettes (eg BluCig, NJoy, V2, Red Dragon, etc)? [Picture of three different e-cigarettes included]
1. Every day
2. Some days
3. Not at all

Schmidt et al., 2014 (US)

Have you ever used an electronic cigarette, even just one time in your entire life?
Do you now use electronic cigarettes every day, some days, rarely, or not at all?

Vardavas et al., 2014 (Eurobarometer 27 countries), dichotomised into regularly, occasionally, tried once or twice vs. otherwise; Agaku et al., 2014 (Eurobarometer, 25 countries), dichotomised into regularly or occasionally vs. otherwise;

Have you ever tried any of the following products? (Electronic cigarettes)

1. Yes, you use or used it regularly.
2. Yes, you use or used it occasionally.
3. Yes, you tried it once or twice.
4. No.
5. Don’t Know.

White et al., 2015, New Zealand national youth tobacco use survey in 2012 and 2014

Ever use: Have you ever tried electronic cigarettes?

Appendix C: Narrative summary of studies on nicotine delivery from e-cigarettes

Early studies

Two studies, both published in 2010, examined nicotine delivery from cigalike EC.

Bullen et al., 2010 used a cross-over design to compare nicotine delivery of a 16mg/ml Ruyan V8 EC with a 0mg/ml EC, a nicotine inhalator (10mg) and a conventional cigarette among 8 smokers who abstained from smoking overnight [43]. Participants puffed on their cigarettes and EC ad libitum over 5 minutes, and on the inhalator over 20 minutes. The nicotine containing EC had similar pharmacokinetic parameters to the inhalator (Cmax: 1.3 vs. 2.1 ng/ml; Tmax: 19.6 vs. 32.0 mins), and both were out-performed by a conventional cigarette (Cmax 13.4 ng/ml; Tmax 14.3 mins).

Vansickel et al., 2010 also used a cross-over design and tested nicotine delivery of two EC (NJOY EC (18mg) and Crown 7 EC (16mg) and participants own brand cigarette[118]. Participants abstained overnight and then took 10 puffs on the EC with a 30 sec inter-puff interval. Only the conventional cigarette produced a significant rise in plasma nicotine, from baseline 2.1 ng/ml (SD 0.32) to a peak at 5 minutes 18.8 ng/ml (SD 11.8).

The poor nicotine delivery of these EC was likely to be due to several factors. The EC tested were some of the first to market. The EC used in the Bullen 2010 study were noted to leak and the vaporising component did not always function. Both of these early studies recruited EC naïve smokers, without opportunity to practice using the EC prior to experimentation.

There are other factors that are associated with nicotine delivery, which we have summarised below.

1) More intensive vaping regimens
Vansickel et al., examined nicotine delivery associated with the use of Vapor King (cigalike EC with 18mg/ml nicotine) in 20 smokers naïve to EC [119]. After overnight abstinence, participants used the EC for 5 minutes on a total of six occasions (10 puffs, 30 sec inter-puff interval) 30 minutes apart. A significant increase in plasma nicotine was observed after the fourth bout of puffing, and mean blood nicotine levels had increased from 2.2 ng/ml (SD 0.78) at baseline to 7.4 ng/ml (SD 5.1) at the end of the last bout of puffing.

2) Experience with EC
Vansickel & Eissenberg (2012) report nicotine pharmacokinetics in eight vapers who had been using EC for average of 11.5 (SD 5.2) months [7]. They used their own EC and e-liquid (the majority used an e-liquid with a concentration of 18 mg/ml).

Participants attended the laboratory after overnight abstinence and used their EC under a standardised vaping regimen (10 puffs with a 30 second inter-puff interval) and then a 60 minutes period of *ad lib* vaping. The PK analyses showed a significant increase in plasma nicotine from baseline 2.0 ng/ml to 0.3 ng/ml within five minutes of the first puff. At the end of the ad-lib vaping period the maximum plasma nicotine concentration was 16.3 ng/ml.

Dawkins and Corcoran (2014) examined nicotine delivery associated with the used of the Skycig 18 mg Crown tobacco bold cartridges in 14 vapers, who had been vaping for almost 5 months on average[6]. Using a similar methodology to Vansickel & Eissenberg (2012), the analysis of plasma nicotine from the seven participants that provided a full blood set, showed that levels had increased from 0.74 to 6.77 ng/ml in 10 minutes. However there was individual variation (2.5 ng/ml to 13.4 ng/ml). After an hour of *ad lib* use the maximum nicotine concentration reached was 13.91 ng/ml, again with a wide range of levels observed between individuals (4.35-25.6 ng/ml).

Spindle et al., 2015 studied 13 experienced EC users (> 3 months, with the majority 9/13 using e-liquid strength of 24mg/ml and all using tank systems)[120]. Taking 10 puffs over 5 minutes resulted in an increase in mean blood nicotine levels from 2.4 ng/ml baseline to 19.2 ng/ml at 5 minutes.

Practice in EC use also results in a modest increase in blood nicotine levels. Hajek et al., 2014 tested Greensmoke EC (a cigalike EC with 2.4% nicotine) in 40 smokers, naïve to EC[115]. Participants abstained from any nicotine use overnight and after a baseline blood sample was collected used the EC, *ad lib*, for 5 minutes. This procedure was undertaken twice, on first use and then again after 4 weeks of use. The maximum plasma concentrations increased from 4.6 ng/ml (range 0.9-9.0) to 5.7 ng/ml (range 1.9-11.0), although this increase was not significant. The area under the curve (AUC), however, did show a significant increase, from 96 (range 12-198) to 142 (range 56-234). The time to maximum plasma concentration (5 minutes) did not change.

Nides et al., 2014 provided EC to participants (29 smokers, mean cigarette consumption of 20 cpd, and of 55% of whom had used EC in past) but also allowed them to practice using the EC (NJOY®King Bold, a cigalike EC, with 26mg nicotine) for a week prior to undertaking a PK analysis [116]. Participants (who abstained from all nicotine products for at least 12 hours) then were asked to use EC (10 puffs with a 30 second inter-puff interval) on two occasions 60 minutes apart. Pharmacokinetic (PK) analyses were undertaken in 16 participants who had no detectable plasma nicotine at baseline. The mean rise in blood nicotine was 3.5 ng/ml (range 0.8-8.5 ng/ml) at 5 minutes after the first round of puffing and 5.1 ng/ml (range 1.1 – 7.1 ng/ml) at 10 minutes after the second.

3) Nicotine concentration and chemical composition of e-liquid

Yan & D'Ruiz (2014) examined nicotine delivery from Blu cigalike EC with differing levels of nicotine (2.4% and 1.6%), glycerin/propylene glycol (75% glycerin and 50% glycerin/20% propylene glycol), and flavours (classic tobacco and menthol)[129]. Participants (23 smokers) were randomized to 5 different EC conditions and smoking a regular cigarette in a cross over design. They were given 7 days to familiarize with EC use, and then abstain from all nicotine products for 36 hours prior to test days. On test days participants were asked to take 50 x 5 second puffs on EC at 30 sec intervals (in the cigarette arm they smoked 1 cigarette with usual puff duration at 30 sec intervals). After the controlled puffing testing ppts were allowed 60 minutes of *ad lib* use.

Peak plasma nicotine concentrations were reached sooner for cigarettes (5 minutes) than for EC (30 minutes). During the 30 minutes controlled puffing phase, within EC conditions the highest Cmax was seen with the 2.4% nicotine, 50% glycerin/20% PG (18.09 ng/ml, SD=6.47 ng/ml). The lowest Cmax was observed in the 1.6% nicotine, 75% glycerine (10.34 ng/ml SD=3.70 ng/ml). The Cmax associated with smoking one conventional cigarette was 15.84 ng/ml (SD = 8.64 ng/ml). At the end of the *ad lib* period, the highest Cmax was seen with the conventional cigarette (29.23 ng/ml SD = 10.86 ng/ml), followed by the 2.4% nicotine, 50% glycerin/20% PG EC (22.42 ng/ml; SD = 7.65ng/ml). The glycerine/PG mix resulted in better nicotine delivery than the 75% glycerine solution, which was confirmed in the bench top tests that measured nicotine content in vapour using the Canadian Intense regimen. The high nicotine content in vapour is a likely consequence of the lower boiling point of PG (187.6 degrees Celsius) compared with glycerine (290 degrees Celsius).

4) Type of EC device

Although many vapers start off with using a cigalike EC experienced vapers are more likely to be using tank systems or variable power EC. One of the reasons for this observation is that the tank systems and variable power ECs deliver nicotine more nicotine to the user.

Farsalinos et al., (2014) examined plasma nicotine levels in experienced vapers (n=23) who used a cigalike (V2 with cartomiser) and a new generation (EVIC set at 9 watts with EVOD atomizer) EC with standardized flavour and nicotine concentration (18mg/ml) in a cross-over design[129]. Participants' abstained from EC use for at least 8 hours before completing a bout of 10 puffs over 5 minutes followed by one hour of *ad lib* use. Use of the cigalike EC was associated with an increase in blood nicotine from 2.80 ng/ml at baseline, to 4.87 ng/ml at 5 minutes and 15.75 ng/ml at the end of ad lib use. Significantly greater increases were observed with use of the new generation EC from 2.46 ng/ml to 6.59 ng/ml to 23.47 ng/ml at baseline, 5 minutes and at the end of the *ad lib* period.

Oncken et al., (2015) also examined nicotine delivery in a tank system EC (Joye eGo-C with 18 mg/ml nicotine e-liquid) in 20 smokers who were asked to use an EC for two weeks[123]. Participants were asked to use the EC for 5 minutes ad lib in two laboratory sessions where blood samples were taken for PK analysis. Blood nicotine concentrations increased, significantly, by 4 ng/ml (Cmax 8.2 ng/ml) at the first session and 5.1 ng/ml (Cmax 9.3 ng/ml) at the second session. These levels were reached at five minutes.

Studies that examine cotinine as a measure of nicotine replacement in vapers

We found eight studies that reported on cotinine in urine, blood or saliva as a marker of nicotine exposure in people using EC.

In an RCT of nicotine containing EC versus placebo Caponnetto and colleagues (2013) measured salivary cotinine in participants who had stopped smoking cigarettes, but were still vaping EC (Categoria 7.5mg/ml)[40]. After 12 weeks of use the mean salivary cotinine concentration was 67.8 ng/ml, which is at the lower end of what is typically observed in smokers (eg 66.9-283.7 ng/ml).

In a study that randomised 48 smokers unwilling to quit to one of two tank system EC (18mg/ml nicotine) or to continue to smoke found that at 8 month follow-up mean salivary cotinine did not significantly differ between those who had stopped smoking but were vaping (428.27 ng/ml), achieved a ≥50% reduction in cigarette consumption (356.49 ng/ml) and those who continued to smoke (545.23 ng/ml, SD = 46.32)[41].

Van Staden et al., (2013) examined the change in serum cotinine in 13 smokers who were asked to stop smoking and instead use a Twisp eGo (18mg/ml nicotine) tank system EC for two weeks[113]. There was a significant decrease in cotinine from baseline 287.25 ± 136.05 to two weeks 97.01 ± 80.91 ng/ml suggesting that the EC used did not provide as much nicotine as participants usual cigarettes.

Norton et al., (2014) observed a similar result in 16 abstinent smokers who used a cigalike EC (11 mg/ml) for five days, finding a significant decrease in saliva cotinine between baseline (338.0 ng/ml) and day five (178.4 ng/ml)[112].

Flouris et al., (2013) measured serum cotinine in 15 smokers, who had abstained overnight, after smoking two of their usual cigarettes over 30 minutes and after 30 minutes of vaping a cigalike EC (Giant, 11mg/ml)[130]. EC and cigarettes produced similar effects on serum cotinine levels (60.6 ± 34.3 versus 61.3 ± 36.6 ng/ml). However measurement of cotinine would not give an accurate indicator of exposure in an acute study such as this.

Experienced vapers, using their own devices, however obtain much better nicotine substitution. Etter and Bullen (2011) measured salivary cotinine concentrations in 30 vapers who had been using EC for approximately 3 months on average and no longer smoking[9]. The mean nicotine content of e-liquid was 18mg/ml. Mean salivary cotinine was found to be 322 ng/ml indicating a high level of nicotine replacement via EC.

Similarly Etter (2014) found mean cotinine levels of 374 ng/ml (95% CI: 318-429) in 62 vapers who had not used any other nicotine containing products in the last 5 days [8].

Hecht et al., 2014 measured nicotine and cotinine in urine of 28 EC users (median use of 9 months, using tank system EC with e-liquid containing, on average 12.5 ± 7.0 mg/ml)[111]. Nicotine and cotinine levels in urine were 869 ng/ml (95% CI: 604-1250) and 1880 ng/ml (95% CI: 1420-2480) respectively, although these levels are lower than what are typically observed in smokers (eg nicotine 1380 ng/ml 95% CI: 1190-1600 and cotinine 3930 ng/ml; 95% CI: 3500-4400).

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Comparison of select analytes in aerosol from e-cigarettes with smoke from conventional cigarettes and with ambient air

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ABSTRACT

Leading commercial electronic cigarettes were tested to determine bulk composition. The e-cigarettes and conventional cigarettes were evaluated using machine-puffing to compare nicotine delivery and relative yields of chemical constituents. The e-liquids tested were found to contain humectants, glycerin and/or propylene glycol, (⩾75% content); water (<20%); nicotine (approximately 2%); and flavor (<10%). The aerosol collected mass (ACM) of the e-cigarette samples was similar in composition to the e-liquids. Aerosol nicotine for the e-cigarette samples was 85% lower than nicotine yield for the conventional cigarettes. Analysis of the smoke from conventional cigarettes showed that the mainstream cigarette smoke delivered approximately 1500 times more harmful and potentially harmful constituents (HPHCs) tested when compared to e-cigarette aerosol or to puffing room air. The deliveries of HPHCs tested for these e-cigarette products were similar to the study air blanks rather than to deliveries from conventional cigarettes; no significant contribution of cigarette smoke HPHCs from any of the compound classes tested was found for the e-cigarettes. Thus, the results of this study support previous researchers' discussion of e-cigarette products' potential for reduced exposure compared to cigarette smoke.

1. Introduction

Electronic cigarettes (e-cigarettes) are a relatively new consumer product. Unlike conventional cigarettes, e-cigarettes do not burn tobacco to deliver flavor. Instead, they contain a liquid-based flavorant (typically referred to as e-liquid or e-juice) that is thermally vaporized by an electric element. This liquid typically consists of a mixture of water, glycerin, and/or propylene glycol. The liquid also contains nicotine and flavor, although nicotine-free products are available.

While there are decades of characterization studies and numerous standardized analytical procedures for conventional cigarettes, relatively little published analytical data exists for commercial e-cigarette products. Furthermore, no standardized test methods or reference products exist for e-cigarettes.

Electronic cigarettes are generally purported to provide reduced exposure to conventional cigarettes' chemical constituents because they deliver flavors and nicotine through vaporization rather than by burning tobacco. Goniewicz et al. (2014) reported low levels of select chemical constituents in select e-cigarette brands commercially available in Poland. A recent review of analyses from diverse e-cigarettes shows comparatively simple chemical composition relative to conventional cigarette smoke (Burstyn, 2014). However, limited published results exist for commercial products that represent a significant presence in the marketplace (Cheng, 2014).

The purpose of this study was to evaluate e-cigarette products with a significant presence in the marketplace for bulk composition, including nicotine, and for select constituents for comparison with conventional cigarette products. Three blu eCigs products (approximately 50% of the US market) and two SKYCIG products (approximately 30% of the UK market) were chosen for evaluation. Marlboro Gold Box (US), and Lambert & Butler Original and Menthol products (UK), with significant market share in their respective geographical areas, were included in the study for conventional cigarette comparisons.

Abbreviations: ACM, aerosol collected mass; HPHC, harmful and potentially harmful constituents; CO, carbon monoxide; TSNA, tobacco-specific nitrosamines; PAA, polyaromatic amines; PAH, polyaromatic hydrocarbons; LOQ, limit of quantitation; LOD, limit of detection; CAN, Health Canada Test Method T-115; blu CTD, Classic Tobacco Disposable; blu MMD, Magnificent Menthol Disposable; blu CCH, Cherry Crush, Premium, High Strength; SKYCIG CTB, Classic Tobacco Bold; SKYCIG CMB, Crown Menthol Bold; MGB, Marlboro Gold Box; L&B O, Lambert & Butler Original; L&B M, Lambert & Butler Menthol; TPM, total particulate matter; PG, propylene glycol.

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The products used in the study were evaluated for content and delivery of major ingredients (glycerin, propylene glycol, water, and nicotine) and for select constituents (carbon monoxide (CO), carbonyls, phenolics, volatile organic compounds (volatiles), metals, tobacco-specific nitrosamines (TSNAs), polyaromatic amines (PAAs), and polyaromatic hydrocarbons (PAHs)). Many of these constituents are included in cigarette industry guidance issued by the FDA that includes reporting obligations for harmful and potentially harmful constituents (HPHCs) in cigarette filler and smoke under section 904(a)(3) of the 2009 Family Smoking Prevention and Tobacco Control Act (FDA, 2012). For delivery studies, the conventional cigarettes were smoked under an intense puffing regime published by Health Canada (1999). The e-cigarettes were tested using minimal modifications to this smoking regime. Ninety-nine puffs were used to collect approximately the same aerosol mass as obtained from conventional cigarette testing. Ambient 'air' samples, empty port collections, were included as a negative control of aerosol testing for cigarette constituents (i.e. HPHC).

2. Materials and methods

2.1. Test products

Two disposable e-cigarette products and three rechargeable e-cigarette products were obtained from the manufacturers. Three conventional cigarette products were purchased through wholesale or retail sources for testing. Information for each of the products is listed in Table 1.

2.2. Methods overview

ISO 17025 accredited analytical methods were used to evaluate the cigarette samples for select HPHCs in mainstream smoke. Official methods are cited and other, internally validated, methods are briefly described for general understanding. Furthermore, because no standardized methods exist for e-cigarette analysis, the methods used to evaluate the conventional cigarettes were adapted to evaluate the e-cigarette products and the study blanks (room air). In an effort to maximize signal and lower methods' limits of quantitation, aerosol collection amounts were maximized (but maintained below breakthrough) and extraction solvent volumes were minimized. In some cases, alternative instrumentation was employed to improve detection. For example, mainstream smoke TSNAs were analyzed by GC–TEA while aerosol and air blank samples were analyzed by LC–MS/MS. Accuracy, precision, and method limits of quantitation and detection (LOQ and LOD) were verified for each method. On average, accuracy and method variability for the analytes tested were determined to be 98% and 3%, respectively. Analyte LOD and LOQ information is listed in Supplemental Appendix A Tables 1 and 2. Method resolution for low levels of analytes was influenced by background levels of select analytes in air control samples. These background levels are attributed to instrument or smoking machine carry-over as evidenced in solvent or air blanks. In addition, the high concentration of glycerin and water in e-cigarette aerosol present challenges for volatile-based measurement systems (i.e. GC). Additional method refinements and dedicated e-cigarette puffing machines are two areas for consideration to improve e-cigarette aerosol method sensitivities. Method development and verification details for e-cigarette liquids and aerosols are the subject of a future publication.

2.3. Smoke and aerosol collection

Cigarette preparation and machine smoking for conventional cigarettes are described in Health Canada Test Method T-115 (CAN) (1999). Two to three cigarettes were smoked per replicate for conventional cigarettes and 99 puffs were taken from single e-cigarettes for no more than approximately 200 mg of particulates collected per pad. Three to five replicates were tested for each measurement. Prior to analysis, filter pads from cigarette smoke collection were visually inspected for overloading of particulates, as evidenced by brown spotting on the back of the filter pad. To ensure no overloading of particulates for aerosol collection, e-cigarette units were weighed before and after collection to verify that product weight change and filter pad weight change were comparable. Air blanks were prepared by puffing room air (99 puffs) through an empty smoking machine port to the indicated trapping media for an analysis method. These air blank samples were prepared and analyzed in the same manner and at the same time as the e-cigarette aerosol samples. Smoke and aerosol collection sections were conducted separately. Smoke and aerosol particulate was collected onto 44 mm glass fiber filter pads with >99% particulate trapping efficiency for each replicate analysis. For carbonyls, smoke/aerosol was collected directly by two impingers, in series. For smoke metals analysis, electrostatic precipitation was used. For volatiles and PAH determinations, single chilled impingers were placed in-line with the filter pads. e-Liquid glycerin and nicotine were quantitated using GC–FID and/or GC–MS using a method equivalent to ISO 10315 (ISO, 2000a). e-Liquid water was quantitated using Karl Fischer analysis. A reference e-liquid was developed and used as a testing monitor for ingredient determinations in the e-liquid samples. The reference e-liquid is composed primarily of glycerin, propylene glycol, and water with low levels of nicotine, menthol, and Tween 80. The Tween 80 is added to improve solubility of menthol in the solution. The reference is not meant to directly mimic an e-liquid used for consumption but merely used for analytical control charts. Three replicates were tested for each sample and the reference.

2.4. Analytical assays

Carbon monoxide was determined concurrently with aerosol and smoke collection for nicotine and water and analyzed by NDIR using ISO method 8454:2007 (ISO, 2007). Carbonyls were trapped using 2,4-dinitrophenylhydrazine as a derivatizing agent with

Table 1
List of cigarette and e-cigarette products tested.

Product	Manufacturer	Product type	Nicotine information provided on packaging
Classic Tobacco Disposable (blu CTD)	blu eCigs	Disposable e-cigarette	Content: 24 mg/unit
Magnificent Menthol Disposable (blu MMD)	blu eCigs	Disposable e-cigarette	Content: 24 mg/unit
Cherry Crush, Premium, High Strength (blu CCH)	blu eCigs	Rechargeable e-cigarette	Content: 16 mg/unit
Classic Tobacco Bold (SKYCIG CTB)	SKYCIG	Rechargeable e-cigarette	Content: 18 mg/unit
Crown Menthol Bold (SKYCIG CMB)	SKYCIG	Rechargeable e-cigarette	Content: 18 mg/unit
Marlboro Gold Box (MGB)	Philip Morris USA	Conventional cigarette	–
Lambert & Butler Original (L&B O)	Imperial Tobacco	Conventional cigarette	Yield: 0.9 mg/cig (ISO)
Lambert & Butler Menthol (L&B M)	Imperial Tobacco	Conventional cigarette	Yield: 0.5 mg/cig (ISO)

subsequent analysis by UPLC–UV using CORESTA method 74 (CORESTA, 2013). For phenolics determination, filter pads were extracted with 20 mL of 1% acetic acid/2.5% methanol (MEOH) in water using 30 min of agitation. Extracts were analyzed by UPLC-fluorescence detection using a C18 column for separation. For volatiles analysis, filter pads and impinger solutions (20 mL MEOH) were combined. Extracts were analyzed by GC–MS in SIM mode using a WAX capillary column. For metals analysis, cigarette smoke was collected using an electrostatic precipitator while e-cigarette aerosol was collected on glass fiber filter pads. After smoking, the cigarette smoke condensate was rinsed from the electrostatic precipitation tube using methanol. The dried condensates were digested using hydrochloric (10% v/v), nitric acids (80% v/v), and heat and were diluted prior to analysis by ICP-MS. For aerosol samples, filter pads were extracted using 20 mL of a mixture of nitric (2% v/v) and hydrochloric acids (0.5% v/v) using wrist action shaker (20 min). Resultant extracts were analyzed by ICP-MS equipped with an octapole reaction cell.

For TSNA analysis of smoke, samples were extracted in nonpolar solvent, treated to an SPE clean-up, concentrated and analyzed by GC–TEA following CORESTA method 63 (CORESTA, 2005). For TSNA analysis of aerosol samples, filter pads were extracted with 20 mL of 5 mM aqueous ammonium with 15 min of shaking. Extracts were analyzed by LC–MS/MS with a C18 column. For PAA determinations, filter pads were extracted using 25 mL of 5% HCl (aq) and shaking (30 min) followed by solvent exchange and derivatization with pentafluoropropionic acid anhydride and trimethylamine. After an SPE clean-up step (Florisil® SEP-PAK), samples were analyzed by GC–MS in SIM mode using negative chemical ionization. PAH analysis was conducted by extraction in MEOH followed by SPE clean-up and analysis by GC–MS in SIM mode (Tarrant et al., 2009).

The results obtained from these analyses were tabulated as mean ± one standard deviation for levels of selected compounds in Supplementary Appendix A. In cases where quantifiable amounts of analyte were present in an e-cigarette aerosol sample above that of the associated air blanks, an Analysis of Variance (ANOVA) was used to compare the means for the cigarette smoke data with respective aerosol data. Statistical analyses were performed using JMP 10.0.0 (SAS Institute, Inc. Cary, NC, USA). The significance level was established as $p < 0.05$ for all comparisons.

3. Results and discussion

3.1. Collection of aerosol

Machine smoking of cigarettes under standardized regimes is for comparative purposes and is not intended to represent the range of consumer smoking behaviors. Thus, standardized equipment, cigarette reference products, and methodology have been established to allow comparison of different products under a common set of controlled conditions. ISO 3308:2000E and Health Canada (CAN) methods are frequently used for standardized smoking of conventional cigarettes for the purposes of laboratory comparisons among products (ISO, 2000b; Health Canada, 1999). Following each of these methods, conventional cigarettes are smoked to a specified butt length using a fixed and specified puffing volume, duration, and interval.

Regarding e-cigarette experimentation, there is no generally accepted standard e-cigarette puffing regime at this time. Topography studies are limited but anecdotal information indicates e-cigarette usage depends greatly on the individual consumer and product design and capabilities. For the purposes of this study, our objective was to collect sufficient aerosol to be able to detect, if present, select HPHCs. A wide range of parameters would be adequate to accomplish this. Given the objectives of this study, use of collection parameters which are compatible with conventional and electronic cigarettes was essential for facilitating comparisons between cigarette smoke and e-cigarette aerosol. The more intense of the standard regimes used with cigarettes, CAN, which requires 55 mL puffs taken twice a minute, was adapted for this investigation. The key difference required for testing e-cigarettes with the CAN method is that a fixed puff count (rather than 'butt length') is necessary for aerosol collection. A standard of 99 puffs was adopted for all e-cigarette and air blank analyses. This puff count provides similar total particulate collection per pad between the e-cigarette samples and the conventional cigarette testing. This also represents approximately 11 times more puffs than are typically observed for a conventional cigarette. Marlboro Gold Box, L&B O, and L&B M averaged 9.1, 8.2, and 7.2 puffs per cigarette, respectively, when machine-smoked to the standard butt length. If more aggressive puffing parameters had been chosen for the study, the puff count specification would have been lowered to maintain the target level of ACM collected. Note that the range of puffs collected in-use may vary widely depending on product design, battery strength, and user puffing preferences. Thus, the 99 puffs collection in this study is not intended to represent a life time use yield for any of the analytes tested.

3.2. Aerosol and smoke characterization – reference information

Traditional cigarette testing incorporates the use of monitor or reference cigarettes that serve as positive controls and provide quality metrics for standardized analytical methods. Key examples are Kentucky Reference cigarettes and CORESTA monitor cigarettes (CORESTA, 2009; ISO, 2003; University of Kentucky, 2014). Each of

Table 2
Percent composition of e-liquid and aerosol.

	Glycerin (%)	Propylene glycol (%)	Water (%)	Nicotine (%)	Flavor[a] (%)
e-Liquid composition					
blu Classic Tobacco Disposable	82	–	9	2	7
blu Magnificent Menthol Disposable	75	–	18	2	5
blu Cherry Crush High Premium	77	–	14	2	7
SKYCIG Classic Tobacco Bold	24	67	6	2	1
SKYCIG Crown Menthol Bold	21	66	7	2	4
e-Cigarette aerosol composition[b]					
blu Classic Tobacco Disposable	73	–	15	1	11
blu Magnificent Menthol Disposable	80	–	18	2	–
blu Cherry Crush High Premium	70	–	19	1	10
SKYCIG Classic Tobacco Bold	24	61	10.4	1.4	3
SKYCIG Crown Menthol Bold	21	59	12	2	6

[a] Flavor content is estimated by difference.
[b] Aerosol % composition calculated based on the ACM delivery as analyte yield (mg)/ACM (mg) × 100.

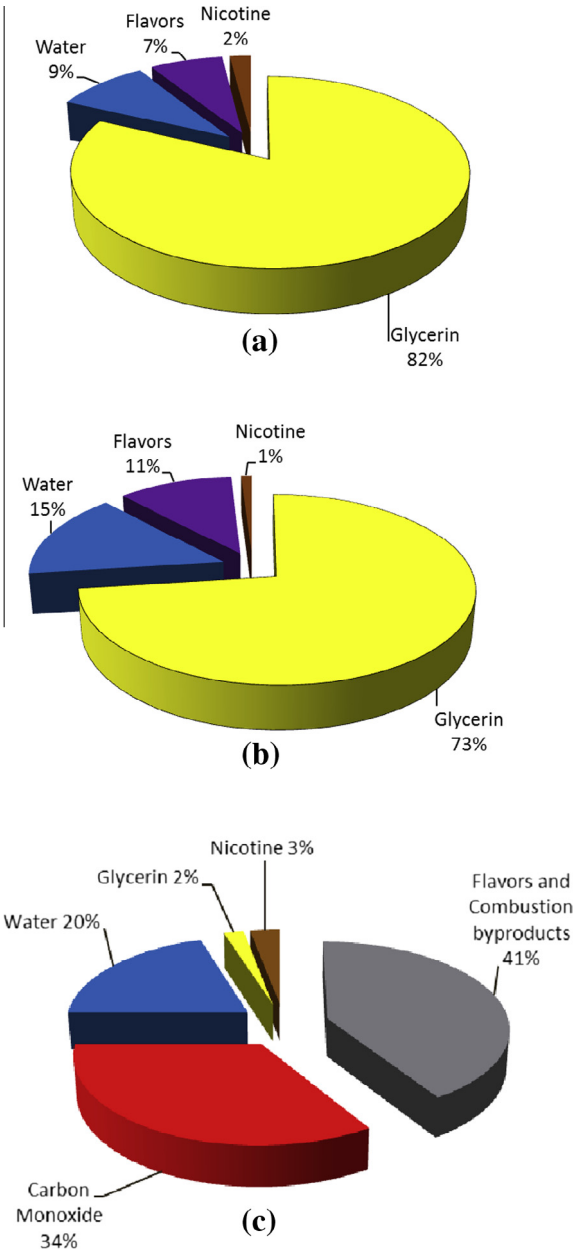

Fig. 1. Percent composition comparison for e-liquid, e-cigarette aerosol, and cigarette smoke: (a) Classic Tobacco Disposable e-liquid Composition. (b) Classic Tobacco Disposable Aerosol Composition (99 puffs, CAN). (c) Marlboro Gold Box Smoke Composition (9 puffs, CAN).

these reference cigarettes can serve as a single positive control and an indicator of method variability within and among laboratories for all analytes of interest. The manufacture, design, and function of these reference products are similar to those of commercial cigarettes. Currently reference products are not available for e-cigarette testing. Given the range of e-cigarette designs, development of a consensus strategy to produce positive controls or monitors for e-cigarette testing is needed.

In the absence of standardized e-cigarette references, measures were taken to ensure experimental robustness. For example, aerosol collected mass (ACM) results for the e-cigarette samples were compared across methods as an indicator of puffing consistency for a given product among the machine-puffing sessions required to conduct the battery of tests. Thus, if a sample set yielded ACM outside of a specified ranged deemed typical for a given product, the sample set was repeated. This range was determined for each product based on collection of 20 or more replicates across the product lot using CAN parameters.

Also, because results from initial analyses indicated low or no measurable levels of many of the analytes, blank samples were included to verify any contribution of analyte from the laboratory environment, sample preparation, and/or analyses for each HPHC test method. The air blank results are listed with the samples' results in Tables 4 and 5. There were instances for which solvent blank and air blank samples had measurable levels of an analyte. This is due to the ubiquitous nature of some of the analytes, such as formaldehyde, or to carry-over. Laugesen reported similar findings (2009). These observations serve as a cautionary note regarding the measurement of extremely low levels of constituents with highly sensitive instrumentation.

3.3. Main ingredients

e-Liquid expressed from the individual products was tested for reported e-cigarette ingredients to compare the percent compositions of the e-liquids and the aerosols. Percent composition calculations of the ingredients are shown in Table 2 for each sample and in Fig. 1 for blu CTD, as this product's comparative results were exemplary of the samples. The primary ingredients in the e-cigarette samples were glycerin and/or propylene glycol ($\geqslant$75%). Water ($\leqslant$18%) and nicotine ($\sim$2%) were also present. Based on a mass balance, other ingredients, presumed to be flavorants, were present at less than 7%. Note that this calculation would also include method uncertainty and any possible HPHCs, if present. The composition of the aerosol was calculated based on the ACM delivery as analyte yield (mg)/ACM (mg) $\times$ 100. The bulk composition of the delivered aerosol was similar to the bulk composition of the e-liquid.

By comparison, the total particulate matter (TPM) of the conventional cigarettes tested is 30% water and <5% nicotine. The essential difference between the ACM composition of the e-cigarettes tested and the TPM of the conventional cigarettes is that the remaining 65% of the TPM of the conventional cigarette is predominantly combustion byproducts. There was no detectable carbon monoxide in the emitted aerosol of the e-cigarette samples. The conventional cigarettes, on the other hand, delivered more than 20 mg/cig of CO. Smoke composition for Marlboro Gold Box, exemplary of the conventional cigarettes tested, is shown in Fig. 1 in contrast to the e-liquid and aerosol results for blu CTD.

While the percent composition of the nicotine in the ACM and TPM are relatively similar, it should be noted that the actual deliveries of nicotine are markedly lower for the e-cigarettes tested than the conventional cigarettes. The nicotine yields ranged from 8 μg/puff to 33 μg/puff for the e-cigarette samples which was 85% lower than the 194–232 μg/puff for the conventional cigarettes. These results are presented in Table 3.

3.4. Aerosol and smoke HPHC testing

For cigarette smoke analysis, the conventional cigarettes were machine smoked by established cigarette smoking procedures. Approximately 7–9 puffs per cigarette were collected. For the e-cigarette samples and air blanks, 99 puffs were collected. Results were compared on an 'as tested' basis; i.e. yields for a single cigarette of 7–9 puffs compared to yields from 99 puffs of an e-cigarette as displayed in Table 4. Additionally, in order to simplify making comparisons between the cigarette and e-cigarette samples, all values were converted to yield per puff. These results are summarized by class in Table 5. Results for individual analytes are tabulated as mean ± one standard deviation in Supplemental Appendix A Tables 1 and 2.

Table 3
Nicotine content and yield comparison between e-cigarettes and conventional cigarettes (mean ± standard deviation).

	Nicotine content (μg/unit)	Nicotine yield (μg/puff)
blu Classic Tobacco Disposable	20,600 ± 1500	33 ± 12
blu Magnificent Menthol Disposable	20,000 ± 300	25 ± 4
blu Cherry Crush High Premium	11,700 ± 300	8 ± 3
SKYCIG Classic Tobacco Bold	12,750 ± 295	29 ± 4
SKYCIG Crown Menthol Bold	13,027 ± 280	33 ± 6
Marlboro Gold Box	11,431 ± 80	226 ± 2
L&B Original	12,941 ± 26	232 ± 5
L&B Menthol	12,131 ± 24	194 ± 10

Number of replicates = 3–5.

Table 4
Analytical characterization of commercial e-cigarettes and conventional cigarettes collected using CAN parameters – select cigarette HPHC methodology (mg/total puffs collected) summary by analyte classes.

	CO	Carbonyls[a]	Phenolics[b]	Volatiles[c]	Metals[d]	TSNAs[e]	PAA[f]	PAH[g]	Sum
Marlboro Gold Box (mg/cig)	27	1.92	0.204	1.430	<0.00020	0.000550	0.000024	0.00222	<30.6 mg
L&B Original (mg/cig)	22	1.89	0.26	1.02	<0.0002	0.000238	0.000019	0.00219	<25.2
L&B Menthol (mg/cig)	20	1.81	0.17	0.94	<0.0003	0.000185	0.000017	0.00153	<22.9
blu CTD (mg/99 puffs)	<0.1	<0.07	<0.001	<0.001	<0.00004	<0.00002	<0.000004	<0.00016	<0.17
blu MMD (mg/99 puffs)	<0.1	<0.08	<0.001	<0.001	<0.00004	<0.00002	<0.000004	<0.00016	<0.18
blu CCHP (mg/99 puffs)	<0.1	<0.05	<0.003	<0.0004	<0.00004	<0.00002	<0.000004	<0.00014	<0.15
SKYCIG CTB (mg/99 puffs)	<0.1	<0.06	<0.0010	<0.008	<0.00006	<0.000013	<0.000014	<0.00004	<0.17
SKYCIG CMB (mg/99 puffs)	<0.1	<0.09	<0.0014	<0.008	<0.00006	<0.000030	<0.000014	<0.00004	<0.20
Air Blank (blu Set) (mg/99 puffs)	<0.1	<0.06	<0.001	<0.0004	<0.00004	<0.00002	<0.000004	<0.00015	<0.16
Air Blank (SKYCIG Set) (mg/99 puffs)	<0.1	<0.05	<0.0009	<0.008	<0.00006	<0.000013	<0.000014	<0.00006	<0.16

< Indicates some or all values were below method limits of quantitation or detection, number of replicates = 3–5.
[a] Formaldehyde, acetaldehyde, acrolein propionaldehyde, crotonaldehyde, MEK, butyraldehyde.
[b] Hydroquinone, resorcinol, catechol, phenol, m-+p-cresol, o-cresol.
[c] 1,3-Butadiene, isoprene, acrylonitrile, benzene, toluene, styrene.
[d] Beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, nickel, selenium, tin.
[e] NNN, NAT, NAB, NNK.
[f] 1-Aminonaphthalene, 2-aminonaphthalene, 3-aminobiphenyl, 4-aminobiphenyl.
[g] Naphthalene, acenaphthylene, acenaphthene, fluorine, phenanthrene, anthracene, fluoranthene, pyrene, benzanthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, B(a)P, indeno[1,2,3-cd]pyrene, benzo(g,h,i)perylene.

Table 5
Analytical characterization of commercial e-cigarettes and conventional cigarettes collected using CAN parameters – select cigarette HPHC methodology (μg/puff) summary by analyte classes.

	CO	Carbonyls[a]	Phenolics[b]	Volatiles[c]	Metals[d]	TSNAs[e]	PAA[f]	PAH[g]	Sum
Marlboro Gold Box	2967	211	22	157	<0.026	0.0604	0.00264	0.244	<3357 μg
L&B Original	2683	230	32	124	<0.024	0.0290	0.00232	0.267	<3069
L&B Menthol	2778	251	24	130	<0.042	0.0257	0.00236	0.213	<3183
blu Classic Tobacco Disposable	<1.0	<0.7	<0.01	<0.01	<0.0004	<0.0002	<0.00004	<0.002	<1.7
blu Magnificent Menthol Disposable	<1.0	<0.8	<0.01	<0.01	<0.0004	<0.0002	<0.00004	<0.002	<1.8
blu Cherry Crush High Premium	<1.0	<0.5	<0.03	<0.004	<0.0004	<0.0002	<0.00004	<0.001	<1.5
SKYCIG Classic Tobacco Bold	<1.0	<0.6	<0.01	<0.08	<0.0006	<0.0001	<0.00014	<0.0004	<1.7
SKYCIG Crown Menthol Bold	<1.0	<0.9	<0.01	<0.08	<0.0006	<0.0003	<0.00014	<0.0004	<2.0
Air Blank (blu Set)	<1.0	<0.6	<0.01	<0.004	<0.0004	<0.0002	<0.00004	<0.002	<1.6
Air Blank (SKYCIG Set)	<1.0	<0.5	<0.01	<0.08	<0.0006	<0.0001	<0.00014	<0.001	<1.6

< Indicates some or all values were below method limits of quantitation or detection, number of replicates = 3–5.
[a] Formaldehyde, acetaldehyde, acrolein propionaldehyde, crotonaldehyde, MEK, butyraldehyde.
[b] Hydroquinone, resorcinol, catechol, phenol, m-+p-cresol, o-cresol.
[c] 1,3-Butadiene, isoprene, acrylonitrile, benzene, toluene, styrene.
[d] Beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, nickel, selenium, tin.
[e] NNN, NAT, NAB, NNK.
[f] 1-Aminonaphthalene, 2-aminonaphthalene, 3-aminobiphenyl, 4-aminobiphenyl.
[g] Naphthalene, acenaphthylene, acenaphthene, fluorine, phenanthrene, anthracene, fluoranthene, pyrene, benzanthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, B(a)P, indeno[1,2,3-cd]pyrene, benzo(g,h,i)perylene.

Table 6
Per puff comparisons of quantifiable analytes for blu eCigs products from CAN puffing – yields and ratios to conventional product yields.

	Marlboro Gold Box μg/puff	blu MMD μg/puff	MGB/blu MMD
Acrolein	16.4 ± 0.2	0.19 ± 0.06	86
Phenol	1.53 ± 0.16	0.0017[a]	900

[a] Fewer than three replicates were quantifiable; no standard deviation is listed.

Table 7
Per puff comparisons of quantifiable analytes for SKYCIG products from CAN puffing – yields and ratios to conventional product yields.

	L&B average μg/puff	SKYCIG CTB μg/puff	SKYCIG CMB μg/puff	L&B average/SKYCIG CTB	L&B average/SKYCIG CMB
Acetaldehyde	174	–	0.32[a]	–	544
Acrolein	17	0.15 ± 0.02	–	113	–
Propionaldehyde	12	–	0.11 ± 0.05	–	109
N-Nitrosoanatabine	0.010	–	0.0002 ± 0.0001	–	50

[a] Fewer than three replicates were quantifiable; no standard deviation is listed.

All analytes tested were present in the cigarette smoke at quantifiable levels except for select metals. These results are consistent with internal historical results for commercial cigarettes tested under the CAN smoking regime. For the cigarette samples, the total yield range was 3069–3350 μg/puff of HPHCs tested.

Of the 55 HPHCs tested in aerosol, 5 were quantifiable in an e-cigarette sample but not the associated air blank. The quantifiable results for aerosol are listed in Tables 6 and 7 in contrast with the conventional cigarettes from the same geographical region. The five analytes which were quantifiable were statistically different ($p < 0.05$) at levels 50–900 times lower than the cigarette smoke samples. Phenol was quantified in one e-cigarette product at 900 times lower than cigarette smoke. N-Nitrosoanatabine was quantified in one product at 50 times lower than cigarette smoke. Three carbonyls (acrolein, acetaldehyde, and propionaldehyde) were quantified at 86–544 times lower than cigarette smoke.

All other analytes were not quantifiable above the air blanks in aerosol samples. The e-cigarettes and air blanks total yields for analytes were <2 μg/puff which is 99% less than the approximately 3000 μg/puff quantified for the cigarette smoke samples. Thus, the results support the premise of potentially reduced exposure to HPHCs for the e-cigarette products compared to conventional cigarette smoke.

4. Conclusions

The purpose of this study was to determine content and delivery of e-cigarette ingredients and to compare e-cigarette aerosol to conventional cigarettes with respect to select HPHCs for which conventional cigarette smoke is routinely tested. Routine analytical methods were adapted and verified for e-cigarette testing. Aerosol collection was conducted using conventional smoking machines and an intense puffing regime. As machine puffing cannot, and is not intended to, mimic human puffing, results of this study are limited to the scope of the comparisons made between the e-cigarette and conventional cigarette products tested.

The main ingredients for the e-cigarettes tested were consistent with disclosed ingredients: glycerin and/or propylene glycol ($\geqslant$75%), water ($\leqslant$18%), and nicotine ($\sim$2%). Machine-puffing of these products under a standardized intense regime indicated a direct transfer of these ingredients to the aerosol while maintaining an aerosol composition similar to the e-liquid. Nicotine yields to the aerosol were approximately 30 μg/puff or less for the e-cigarette samples and were 85% lower than the approximately 200 μg/puff from the conventional cigarettes tested.

Testing of the e-cigarette aerosol indicates little or no detectable levels of the HPHC constituents tested. Overall the cigarettes yielded approximately 3000 μg/puff of the HPHCs tested while the e-cigarettes and the air blanks yielded <2 μg. Small but measurable quantities of 5 of the 55 HPHCs tested were found in three of the e-cigarette aerosol samples at 50–900 times lower levels than measurable in the cigarette smoke samples. Overall, the deliveries of HPHCs tested for the e-cigarette products tested were more like the study air blanks than the deliveries for the conventional cigarettes tested. Though products tested, collection parameters, and analytical methods are not in common between this study and others, the results are very consistent. Researchers have reported that most or all of the HPHCs tested were not detected or were at trace levels. Burstyn (2014) used data from approximately 50 studies to estimate e-cigarette exposures compared to workplace threshold limit values (TLV) based on 150 puffs taken over 8 h. The vast majority of the analytes were estimated as $\ll$1% of TLV and select carbonyls were estimated as <5% of TLV. Cheng (2014) reviewed 29 publications reporting no to very low levels of select HPHCs relative to combustible cigarettes, while noting that some of the tested products exhibited considerable variability in their composition and yield. Goniewicz et al. (2014) tested a range of commercial products and reported quantifiable levels for select HPHCs in e-cigarette aerosols at 9- to 450-fold lower levels than those in cigarette smoke that in some instances were on the order of levels determined for the study reference (a medicinal nicotine inhaler). Laugesen (2009) and Theophilus et al. (2014) have presented results for commercial e-cigarette product liquids and aerosols having no quantifiable levels of tested HPHCs, or extremely low levels of measurable constituents relative to cigarette smoke. Additionally, findings from several recent studies indicate that short-term use of e-cigarettes by adult smokers is generally well-tolerated, with significant adverse events reported relatively rarely (Etter, 2010; Polosa et al., 2011, 2014; Caponnetto et al., 2013; Dawkins and Corcoran, 2014; Hajek et al., 2014). Thus, the results obtained in the aforementioned studies and in the present work broadly support the potential for e-cigarette products to provide markedly reduced exposures to hazardous and potentially hazardous smoke constituents in smokers who use such products as an alternative to cigarettes.

Additional research related to e-cigarette aerosol characterization is warranted. For example, continued characterization of

major components and flavors is needed. Establishment of standardized puffing regimes and reference products would greatly aid sharing of knowledge between researchers. Continued methods' refinement may be necessary for improved accuracy for quantitation of analytes at the low levels determined in this study. To that end, it is critical that negative controls and steps to avoid sample contamination be included when characterizing e-cigarette aerosol since analytes are on the order of what has been measured in the background levels of a laboratory setting. Though researchers have reported quantification of select analytes, great care must be taken when interpreting results at such trace levels.

Conflicts of interest

The company for which the study authors work and the companies that manufacture the e-cigarettes tested for this study are owned by the same parent company.

Acknowledgments

We thank the analytical testing laboratories at Lorillard Tobacco Company for methods development and testing and Drs. Brown, D'Ruiz, Heck and Stevens for technical discussions.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.yrtph.2014.10.010.

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Second Safety Report on the Ruyan® e-cigarette

Murray Laugesen

Health New Zealand Ltd

9 April 2008

Contents

Foreword

This report is entitled a second report, and further test results will be added as they come to hand. Ruyan has allowed flexibility in the nature of investigations carried out. The tests reported are backed up by signed reports from the contracted laboratories. No completed test results have been withheld.

The Ruyan® e-cigarettes and the funds for testing them were supplied under a contract by Ruyan (Holdings) Ltd Hong Kong, but the findings are those of the author. Neither the author nor Health New Zealand Ltd holds stock in Ruyan (Holdings) Co. Ltd.

(Dr) Murray Laugesen

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9 April 2008.

Summary

Aim This report aims to assist regulators in initial assessment of the safety of the Ruyan® e-cigarette, and the possible risks and benefits from permitting its sale.

Safety The Ruyan® e-cigarette is designed to be a safe alternative to smoking, and on examination from a number of aspects, appears to very safe relative to cigarettes, and also safe in absolute terms on all measurements we have applied. Using micro-electronics it vapourizes, separately for each puff, very small quantities of *nicotine* dissolved in *propylene glycol*, two small well- known molecules with excellent safety profiles, – into a fine aerosol. Each puff contains one third to one half the nicotine in a tobacco cigarette's puff. The cartridge liquid is tobacco-free and no combustion occurs.

By May 2008 at latest, we intend to release results of our study of efficacy of the e-cigarette in raising nicotine blood levels and in relieving cigarette cravings. That study was of smokers using the e-cigarette for the first time, without prior experience of its use.

By June or July 2008, we plan another edition of this report, in response to findings to date. Upgrade of the cartridge liquid is planned to eliminate traces of contaminants.

Once on sale, its on-going safety profile depends on 1) good manufacturing practice and pharmaceutical-grade purity of the nicotine and propylene glycol used in the cartridge liquid. 2) the prevention of shared use which could result in cross infection.

- A number of e-cigarettes are on sale on the internet from China. This report is specific for the Ruyan® e-cigarette, manufactured by Ruyan (Holdings) Co. Ltd, Hong Kong and Beijing, who invented it, and hold the required patents.

1 Background

1.1 Risks of smoking

According to the World Health Organization, the annual death toll from tobacco smoking was 7.6 million world-wide in 2000, and rising.[1] Globally, smoking will soon exceed AIDS-HIV as the leading preventable cause of death.
Smoking multiplies the risk of dying early, doubling the risk for those who smoke 5 to 9 cigarettes a day, tripling the risk for smokers of 20 cigarettes a day, quadrupling the risk for smokers of over 25 per day.[2]

1.2 Separating nicotine from the smoke

Smokers smoke for nicotine but do not die from the nicotine[3] – they die from the smoke. *Smoking kills*, the warning on cigarette packets in many countries, is a precisely accurate statement.

Smoking kills because tobacco smoke contains cancer-causing tar solids (visible particles) in smoke, and certain known invisible toxicant gases such as butadiene (cancer-causing); hydrogen cyanide and carbon monoxide (affecting heart and blood vessels); and acrolein (damaging to the lungs).
Smoking tobacco is, until now, the only way to inhale nicotine into the lungs. The invention of the Ruyan® nicotine e-cigarette in 2004 is about to change that. The Ruyan® e-cigarette takes advantage of the fact that inhalation via a cigarette is the fastest route for nicotine absorption, and absorption by this route is 99% complete.

Before cigarettes were invented, lung cancer was unknown. People sniffed tobacco in the form of nasal snuff, or sucked or chewed it as oral snuff, instead of smoking it.
Pharmacies today stock a range of nicotine products. Nicotine from patches is slowly and completely absorbed through the skin. The mouth mucosa filters out 60% of the nicotine in gum, lozenges and tablets, and absorption through the mouth can take half an hour. None of these methods allows the smoker to continue to enjoy the sensation of drawing on a cigarette to get the nicotine.

1.3 Stopping smoking only way to prevent smoking deaths in next 20 years

- As almost all tobacco smoking deaths occur at age 35 years onwards,[4] those smokers who will die of smoking in the next 20 years, are already smokers – and their deaths can only be averted if they can be persuaded to stop smoking. Stop

[1] Tobacco Atlas. World Health Organization. www.who.int/tobacco/en/atlas11.pdf
[2] Bjartveit K, Tverdal A. Health consequences of smoking 1-4 cigarettes per day. Tobacco Control 2005; 14: 315-20, based on follow-up of 43,000 Norwegians from 1970s to 2002.
[3] Murray RP, et al. Safety of nicotine polacrilex gum used by 3094 participants in the Lung Health Study. Chest 1996; 109: 438-45. Followed for 5 years, compared with 1900 controls. No increase in hospitalization or mortality was found in the nicotine gum chewers, whether still smoking or not.

smoking can be either by quitting smoking entirely, or switching to a non-tobacco smoking product.

- Unfortunately, even world-leading programmes to reduce smoking (such as New Zealand's) are succeeding only slowly, so that, by promoting quitting alone, smoking will take another 70 years to reach zero.
- A large part of the problem is that many smokers are unwilling to quit their addiction to nicotine. The Ruyan® e-cigarette provides an easier escape route for smokers.
- WHO has recommended that alongside the individual approach (including pharmacological interventions), a supportive (policy) environment is needed, and recommends "a broad framework for addressing smoking cessation and treatment of tobacco dependence."[4]
- Such a framework would logically permit widespread sale of a range of cigarette substitutes that each provided "clean" nicotine for lung inhalation.

1.4 Life years reclaimed if smokers switch to smoking the Ruyan® e-cigarette

Here we estimate the public health benefits of widespread adoption of the Ruyan® e-cigarette *or any other product, policy or programme* that can likewise persuade smokers to stop smoking.

At personal level. For every two continuing smokers, one will die early from smoking (on average 13 years early[5]). So if two smokers both switch to Ruyan® e-cigarettes from the beginning, or otherwise succeed in quitting smoking, then 13 life years will be reclaimed.

In percentage terms. Similarly, for every 100 continuing smokers, 50 will die early from their smoking (on average dying 13 years early)[6] If, however, all 100 switch to e-cigarettes (or otherwise stop smoking tobacco) before 35 years of age, we would expect that 50 fewer will die early, a total of 650 life-years reclaimed, per 100 smokers. This is based on the proven zero excess mortality effect from daily use for five years of nicotine without tobacco.

At country level For New Zealand, with 21% of adults smoking and 656 000 daily smokers,[7] 4.3 million life years would be saved, in country of 4.2 million population, or one life-year reclaimed per capita, if everyone stopped smoking; equal to increasing life expectancy by one year averaged over the entire population. In reality, it is the smokers who stop smoking by abstinence or switching to the Ruyan® e-cigarette, who obtain this gain in longer life.

[4] da Costa e Silva V. Policy recommendations for smoking cessation and treatment of tobacco dependence. Tools for Public Health. World Health Organization 2003. 107 pp. ISBN-13. 9789241562409.
[5] Peto R, Lopez AD, Boreham J. et al. Mortality from smoking in developed countries, 2004. www.ctsu.ox.ac.uk New Zealand data.
[6] Peto R, Lopez AD, Boreham J. et al. Mortality from smoking in developed countries, 2004. www.ctsu.ox.ac.uk
[7] New Zealand Census March 2006. Smoking prevalence 20.7%. www.statistics.govt.nz

2. Description

The Ruyan® (pronounced Roo yen) (e for electronic) cigarette, like a tobacco cigarette, can rapidly deliver nicotine into the lungs, but without smoke carcinogens and toxicants.

The Ruyan® e-cigarette was first sold in May 2004, in China, with annual sales since of around 300,000 per year, and advertising on television, but no adverse effects reported by the English language dailies in China. Its December 2007 internet price was around US $208, with nicotine cartridge refills required every 300 puffs (1-4 days) costing extra. After 1300 puffs the battery is recharged from the mains.

2.1 Structure.

The distal segment with a red light indicating inhalation, contains the re-chargeable battery and is the controlling part. The middle part contains a vaporising chamber. The mouthpiece and nicotine cartridge are one piece, and a new one is inserted after 300-350 puffs. The nicotine in the cartridge is dissolved in propylene glycol (PG). Table 2.1 enables estimation of the weight of the liquid in the container.

Table 2.1. Ruyan V8 electronic cigarette 16 mg cartridge, components by weight

Component		g	g	g
Battery (distal segment)				13.9
Atomiser (middle segment)				8.58
Cartridge (mouth end segment)				
Cartridge part (white)			1.67	
	Plastic shell	0.436		
	Silicon foam, dry	0.061		
	Liquid, full	1.173*		
Mouthpiece (black)			0.89	
				2.56

* Estimated by subtraction. Of the 1.173 g, 1g may be extractable.

2.2 Function.

The Ruyan® e-cigarette is flameless and non-flammable. The pressure sensor in the controlling part electronically initiates rapid vaporisation of a dose of liquid propylene glycol containing nicotine into a fine aerosol that reaches the lung rapidly.[8] The dose per puff depends on the volume and force of the inhalation, and the number of puffs determines total dose.

3. Nicotine effects

The safety and toxicity of nicotine has been exhaustively reviewed.[9] The safety of pure nicotine alone, relative to tobacco smoking is not in question, nor is its overall safety in

[8] Hon, Lik. China. A non-smokable electronic spray cigarette. Patent CA 218174, published 2004/03/08.
[9] Nicotine Safety and Toxicity. Ed. NL Benowitz. Oxford. OUP. 1998.

absolute terms. Death has been recorded occasionally from accidental poisoning from nicotine (Section 7), but not from medicinal use.

No nicotine poisoning effects have been reported for the Ruyan® e-cigarette. In contrast to the use of alcohol or oral snuff, the very rapid absorption enables the user to become aware of the first effects (light-headedness, queasiness) before serious overdosing can occur.

3.1 Short-term effects

Dose-control. For each puff, "what you inhale is what you get". The smoker is protected from unwanted nicotine by the electronic circuitry shutting off almost immediately after each puff is taken. The smoker controls the size of the puff which determines the nicotine dose. The strength of the dose is immediately and correctly signalled by the irritation to the back of the throat, as no menthol is used to anaesthetise it. Thus the smoker is able to accurately control the dose from puff to puff.

With a zero-nicotine Ruyan® e-cigarette, there is no harshness on the throat, and without such negative feedback, the smoker may puff more frequently, but virtually no nicotine is inhaled. Purchasing 16 mg, 11 mg, 6 mg or 0 mg nicotine strengths of cartridge provides another way in which Ruyan® e-cigarette smokers can pre-regulate their nicotine intake.

Efficiency. No nicotine is wasted in the Ruyan® e-cigarette– over one to four days its nicotine is eventually all inhaled, thus differing from the 12% uptake of nicotine from the tobacco cigarette. In the tobacco cigarette, after combustion, most is lost in side-stream smoke. Of the mainstream smoke some is entrapped in the cigarette filter, while only 1.5 mg (12%) of the cigarette's original nicotine content of 13 mg is inhaled. (Table 1).

In first-time smokers. Acute nicotine toxicity occurs when never-smokers smoke their cigarette (whether tobacco or e-cigarette), becoming light-headed, with nausea and even vomiting, lasting typically for half an hour. Many would-be smokers are thus discouraged from learning to smoke.

Maintenance of steady nicotine blood levels. The experienced smoker of the Ruyan® e-cigarette controls the nicotine intake to maximise pleasure and minimise discomfort. A regular e-cigarette or tobacco cigarette smoker adjusts the size or frequency of each subsequent puff, to maintain nicotine blood levels high enough to avoid unpleasant craving for a cigarette, and low enough to avoid excessive harshness on the back of the throat, or light-headedness due to a high blood level of nicotine.

Self-medication. In a relaxed situation, a smoker may deliberately inhale to achieve the nicotine rush or buzz or light-headed feeling, which will pass within half an hour or so. This is nicotine self-medication, or drug-effect seeking behaviour, which many smokers practice. Inhaling to the point of light-headedness can be harmful for tobacco smokers, tobacco snuff users and e-cigarette smokers who have to drive a car or operate heavy machinery immediately afterwards.

3.2. Long term effects. Thousands of smokers and former smokers have used nicotine in the form of gum for five years with no increase in mortality or hospitalisation.[3]

Longevity The cumulative excess risk of continuing to smoke tobacco cigarettes beyond age 35 years is one in two.[2] As the Ruyan® e-cigarette carries no risk to longevity, the average smoker switching to the Ruyan® e-cigarette before age 35 years will reduce their risk of dying early by one in two.

Cancer and Cardiovascular toxicity. Nicotine is not a cause of cancer. The tendency for nicotine to temporarily increases heart rate and blood pressure flattens out above 8 mg yield per cigarette, so that low doses produce much the same effect as high doses,[6] suggesting that nicotine does not cause cardiovascular toxicity.

3.3 Previous tobacco smoking puts e-cigarette users at risk.

Ruyan® e-cigarette users will be mainly current or past tobacco smokers, and for that reason are at increased risk of heart attack, stroke or lung cancer. Tobacco cigarette smokers have two to three times the annual death rate of non-smokers, and have ten times the risk of sudden cardiac death. Deaths of e-cigarette users may be wrongly blamed on their new e-cigarettes, rather than their past smoking of tobacco.

3.4 Dual use.

Smokers may take some time to switch completely from tobacco to nicotine smoking. As long as they continue to smoke even a few cigarettes a day their risk of dying early remains excessive. (The risk of smoking even 1-4 cigarettes a day carries a 60% excess risk of dying early. Smoking 5-9 cigarettes a day doubles the risk of dying early, compared with never smoking[2]). In particular their excess risk of heart attack will not diminish substantially until they quit tobacco smoking entirely.

4. Nicotine dose, consumption, and labelling

4.1 Correct dose.

Each smoker is accustomed to a certain amount of nicotine each day. This varies greatly between smokers, but for each smoker, varies little from day to day. Heavy tobacco cigarette smokers in the United States smoking an average 36 cigarettes (range 20-62) per day absorb about 37 mg per day (range 10-79 mg)[10].

The Ruyan® e-cigarette cartridge can supply 16 mg nicotine per day. Non-inhalers and smokers of light cigarettes inhale less nicotine. If smoking one cartridge of the 16 mg Ruyan® e-cigarette per day is not able to control cravings, a second e-cartridge for the day might be needed.

Table 4.1 shows that, the 16 mg nicotine Ruyan® e-cigarette cartridge provides nicotine equal to 7 to 10 factory-made tobacco cigarettes. Once the smoker stops smoking tobacco cigarettes, the Ruyan® e-cigarette by itself is unlikely to cause nicotine overdose. Any smoker becoming light headed while smoking an e-cigarette, should stop smoking tobacco.

[10] Benowitz ibid. p.6.

Table 4.1 Nicotine content and delivery or absorption per puff, per smoke, and per day, factory-made tobacco cigarette and Ruyan® e-cigarette compared.

	Content Nicotine in each unburnt tobacco cigarette, or in each Ruyan® e-cigarette cartridge** mg	**Per puff** Nicotine delivery per puff; 99% absorbed## mg	**Per smoke** Nicotine delivery and absorption# per cigarette or Ruyan® e-cigarette smoke' mg	**Per day*** Nicotine delivery and absorption (per 300 puffs from 20 cigarettes or 20 Ruyan® e-cigarette 'smokes' mg
	A	**B****	**C**	**D**
Factory-made cigarettes	A	B=C/15	C	D=C*20
Regular filter cigarettes	13	0.16	1.4 to 2.4 assume 2.0	28 – 48, assume 38
Ruyan ® e-Cigarettes	A	B=A/300***	C=b*15	D=C*20
Ruyan® cartridge Label:**16 mg**	14~ - 16	0.053	0.80	14-16
Ruyan® cartridge Label = **11 mg**	10~ - 11	0.037	0.56	10-11
Ruyan® cartridge Label **6 mg**	6~	0.02	0.3	6
Ruyan® cartridge Label **0 mg**	0-0.5~	0	0	0-0.5

* Ruyan® cartridge lasts one to four days. If it lasts four days, divide Ruyan values in D by 4.
** Assumes 15 puffs per cigarette.
*** Assumes 300 puffs per Ruyan® e-cigarette cartridge. Smokers taking larger puffs may finish the cartridge before 300 puffs. ~ Benchtop test value.
# Nicotine absorbed per cigarette = 1.4 mg (Fagerstrom, for Sweden),[11] 2.4 mg (Djordjevic for USA).[12] The nicotine absorbed from tobacco smoking is much greater than what is printed on cigarette packets.
When nicotine aerosol is inhaled into lungs, approximately 99% of nicotine is retained.[13]
~ ESR Porirua October 2007.

4.2 Nicotine consumption per day. As puffs from the 16 mg nicotine Ruyan® cartridge contain one third to one half the nicotine in a tobacco cigarette puff, and Ruyan® e-cigarette smokers take up to four days to finish a cartridge, smokers are most unlikely to absorb more nicotine from Ruyan® e-cigarettes than previously absorbed from tobacco.

Smokers of the Ruyan® e-cigarette say a cartridge lasts 1 to 4 days, which for a 16 mg cartridge is equal to 4 to 16 mg per day daily or equal to 2.5 to 10 tobacco cigarettes a day unaccompanied by tar or gas toxicants (Table 1). Pure nicotine in this dose is neither excessive nor harmful.

As virtually all cartridge nicotine is eventually inhaled, and over 98% of inhaled nicotine is absorbed[13] the consumption of nicotine cartridges per smoker will reliably establish the level of nicotine absorption per day, provided no tobacco or other nicotine product is being used. This enables clinicians and researchers to estimate nicotine consumption with more precision than is possible with tobacco consumption.

4.3 Nicotine per puff

Method 1) 'Smoke', 35 ml per puff, was drawn from the mouthpiece of the Ruyan e-cgiarette until no more was obtainable. The total puffs per cartridge were thus documented for the manufacturer at a well-known Beijing laboratory.[14]
2) An e-cigarette (0 mg nicotine) was smoked for a total of 80 breaths – 40 shallow, and 40 by deep lung inhalation. The puffing was measured by CreSSmicro interposed between smokers and the e-cigarette. (Table 4.3)

Results.

1) By volume measurement, the manufacturer's estimate was 350 breaths per cartridge. Table 4.1 is based on this estimate.
2) By weighing the decreases per ten puffs taken, (Table 4.3) the average weight of liquid used per puff was 1.5 mg for lung inhalations, and 0.5mg for shallow mouth-throat inhalation. As extractable propylene glycol is approximately 1.0 g, one cartridge should provide 667 lung inhalations.

Conclusion.

These two methods give different results. Further tests in human subjects will clarify how many puffs are obtained by most smokers per cartridge.
If the e-cigarette contained a 16 mg per 1 g of cartridge liquid, instead of the 0 mg cartridge as in Table 2, then, assuming the nicotine was equally concentrated across all puffs, and assuming all breaths are lung inhalations, 1.5 mg of liquid went into the average puff, providing an estimated 1.5 * 16ug nicotine per puff = 24 micrograms of nicotine,. Fifteen puffs would thus supply 360 ug or 0.36 mg of nicotine, that is one fifth of the amount from one cigarette. And 15 shallow puffs would only supply 0.12 mg of nicotine. Volume and weight calculations thus give differing values. Pharmacokinetic testing will show whether smokers obtain sufficient nicotine from the e-cigarette.

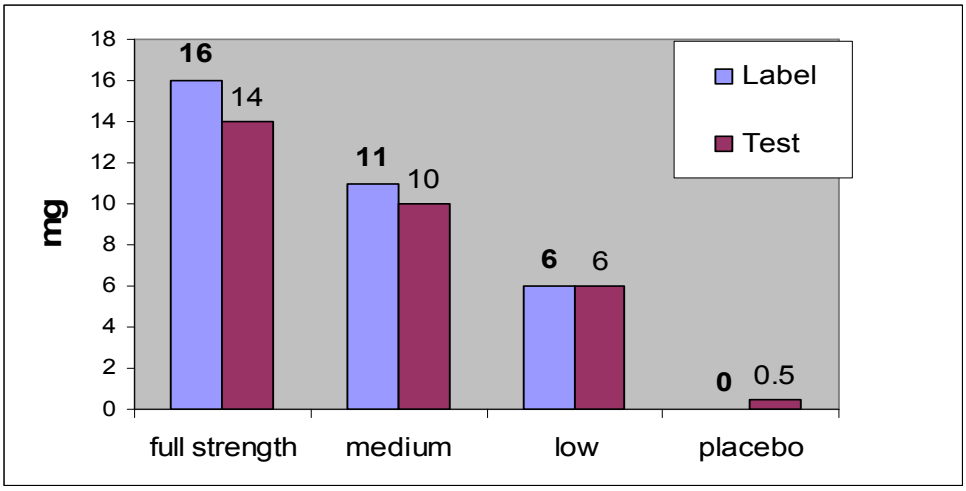
Table 4.3. Weight loss of the 0 mg e-cigarette as a measure of vapourisation of the cartridge liquid

Method	Average puff duration in seconds	Average volume per puff mL	Puff Count	Weight change in e-cigarette Mg	Weight loss per breath mg
Inhaled into mouth and throat (puff volume 21 ml)					
Mouth/throat	0.76	21.1	40	20	0.5
Inhaled into lungs (average puff volume 44 ml)					
Total lung	1.63	43.8	40	60	1.5
Total all	1.20	31.9	80	80	1.0

Lung inhalation results in three times as much cartridge liquid being inhaled, as from shallow inhalation confined to mouth and throat.

4.4 Accuracy of nicotine dose labels

Table 4.4 Ruyan® e-cigarette per cartridge nicotine content by label and by test



The only biologically active ingredient expected in the Ruyan® e-cigarette cartridge liquid is nicotine. On analysis[15], the cartridges labelled as 16 mg actually contained 14.1 mg of nicotine; those labelled 11 mg contained 10.0 mg; those labelled 6 mg contained 5.9 mg; and those labelled 0 mg of nicotine contained 0.5 mg.

In a separate estimation, the nicotine alkaloid β-nicotyrine ($C_{10}H_{10}N_2$) was detected on scan of the headspace in the cartridge by microextraction. The area under the peak was 4% that of nicotine. ($C_{10}H_{12}N_2$). This requires re-analysis once the source of nicotine for the e-cartridge is upgraded.

5. Risk of addiction

5.1 Tobacco versus nicotine addiction.

The extent of the addictive potential of the Ruyan® e-cigarette is not yet known. The frequency of nicotine addiction is lower for all nicotine products so far developed, than for tobacco products, but the e-cigarette represents the first time a pure-nicotine-smoking product is available to be compared with a tobacco cigarette. The illness consequences of addiction to lit tobacco smoke however, are infinitely greater than from addiction to nicotine;without the products of combustion.[3]

Other active substances in tobacco. MAO inhibitor compounds (such as harman and norharman) in tobacco smoke are believed by many to potentiate the effect of the nicotine. If this proves to be a strong factor with respect to tobacco smoke, then the nicotine-only e-cigarette will be much less addictive than smoking tobacco cigarettes. Vapours from the e-cigarette cartridge do not inhibit MAO enzymes. See 8.1.2

Other factors. The cost of buying the e-cigarette, and the need to use a credit card to order it by mail, will likely deter most young people obtaining the e-cigarette for personal

use. If some youths do use it, and develop a taste for nicotine, the price of nicotine refills versus cigarettes will be decisive for many. It also depends on fashion, safety concerns, and whether parents, health groups and doctors approve its use.

5.2 Addiction in smokers

The Ruyan® e-cigarette does not cause nicotine addiction in smokers, as most cigarette smokers are already addicted to nicotine. E-cigarettes are not expected to increase the need for nicotine in smokers, as each smoker needs a certain amount of nicotine each day, and the brain receptor cells cannot distinguish where the nicotine molecule comes from (smoked tobacco, tobacco snuff, or e-cigarette). The e-cigarette does not increase the daily customary dose; from the first day of using the Ruyan® e-cigarette most smokers tend to smoke very few tobacco cigarettes, and surprisingly, seem to use few e-cigarette cartridges in their place. This however is yet to be researched.
Once the daily dose is obtained, the smoker will not reach for another puff from either their tobacco cigarette or their e-cigarette: no pleasure is obtained and there is no craving to relieve.

Further research on quitters is required to find out how many will prefer to continue using the e-cigarette one year after quitting smoking.

Smokers quitting smoking in countries which encourage quitting, are likely to use the e-cigarette to gain control of their nicotine needs, and use it temporarily – for a few weeks only, after stopping smoking. Quitting smoking is often part of a lifestyle change which will often include quitting tobacco and nicotine altogether. By the time smokers are ready to quit cigarettes, many also want to end their nicotine addiction.

The 16 mg, 11 mg nicotine cartridges are expected to satisfy the cravings and maintain the addiction of smokers who wish to stay on nicotine. This is the subject of further tests in 2008.

On the basis of similarity to the rapid action of nicotine nasal spray, we assume that one year after smokers' first using the Ruyan® e-cigarette as a stop smoking aid, no less than 15% would become long term users. (See data for nicotine nasal spray below)..

The 6 mg nicotine cartridge if used up in one day may provide just enough nicotine to maintain addiction. Used over 4 days it would not be sufficient. Very recent quitters using the 6 mg cartridge would likely have cravings for cigarettes and be at risk of smoking tobacco again.

The 0 mg nicotine-labelled cartridge will not maintain addiction. It will provide 0.002 mg nicotine per puff, 0.025 mg per smoke, which at even 300 puffs a day amounts at most to 0.6 mg per day, much less than the estimated 5 mg daily required to sustain addiction[16]. The labels were therefore safe estimates of the dose of nicotine to be expected, and the 0 mg e-cigarette can be used without risk of creating or maintaining dependence on nicotine. Nicotine is not recommended for non-smokers but for smokers already addicted (dependent) to nicotine, who wish to avoid inhaling tobacco smoke.

Tobacco cigarettes Some 84% view their own use of cigarettes as an addiction[17].

Comparison with nicotine medications (Nicotine Replacement Therapy, NRT) Of users of nicotine medications some are still using the medication after one year and assumed to be addicted. (2% for patch, 8% for spray, 9% for gum and 15% for nasal spray) [18].

6. Addiction in young people

Tobacco, tobacco snuff, nicotine snuff (Niconovum) and the e-cigarette can all be expected to induce nicotine addiction in many young people. This involves a subtle loss of autonomy or control over their new habit. Once addicted to nicotine, the concern is that tobacco, snuff and the e-cigarette could be used interchangeably.

The answers to this concern depend on what policies society has put in place to steer young people away from addiction of any kind, and away from tobacco smoking in particular. In 2007, New Zealand smokers could buy an e-cigarette from the internet for the price of a carton of cigarettes. If cigarettes cost much more, more would buy the e-cigarette. Similarly, graphic disease warnings on cigarette packets may persuade smokers to quit or switch to other alternatives such as the e-cigarette which do not require or merit such disease warnings.

Addiction to smoking tobacco cigarettes ensures young smokers remain smokers into adult life and continue to smoke beyond 35 years of age when the risks of smoking deaths begin to increase. Similarly smoking the e-cigarette makes it less likely that the smoker will ever want to smoke tobacco cigarettes again.

Young people may use the e-cigarette as a temporary crutch while stopping smoking and so avoid the future increased mortality risks of smoking. If the e-cigarette was widely available to young people, their cigarette smoking would decrease, life expectancy increase and respiratory health would improve, without any extra mortality from nicotine.

The fate of users of the e-cigarette

Smokers who try the e-cigarette will either:

- Try the e-cigarette experimentally, then revert to tobacco smoking as before.
- Use the e-cigarette as a temporary aid to quitting smoking entirely.
- Switch permanently to e-cigarette (and no longer smoke tobacco) .
- Continue to use both e-cigarette and tobacco cigarettes (See 3.4 above).

First cigarettes The first tobacco cigarettes smoked result in one on four adolescents losing some autonomy (control) over their smoking[19]. Whether some adolescents would soon lose partial control over their use of the Ruyan nicotine e-cigarette is not clear.

Addictive potential The proportion of young people who will prefer the e-cigarette over tobacco, and who use it long term, is unknown. It will vary by country. If government and health groups regard the e-cigarette as almost as dangerous as smoking, e-cigarette

smokers may adopt a "why not" approach to tobacco cigarette smoking, and tobacco cigarette smoking will not be reduced. If, however, society approves the e-cigarette as a cigarette alternative, its users can smoke it openly, without damaging their health. It will be a much safer habit than either smoking tobacco or drinking alcohol.

Graphic and varied health warnings The e-cigarette is not likely to cause addiction any more than cigarettes, which most adolescents can obtain with ease. On the other hand, the e-cigarette supplies safe nicotine, without risk of early death due to lung cancer, heart disease, or emphysema. A simple, truthful warning is therefore suggested below for the e-cigarette.

Graphic warnings on cigarette packets will discourage tobacco smoking.. Better information about the health risks of smoking, and higher prices for tobacco, will mean that as the e-cigarette becomes available, the proportion of young people smoking tobacco should decrease more rapidly.

Possible health warning

This nicotine product is addictive but avoids the other risks of smoking.

Tobacco cigarettes in many countries now warn the smoker "Smoking is addictive". Similar warnings are needed on the e-cigarette packaging, pointing up the difference between the e-cigarette and tobacco cigarettes. Although the manufacturer's pamphlet warns that the e-cigarette is not suitable for young people or non-smoking adults, some may gain access to it.

If young people see graphic disease warnings and high prices on tobacco packets, young people will abstain from tobacco smoking or possibly switch to e-cigarette smoking instead. In due course, fewer will die early from tobacco smoking.

Conclusion.

The invention of the e-cigarette means society must now distinguish between

- Very harmful (tobacco) smoking, and harmless (e-cigarette) smoking; and
- very harmful addiction (associated with smoking) and fairly harmless addiction (associated with the e-cigarette).

Regulators in Western countries are likely to

- prohibit sale of nicotine e-cigarette refills to under-18s, in line with restrictions on cigarette sales to youth
- permit e-cigarette use in most areas where tobacco cigarette smoking is banned
- permit e-cigarette advertising in countries permitting advertising of NRT.
- continue to enforce existing bans on the advertising of smoking tobacco.

7. Risk of accidental ingestion of nicotine

Accidental ingestion of the e-cigarette is theoretically possible, though it has not been mentioned in the English news media in their articles on the Ruyan® e-cigarette from China, where 300,000 units are sold annually since 2004. Poisoning by ingesting tobacco cigarettes is rare, even though children can easily access tobacco cigarettes in the home.

7.1 Ruyan nicotine cartridges, when sold separately are packed in individually sealed child-proof canisters. Without scissors, even adults find them difficult to open. In this packaging, unattended children in car or home are not at risk from the nicotine.

7.2 The nicotine cartridge assembled into the e-cigarette is better child-proofed than a packet of tobacco cigarettes.

- Many Ruyan® smokers keep their e-cigarette close by, reducing risk of child access.
- Once assembled, the join between the e-cigarette mouthpiece/ cartridge, and the metal shell of the middle section is normally difficult even for an adult to pull apart. It is not a screw join.
- If, unusually, this join was loose, it prevents normal use of the e-cigarette, so does not remain loose for long.
- If unusually a child gained access to it and pulled it apart, put the cartridge in the mouth and sucked on it, then the nicotine impregnated in the cartridge could be absorbed through contact with mouth mucosa causing acute toxicity.

Swallowing is less likely, as the mouthpiece-cartridge measures 5 cm in length by 1cm diameter, and requires adult force to separate its two parts.

The highest dose e-cigarette cartridge contains 16 mg of nicotine. The factory-made tobacco cigarette contains 13 mg[20]. The lethal nicotine dose for a child is known to be 10 mg.

8. Safety of the cartridge liquid and inhaled aerosol

Propylene glycol makes up 89-90% of the liquid in the nicotine cartridge that generates the aerosol inhaled by the e-cigarette smoke. (See Appendix 1, Table 2).
Propylene glycol is virtually non-toxic, See Appendix 3.

8.1 Tobacco flavour, Nitrosamines and MAO inhibitor effects

In cartridges dated November and December 2007, the fragrance, odour and taste of tobacco remained. The manufacturer's recipe (Appendix 1) suggests this comes from a flavour base containing tobacco extract weighing 6 mg per cartridge. As we now show, the cartridge liquid does not behave like tobacco:

8.1.1 Tobacco-specific nitrosamines Traces of these nitrosamines, found only in tobacco, were not found in the Ruyan® e-cigarette cartridge liquid except at trace quantity, at a level equal to that reported for medicinal Nicorette gum, at a low level uncharacteristic of tobacco. On this basis, the Ruyan® e-cigarette is a nicotine product, not a tobacco.

The maximum level of tobacco specific nitrosamines of 8 ng TSNAs per gram of cartridge liquid (8 parts per billion or ppb) found in 16 mg nicotine cartridges, compares closely to the 8 ng per gram found in Nicorette gum sold as a nicotine replacement therapy medicine in the United Kingdom[21]. The e-cigarette TSNA content is 200 times less than the amount found in Swedish moist snuff (1000 to 2400 ppb), and 150 times

less than the amount found in unburnt tobacco in the most popular filter cigarette and cigarette tobacco brands (1230 ppb)[22].

Table 8.1 Tobacco specific nitrosamines (TSNAs) in the cartridge liquid of the Ruyan ® e-cigarette, November 2007

Nicotine per Cartridge	Sample ID	NNN (ng/cartridge) Observation	NAT (ng/cartridge) Observation	NAB (ng/cartridge) Observation	NNK (ng/cartridge) Observation	TSNAs Ng/cartridge total
0 mg	073277	BDL	BDL	NQ	0.260	0.260
6 mg	073278	1.42	1.02	BDL	0.628	3.068
11 mg	073279	1.83	1.36	NQ	1.01	4.200
16 mg	073280	3.87	2.16	0.693	1.46	8.183
Labstat 2007[23].					Average TSNAs	3.928
BDL = Below the limit of detection. NQ = Not quantifiable. TSNA = tobacco specific nitrosamines. NAB= nitrosoanabasine NNN= nitrosonornicotine, NAT= nitrosoanatabine, NNK= 4-nitrosomethylamino-1-(3-pyridyl)-1-butanone						

8.1.2 <u>Monoamine oxidase</u>. The cartridge liquid retains a tobacco fragrance or odour. (Appendix 1). Monoamine oxidase (MAO) enzymes both A and B, are strongly inhibited by tobacco smoke extract but the cartridge liquid had no such effect[24]. MAO, found in blood platelets and the brain, has been regarded as a potentiator of the reinforcing (addictive) effects of nicotine. The test results have several implications:

1) The e-cigarette liquid in the cartridge lacks the MAO inhibiting effect of tobacco.

2) Any addictive potential of the e-cigarette is due to nicotine (complemented by nicotine analogues) but the nicotine effect is not reinforced by MAO. This provides a biomedical basis for the e-cigarette to be less addictive than smoking tobacco.

3) If the e-cigarette proves to be no less addictive than the tobacco cigarette, the difference could be explained by less nicotine inhaled from the e-cigarette; or it could be due to MAO in tobacco.

4) The closer the addictive potential of the e-cigarette to that of tobacco cigarettes, the less likely it is that MAO in tobacco is important in reinforcing nicotine's addiction potential.

8.1.3 Benzo(alpha)pyrene The cartridge liquid was tested for benzo(alpha)pyrene, a probable human carcinogen (detectable in tobacco cigarette smoke at 35 nanograms (ng) per cigarette). The value obtained from the e-cigarette liquid was below the method's limit of detection of 1 ng[25]. As the e-cigarette cartridge is equivalent in nicotine to no more than 10 cigarettes, e-cigarette smoking delivers 350 times <u>less</u> benzo(alpha)pyrene than does tobacco cigarette smoking.

8.2 Volatile organic compounds (VOCs)

8.2.1 In e-cigarette 'smoke'.

The yield of VOCs in the "smoke" of the e-cigarette has not been analysed. Volatile organic compounds are small molecules, the products of combustion, and found in all tobacco smoke. The e-cigarette generates no flame or fire; and does not heat up the e-cigarette. The very high temperatures of a burning cigarette (combustion) are not achieved in e-cigarette smoke.

Analysis of VOCs is planned before the next and final version of this report is issued.

8.2.2 In the e-cigarette cartridge liquid.

A) By SIFT-MS (Selected Ion Flow Tube and Mass Spectrograph) method

Aim To test the headspace of liquid from freshly opened (un-smoked) cartridges by SIFT-MS method, and incubate for one hour at 37 deg C.

Method Ruyan e-Cigarette cartridges (16 mg nicotine; batch 20071228) had their wisp removed and one was placed in each of two 500-mL glass Schott bottles, which were then capped with pierceable septa. Duplicate blank samples of laboratory air were also analysed for comparison. Bottles were then incubated at 37 °C for approximately 60 minutes prior to analysis.

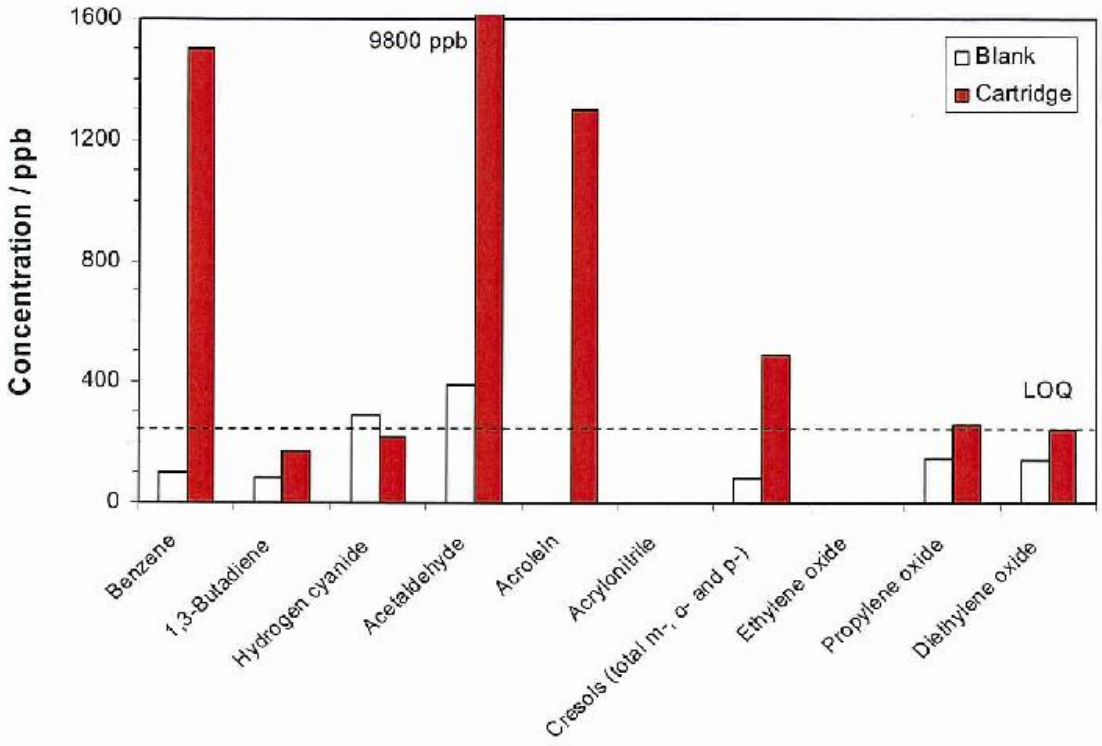
Method
SIFT-MS analyses gas samples for volatile organic compounds (VOCs) and certain inorganic compounds.[1] Typically it can accurately detect and quantify these compounds in real time at very low concentrations (usually to parts-per-trillion {ppt} levels), even at breath humidity. SIFT-MS does not employ chromatographic separation and hence cannot perform well when high levels of organic solvents are present. A Syft Technologies Voice100^{TM} instrument was used for this work. It was operated in two modes- selected ion mode (SIM) or Full Scan Mode (FSM).

Results
The results of the analysis are shown in Figure 8.2.2a and Table 8.2.2b. High levels of ethanol were found in the cartridges (identified from the full scans). This meant that the SIFT-MS instrument had to be run at reduced sensitivity for the analysis presented here, with a degraded limit of quantification (LOQ = 300 ppb). Consequently, some target compounds could not be reported, as all their available ion products suffered significant interference; and for the toxicants reported, the results represent an upper limit to the true concentration in the wisp.

- Using SIFT-MS, (Figure 8.2.2a), due to interference from alcohol in the Ruyan cartridge, ethylene oxide could not be separated from acetaldehyde. Meantime, using HS SPME method (below) ethylene oxide was not detected in the headspace of the Ruyan cartridge, and therefore the 9500 ppb seen in Figure 1 is all due to acetaldehyde.
- Acrylonitrile does not register in the graph: no response was obtained. Although below the level of quantitation of 0.3 ppm, it suggests that acrylonitrile is absent.

Figure 8.2.2a: SIFT-MS headspace analysis of the Ruyan® e-cigarette cartridge (mean of two replicates), showing the instrument's estimated limit of quantitation.

Figure 1: *SIFT-MS headspace analysis of the Ruyan e-Cigarette cartridge (mean of two replicates), showing the instruments estimated limit of quantitation in this case.*



"The results presented here are preliminary, due to interferences caused by ethanol, which is present at very high concentrations in the wick. The results represent an upper limit. However the measurements do show definitively that a number of tobacco-related toxicants are not present at significant levels in the e-Cigarette, such as hydrogen cyanide, 1,3-butadiene and acrylonitrile. For toxicants that appear to have concentrations above the limit of quantitation (LOQ), it is recommended that other techniques (for example, GC-MS or LC-MS) be used for more definitive analysis."

Accordingly, on this recommendation we used GC-MS analysis (See 8.2.2B below).

Table 8.2.2b: SIFT-MS headspace analysis of the Ruyan® e-cigarette cartridge (mean of two replicates). "<LOQ" = less than the limit of quantitation.

Toxicant	Concentration in blank (parts per billion; ppb)	Concentration in headspace of cartridge (parts per billion; ppb)
Acetaldehyde	<LOQ	9500
Benzene	<LOQ	1500
1,3-Butadiene	<LOQ	<LOQ
Hydrogen cyanide	<LOQ	<LOQ
Acrolein	<LOQ	1300
Acrylonitrile	<LOQ	<LOQ
Cresols (total m-, o- and p-)	<LOQ	490
Propylene oxide	<LOQ	<LOQ
Diethylene oxide	<LOQ	<LOQ

Langford 2008[26]

B) Volatile Profile of the Sample Ruyan® e-cigarette by using HS-SPME and GC-MS[27]

Introduction

Head Space Solid-Phase Micro-Extraction (HS-SPME) was the sampling technique used to sample the headspace volatiles emitted from the sample upon heating. This involved exposing a conditioned fibre into the headspace of a sealed vial and allowing the volatile compounds in the headspace to absorb onto the fibre surfaces. These volatile compounds were then introduced into the GCMS by exposing the fibre inside the GC injection port where they were stripped off at a high temperature.

The compounds detected by the mass spectrometer were Qualified only, i.e. identified by comparison with a mass spectral library and their relative abundances reported. Concentrations for these compounds were not obtained using this technique. In order to obtain concentration information the protocol used would need to be changed to include the use of standards, both internal and external.

Method

Samples were analysed using a Shimadzu GCMS-QP2010 gas chromatograph mass spectrometer fitted with a Restek Rtx-WAX fused silica capillary column (30.0m x 0.25mmi.d. x 0.50µm film thickness) coupled in series with a Restek Rtx-1ms fused silica capillary column (15m x 0.25mm id x 0.25µm film thickness).

Sample preparation involved placing the ecigarette into a 20 ml SPME sample vial where it was then quickly capped. Using a CTC-Combi PAL auto sampler (Shimadzu AOC-5000), samples were incubated for 60 min at 37ºC with their enclosed headspace

exposed to a 2 cm long DVB/CAR/PDMS combination SPME fibre (Supelco). During this exposure period the headspace volatiles were absorbed onto the fibre.

Desorption of these volatiles occurred when the SPME fibre was inserted (by the Atuosampler) into the heated (250 deg C) injection port of the Shimadzu GCMS-QP2010 gas chromatograph–mass spectrometer. The injection port was then used in Splitless mode operating with a Helium carrier gas linear flow of 25.9cm/s (column flow). The GC columns were held initally at 35 deg C for 5mins, ramped to 100 deg C at 7 deg C/min where it was then ramped to 200 deg C at 3 deg C/min, and then finally ramped to 250 deg C at 7 deg C /min and held for 10mins.

During the elution of the compounds the GC–MS was operated in scan mode at a detector voltage of 1.2kV and electron impact ionisation voltage of 70 eV. All compounds detected were identified by matching their mass spectra with the spectra of reference compounds found in the NIST EPA/NIH Mass Spectral Library database (National Institute of Standards and Technology, NIST05).

Results

Table 8.2.2c. Screening of headspace vapour of a just-opened Ruyan® e-cigarette cartridge by different methods- SIFT-MS (Selected Ion Flow Tube with Mass Spectrometry), Solid phase microextraction (HS-SPME), and exhaled CO.

Compound	Toxicology *	**MRLs** Minimal Risk Levels non-cancer effects) ppm**#	**PELs** Permissible Exposure Levels of OSHA) ppm***	Detected in headspace vapour of Ruyan® e-cigarette cartridge Detected YES or NO	
				SIFT-MS Mass Screen ppm, 37deg C	HS-SPME 37deg C
Acetaldehyde	CA?, R.	Not listed	200	YES <9.5ppm	YES
Acetone	N	13 Chronic	1000	Not tested	YES
Acrolein	R	0.00004 I	0.1	YES < 1.3	NO
Acrylonitrile	CA, R	0.1 Acute	Not listed	NO. <<0.3	YES
Benzene	CA, CVD	0.003 Chronic	10	YES < 1.5	NO
1,3, Butadiene	CA	Not listed	1-5	NO <0.3	NO.
m-, o-, p- Cresols	CVD	Not listed	5	YES <0.495	NO
Carbon monoxide	CVD^	Exhaled.breath	50	15 puffs do not raise CO	
Ethylene oxide	CA	0.09 ppm I	Not listed	Not reported.	NO
Hydrogen cyanide	CVD	Not listed	10	NO < 0.3	NO
Propylene glycol	Not toxic	0.009 ppm I	None listed	YES	YES
Styrene	? CA	0.2 chronic	100	Not tested	YES
Xylenes	N	0.05 chronic	100	Not tested	YES

* CA= carcinogen, CVD= cardiovascular toxicant, N= neurological toxicant, R= respiratory toxicant.

^CVD risk for increased risk of ventricular fibrillation begins at 33 ppm (COHb=5%) and above. http://www.atsdr.cdc.gov/interactionprofiles/IP-12/ip12-a.pdf
**Minimum Risk Levels for hazardous substances.US Public Health Serivce, Agency for Toxic Substances and Disease Registry. Nov. 2007.http://www.atsdr.cdc.gov/toxpro2.html
***Permissible Exposure Levels. OSHA. Sept. 2007.
http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992

Acute effect = 1-14 days, I=Intermediate effects = 14-364 days, Chronic effect = 365 days or longer.
< LOQ= below the limit of quantitation. ppm = at 37 degrees Centigrade.

Summarising Table 8.2.2c above, the volatile organic compounds detected had either

- High permitted level for chronic exposure, as for acetone, acetaldehyde, styrene or xylene. (10 to 1000 ppm), but not yet quantified, or
- No listing under OSHA, but not exceeding 0.3 ppm on SIFT-MS, or
- No listing under OSHA, lack of proven toxicity. Example: propylene glycol, Present in ample quantity.

Table 8.2.2d. Toxicants ranked by Permitted Exposure Levels,* and whether present in Ruyan® e-cigarette cartridge vapour as detected by HS-SPME and exhaled CO.

Permitted Exposure Level PEL, ppm*	Compound Ppm	Detection by HS-SPME	SIFT-MS	CO Monitor, Exhaled breath	Remarks
< 1 ppm	Acrolein	NO	1.3 ppm		Need to quantify further
10 or less	HCN, butadiene	NO	<LOQ		Major toxicants
50	Carbon monoxide			NO, Not increased	
100 100 200 1000	Styrene Xylene Acetaldehyde Acetone	YES YES YES YES	9.5 ppm		OSHA permits higher levels in air for chronic exposure to these gases
Not listed by OSHA	Propylene glycol	YES	YES		Not considered toxic
	Acrylonitrile	YES	<<0.3 ppm, virtually zero.		Need recheck and quantify by a GC-MS method
	Ethylene oxide	NO			

***Permissible Exposure Levels**. OSHA. Sept. 2007 for weighted average exposures during an 8 hour shift.
http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992

For a graphic of the run result, see www.healthnz.co.nz/Portland2008ECIG.pdf

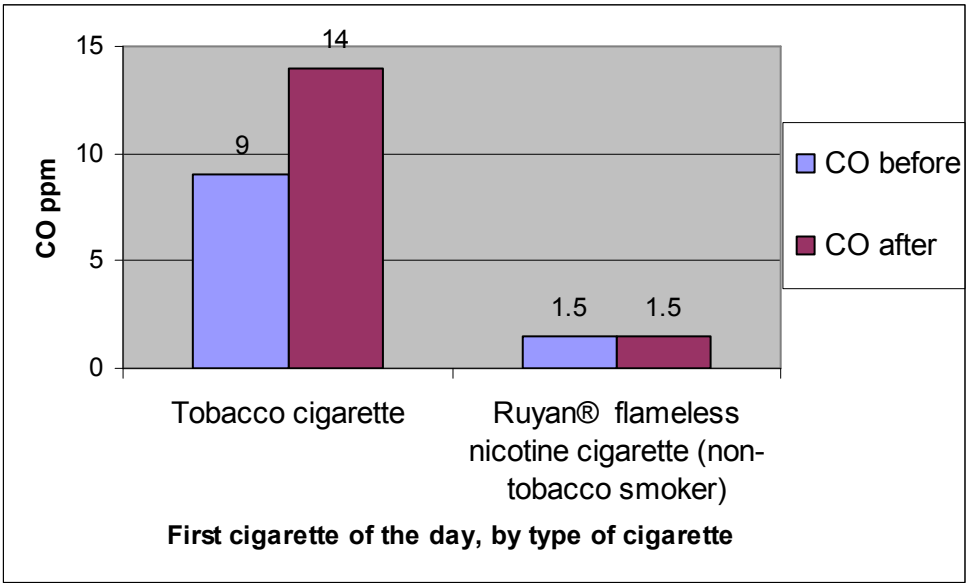
8.2.3 Analysis of the exhaled breath after using the Ruyan® e-cigarette

Carbon monoxide is a product of combustion and therefore can distinguish between the smoke produced by burning tobacco versus flameless cigarettes.

Method
Five minutes after their final puff of their first cigarette of the day, 17 smokers exhaled into a MicroMedical CO analyzer.[28] A non-tobacco smoker with a smokefree home and workplace, was similarly tested after 20 lung inhalations from of the Ruyan® e-cigarette.

Results

Table 8.2.3 Carbon monoxide in exhaled breath, before and after the first cigarette of the day, tobacco versus Ruyan® e-cigarette



The tobacco cigarette boosted CO in exhaled breath by an average of 5 ppm, but did not increase it in the non-smoker inhaling from the flameless Ruyan® e-cigarette

8.3 Impurities

8.3.1 In Propylene glycol. Impurities might arise in the manufacture or storage of propylene glycol.

Propylene oxide and ethylene oxide (a carcinogen) were not detected above the limit of detection 16.75 ug/ml and 42.5 ug/ml respectively on GCMS (gas chromatograph, mass spectrograph) testing.[29]. Some interference (matrix effect) prevented accurate quantification. However neither compound was detected by the HP-SPME scan, suggesting their levels if present were likely to be under 1 ppm.

8.3.2 Heavy metal traces. Heavy metals such as chromium, arsenic, and nickel can cause cancer, and lead is a neuro-toxicant. The liquid was tested for heavy metals (Arsenic, Antimony, Cadmium, Chromium, Cobalt, Copper, Lead, Manganese and Nickel), and the concentrations in each case were less than 1 part per million.
No hazardous effects are expected from heavy metals at this concentration[2] .

9. Risk of cross-infection from use

9.1 Risk of contamination from the mouthpiece. Public health agencies typically advise smokers not to share drinking glasses or cigarettes, due to the risk of cross-infection from lip saliva on the mouth end, with the risk of meningitis. This advice holds true for any electronic cigarette.

9.2 Risk of micro-organisms in the cartridge liquid. Another risk would be if the liquid in the cartridge acted as a culture medium for micro-organisms. The 5% alcohol content of the cartridge liquid (See Appendix 1) might be expected to inhibit growth of micro-organisms.
Environmental Science Research tested one used and one unused Ruyan® cartridge for the presence of the three main classes of micro-organism (aerobic, anaerobic and Legionella)[30]. None was found.
We conclude there is no inherent tendency in the design of the Ruyan® e-cigarette towards contamination from growth of organisms in the cartridge liquid. Nevertheless, instructions to users (and to tobacco cigarette smokers) should discourage cigarette sharing because of the risk of transfer of meningococcal meningitis, tuberculosis and other infectious diseases.

10. Safety of Ruyan® e-cigarette 'smoke' for bystanders.

Because inhaled nicotine is over 98% absorbed[6], the exhaled 'smoke' is propylene glycol minus the nicotine, and any exhaled PG mist dissipates within seconds. Without the gaseous products of combustion, the 'smoke' is not harmful to bystanders. The 'smoke' or mist is not tobacco smoke, and not from combustion – no flame is lit – and is not defined as environmental tobacco smoke. and e-cigarette "smoking" would be permitted under New Zealand's Smoke free Environments Act[31].

11. Further safety testing

Analyses have been requisitioned for further testing for possible impurities in the cartridge liquid.

Also, in January to March 2008, as part of a further trial of safety and efficacy, Clinical Trials Research Unit, University of Auckland independently monitored the use of the e-cigarette by some 50 subjects, over the course of one day, and recorded any adverse effects. These results are not yet available, and so will form the basis of a separate report to be published later in 2008.

Appendix 1. Safety of cartridge liquid in the Ruyan® e-cigarette

Summary:
Based on the manufacturer's information, the composition of the cartridge liquid is not hazardous to health, if used as intended.

Table 1.1: Chemical compositions (quantity) released from each Ruyan® cartridge

Chemical content released from each cartridge	Cartridge Specification, named by nicotine content			
	16mg	11mg	6mg	0mg
Water (mg)	40	40	40	40
Alcohol (mg)	50	50	50	50
Propylene glycerol (mg)	888	893	898	904
Nicotine (mg)	16	11	6	0
Flavor Base (mg) *	6	6	6	6
Total (mg)	1000	1000	1000	1000

Source: Manufacturer's data

Table 1.2: Chemical compositions (percentage w/w) released from each cartridge

Chemical content released from each catridge	Cartridge Specification, named by nicotine content.			
	16mg	11mg	6mg	0mg
Water	4%	4%	4%	4%
Alcohol	5%	5%	5%	5%
Propylene glycerol***	88.8%	89.3%	89.8%	90.4%
Nicotine	1.6%	1.1%	0.6%	0.0%
Flavour base *	0.6%	0.6%	0.6%	0.6%
Total	100%	100%	100%	100%

Source: Table 1.1.

*** See Appendix 3. Safety of Propylene Glycol.

***Safety Evaluation: 4-hydroxy-2,5-dimethyl-3(2H)-furanone and Acetyl pyrazine**

1). **4-hydroxy-2,5-dmethyl-3(2H)-furanone**
4-Hydroxy-2,5-dmethyl-3(2H)-furanone (FEMA 3174, CoE 536) is naturally occurring in various foods and plays an important role in the flavor of numerous fruits as well as in roasted products. 4-hydroxy-2,5-dmethyl-3(2H)-furanone has the odor and taste of fruity, caramelized pineapple-strawberry and is widely used in fresh bread, butter, chocolate, chocolate cocoa, coffee, meat roasted and nut almond.

Over 90% of annual production volume of tetrahydrofuran and furanone flavoring agents is 4-hydroxy-2,5-dmethyl-3(2H)-furanone. The estimated daily *per capita* intake is 5300 μg in Europe and 5200μg in the USA. Due to the large consumption, the safety of 4-hydroxy-2,5-dmethyl-3(2H)-furanone is extensively investigated. The oral LD_{50} for

mouse is 1,608mg/kg. Genotoxicity is observed at high dose, but it is related to a mechanism involving reactive oxygen species, rather than the generation of an active metabolite. A 2-year study in which rat were given a dose up to 400mg/kg bw from diet daily showed no evidence of carcinogenicity. Considering the fact that NOEL of 200mg/kg bw in rat is >2300 times the daily intake as a flavoring agent, the WHO Committee on Food Additives concludes that "the safety of this agent would not be a concern at the estimated current intake"[1].

2)**. Acetyl pyrazine**

Acetyl pyrazine (2-acetyl pyrazine, FEMA 3126, CoE 2286) is found in beef, coffee, popcorn, sesame seed, almond, wheat bread, cocoa, peanut, pork and potato chips, etc. According to the documentation from tobacco industry, acetyl pyrazine is added to cigarettes to give a pop-corn-like flavor and aroma to the tobacco.

Acetyl pyrazine belongs to a group of 41 flavoring agents consisting of pyrazine and pyrazine derivatives. Among them, acetyl pyrazine is detected naturally and its daily intake threshold for humans is 540mg/day. The estimated annual consumption of acetyl pyrazine is 920kg in the USA, corresponding to 120μg/person per day. In Europe, the intake of acetyl pyrazine is 14μg/person per day. The consumption of the parent substance pyrazine from food is about 36,000 times greater than its intake as a flavoring agent[2]. Compared to the 540mg/day human intake threshold, the amount is much lower and it is not a safety concern[3].

Toxicity data support the above conclusion. In an acute toxicity test on rat, LD_{50} through gavage was >3,000mg/kg. A group of 32 Wistar rats were maintained on diets containing acetyl pyrazine 8.2mg/kg bw for 90 days. Control group was given basic diet. At the end of experiment, measurements of growth rate, food intake, haematological and clinical chemical parameters, organ weights, and gross and histopathological appearance showed no differences between test and control animals[4].

Conclusion. Based on the manufacturer's information, the composition of the cartridge liquid is not hazardous to health, if used as intended.

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Appendix 2. Ruyan® e-cigarette. New Zealand testing to date, as of 9 April 2008

Topic	Name of test	Purpose	Status	Result
Toxicology	Nicotine content of liquid in cartridges	Confirm labelling states contents correctly	Completed	Generally around 90% of label.
	Benzo-alpha-pyrene in liquid	Whether liquid carcinogenic	Completed	None found
	Heavy metal traces in cartridge liquid	Whether liquid carcinogenic	Completed	Less than one part per million
	Tobacco specific nitrosamines in cartridge liquid	Whether liquid carcinogenic	Completed	Same as in Nicorette gum
	MAO inhibitors found in tobacco	Whether tobacco like effect found.	Completed	MAO effect not detected.
	Headspace tests for volatile organic compounds	To detect any impurities in cartridge liquid	Completed ,	Some detected and need quantifying.
	Draw-over 'smoke' tests	for quantifying gases detected	Booked for April 2008	Available May 2008
	Test for bacteria	To rule out infectivity. Whether bacteria grow in used and unused cartridges.	Completed	No growth of aerobic, anaerobic bacteria or legionella
Adverse effects	50 smokers to use each product for one day	Note how adverse events compare.	February-March 2008	Expected May 2008
Satis-faction ratings	50 smokers to use 16 mg Ruyan® e-cigarette for one day; and on other days use 0 mg Ruyan® e-cigarette, 10 mg Nicorette inhaler and own cigarette.	Rate satisfaction with product at end of day.	February March 2008	Expected May 2008
Efficacy Effect on urge to smoke (cigarette cravings)		Compare urge to smoke before are many times after using each product.	February-March 2008	Expected May 2008
Efficacy Pharmaco-kinetic study	Blood nicotine taken before and after using Ruyan® e-cigarette. (12 tobacco smokers)	Test and compare increase in blood nicotine after use of each product over two hours.	February-March 2008	Expected May 2008

Appendix 3. Safety of Propylene Glycol

Summary: Propylene glycol (PG) is virtually non-toxic.

Properties and uses. Propylene glycol $C_3H_8O_2$ is a completely water soluble liquid, and is prepared by hydrolysis of propylene oxide under pressure at high temperature without a catalyst. It is used in pharmaceuticals, as a drug vehicle (for example as an FDA approved solvent for intravenous diazepam) and preservative. It is used also in personal lubricants. It is used in semi-moist pet food and as a humectant for tobacco. In the food industry it is used as a solvent, humectant and preservative. Its mist is used in theatrical stage productions.[2]

Animal studies

In a study of rats exposed for 60 hours over two weeks, the highest concentration tested, 1800 mg/m(3), which was the highest concentration that could practically be generated, was the no-observed-effect level (NOEL). PG does not appear to pose a significant hazard via inhalation of either the vapor or a vapor/aerosol mixture.[3]

Addition of propylene glycol at 2.2% w/w tobacco does not increase the toxicity of cigarette tobacco.[4] In rats PG levels in plasma and lung are super-imposable with half an hour. A mild cumulative build up (30% or less) occurred after 28 days.[5]

Propylene glycol in humans
The toxicology website http://toxnet.nlm.nih.gov/ was searched for PG, using terms such as human, aerosol, NOEL, carcinogenicity, inhalation.
A review of PG has concluded it is safe for use in cosmetics at concentrations up to 50%.[6]
Absorption PG vapour has 100% deposition efficiency in human airways.[7]
It is partly absorbed on inhalation. PG is absorbed completely from the gastrointestinal tract and partly via the skin and the lungs.

Metabolism. It is metabolized to lactic acid and pyruvic acid, and further oxidized to glycogen or carbon dioxide and water. In man, approximately 20 - 25% of the PG is eliminated unchanged via the kidney.
Toxicity The website www.pneumotox.com devoted to inhalational toxicology, registers one case report of bronchospasm[8] but no other adverse effects.
Since PG is less efficiently absorbed following dermal and inhalation exposure compared to oral exposure, it is likely to have a low acute toxicity by these routes of exposure. CNS depression causing mortality has been described in premature infants after repeated exposure to medication containing PG.[9]

Carcinogenicity. There is no evidence that PG is a carcinogen.
PG exposure per puff of the Ruyan® e-cigarette The cartridge of the Ruyan® e-cigarette contains approximately 1g of PG, of which 0.9 g is extractable from the pad. The concentration of PG in the mouth from one drag of the Ruyan® e-cigarette (900 mg per cartridge, 300 puffs = 3mg) is 3 mg per mouthful).

PG exposure per day of using Ruyan® e-cigarette If the cartridge lasts 2-3 days as expected, then the inhaled dose is 0.3 to 0.45 g per day, and if used more intensively, could result in 0.9 g of PG inhaled and probably absorbed.

Absorption PG is absorbed rapidly and completely when taken orally. Humans have been given 40 g per 12 hours for 3 days to establish a steady state. After 3 days blood levels reached maximum one hour after administration of the PG dose.[2] We could find no data on the proportion of PG absorbed by inhalation. However the proportion is expected to be high, as it is highly soluble.

No-observed-effects level (NOEL) and RfD (reference dose) for humans for sub-chronic (less than a lifetime) and chronic inhalational exposure to PG is estimated by US EPA at 116 mg per 70 Kg human. This level, derived from rat studies, allows a safety factor of 100, 10 for inter-species extrapolation, and 10 to allow for susceptible individuals.[2] This NOEL, however, is artificially low - an artefact of the vapour pressure, as the researchers could not ensure higher concentrations of PG into the air breathed by the rats.

Inhalational Minimal Risk Levels (MRLs) No MRLs for acute- or chronic-duration inhalation exposure to propylene glycol were derived because data are insufficient.[10]

Inhalation threshold. The USEPA has developed no inhalation threshold value for it, nor has Cal/EPA. Inhalation toxicity is not an issue.

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Second Safety Report on the Ruyan® e-cigarette

Murray Laugesen

Health New Zealand Ltd

9 April 2008

Contents

Foreword

This report is entitled a second report, and further test results will be added as they come to hand. Ruyan has allowed flexibility in the nature of investigations carried out. The tests reported are backed up by signed reports from the contracted laboratories. No completed test results have been withheld.

The Ruyan® e-cigarettes and the funds for testing them were supplied under a contract by Ruyan (Holdings) Ltd Hong Kong, but the findings are those of the author. Neither the author nor Health New Zealand Ltd holds stock in Ruyan (Holdings) Co. Ltd.

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9 April 2008.

Summary

Aim This report aims to assist regulators in initial assessment of the safety of the Ruyan® e-cigarette, and the possible risks and benefits from permitting its sale.

Safety The Ruyan® e-cigarette is designed to be a safe alternative to smoking, and on examination from a number of aspects, appears to very safe relative to cigarettes, and also safe in absolute terms on all measurements we have applied. Using micro-electronics it vapourizes, separately for each puff, very small quantities of *nicotine* dissolved in *propylene glycol*, two small well- known molecules with excellent safety profiles, – into a fine aerosol. Each puff contains one third to one half the nicotine in a tobacco cigarette's puff. The cartridge liquid is tobacco-free and no combustion occurs.

By May 2008 at latest, we intend to release results of our study of efficacy of the e-cigarette in raising nicotine blood levels and in relieving cigarette cravings. That study was of smokers using the e-cigarette for the first time, without prior experience of its use.

By June or July 2008, we plan another edition of this report, in response to findings to date. Upgrade of the cartridge liquid is planned to eliminate traces of contaminants.

Once on sale, its on-going safety profile depends on 1) good manufacturing practice and pharmaceutical-grade purity of the nicotine and propylene glycol used in the cartridge liquid. 2) the prevention of shared use which could result in cross infection.

- A number of e-cigarettes are on sale on the internet from China. This report is specific for the Ruyan® e-cigarette, manufactured by Ruyan (Holdings) Co. Ltd, Hong Kong and Beijing, who invented it, and hold the required patents.

1 Background

1.1 Risks of smoking

According to the World Health Organization, the annual death toll from tobacco smoking was 7.6 million world-wide in 2000, and rising.[1] Globally, smoking will soon exceed AIDS-HIV as the leading preventable cause of death.
Smoking multiplies the risk of dying early, doubling the risk for those who smoke 5 to 9 cigarettes a day, tripling the risk for smokers of 20 cigarettes a day, quadrupling the risk for smokers of over 25 per day.[2]

1.2 Separating nicotine from the smoke

Smokers smoke for nicotine but do not die from the nicotine[3] – they die from the smoke. *Smoking kills*, the warning on cigarette packets in many countries, is a precisely accurate statement.

Smoking kills because tobacco smoke contains cancer-causing tar solids (visible particles) in smoke, and certain known invisible toxicant gases such as butadiene (cancer-causing); hydrogen cyanide and carbon monoxide (affecting heart and blood vessels); and acrolein (damaging to the lungs).
Smoking tobacco is, until now, the only way to inhale nicotine into the lungs. The invention of the Ruyan® nicotine e-cigarette in 2004 is about to change that. The Ruyan® e-cigarette takes advantage of the fact that inhalation via a cigarette is the fastest route for nicotine absorption, and absorption by this route is 99% complete.

Before cigarettes were invented, lung cancer was unknown. People sniffed tobacco in the form of nasal snuff, or sucked or chewed it as oral snuff, instead of smoking it.
Pharmacies today stock a range of nicotine products. Nicotine from patches is slowly and completely absorbed through the skin. The mouth mucosa filters out 60% of the nicotine in gum, lozenges and tablets, and absorption through the mouth can take half an hour. None of these methods allows the smoker to continue to enjoy the sensation of drawing on a cigarette to get the nicotine.

1.3 Stopping smoking only way to prevent smoking deaths in next 20 years

- As almost all tobacco smoking deaths occur at age 35 years onwards,[4] those smokers who will die of smoking in the next 20 years, are already smokers – and their deaths can only be averted if they can be persuaded to stop smoking. Stop

[1] Tobacco Atlas. World Health Organization. www.who.int/tobacco/en/atlas11.pdf
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smoking can be either by quitting smoking entirely, or switching to a non-tobacco smoking product.

- Unfortunately, even world-leading programmes to reduce smoking (such as New Zealand's) are succeeding only slowly, so that, by promoting quitting alone, smoking will take another 70 years to reach zero.
- A large part of the problem is that many smokers are unwilling to quit their addiction to nicotine. The Ruyan® e-cigarette provides an easier escape route for smokers.
- WHO has recommended that alongside the individual approach (including pharmacological interventions), a supportive (policy) environment is needed, and recommends "a broad framework for addressing smoking cessation and treatment of tobacco dependence."[4]
- Such a framework would logically permit widespread sale of a range of cigarette substitutes that each provided "clean" nicotine for lung inhalation.

1.4 Life years reclaimed if smokers switch to smoking the Ruyan® e-cigarette

Here we estimate the public health benefits of widespread adoption of the Ruyan® e-cigarette *or any other product, policy or programme* that can likewise persuade smokers to stop smoking.

At personal level. For every two continuing smokers, one will die early from smoking (on average 13 years early[5]). So if two smokers both switch to Ruyan® e-cigarettes from the beginning, or otherwise succeed in quitting smoking, then 13 life years will be reclaimed.

In percentage terms. Similarly, for every 100 continuing smokers, 50 will die early from their smoking (on average dying 13 years early)[6] If, however, all 100 switch to e-cigarettes (or otherwise stop smoking tobacco) before 35 years of age, we would expect that 50 fewer will die early, a total of 650 life-years reclaimed, per 100 smokers. This is based on the proven zero excess mortality effect from daily use for five years of nicotine without tobacco.

At country level For New Zealand, with 21% of adults smoking and 656 000 daily smokers,[7] 4.3 million life years would be saved, in country of 4.2 million population, or one life-year reclaimed per capita, if everyone stopped smoking; equal to increasing life expectancy by one year averaged over the entire population. In reality, it is the smokers who stop smoking by abstinence or switching to the Ruyan® e-cigarette, who obtain this gain in longer life.

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[7] New Zealand Census March 2006. Smoking prevalence 20.7%. www.statistics.govt.nz

2. Description

The Ruyan® (pronounced Roo yen) (e for electronic) cigarette, like a tobacco cigarette, can rapidly deliver nicotine into the lungs, but without smoke carcinogens and toxicants.

The Ruyan® e-cigarette was first sold in May 2004, in China, with annual sales since of around 300,000 per year, and advertising on television, but no adverse effects reported by the English language dailies in China. Its December 2007 internet price was around US $208, with nicotine cartridge refills required every 300 puffs (1-4 days) costing extra. After 1300 puffs the battery is recharged from the mains.

2.1 Structure.

The distal segment with a red light indicating inhalation, contains the re-chargeable battery and is the controlling part. The middle part contains a vaporising chamber. The mouthpiece and nicotine cartridge are one piece, and a new one is inserted after 300-350 puffs. The nicotine in the cartridge is dissolved in propylene glycol (PG). Table 2.1 enables estimation of the weight of the liquid in the container.

Table 2.1. Ruyan V8 electronic cigarette 16 mg cartridge, components by weight

Component		g	g	g
Battery (distal segment)				13.9
Atomiser (middle segment)				8.58
Cartridge (mouth end segment)				
Cartridge part (white)			1.67	
	Plastic shell	0.436		
	Silicon foam, dry	0.061		
	Liquid, full	1.173*		
Mouthpiece (black)			0.89	
				2.56

* Estimated by subtraction. Of the 1.173 g, 1g may be extractable.

2.2 Function.

The Ruyan® e-cigarette is flameless and non-flammable. The pressure sensor in the controlling part electronically initiates rapid vaporisation of a dose of liquid propylene glycol containing nicotine into a fine aerosol that reaches the lung rapidly.[8] The dose per puff depends on the volume and force of the inhalation, and the number of puffs determines total dose.

3. Nicotine effects

The safety and toxicity of nicotine has been exhaustively reviewed.[9] The safety of pure nicotine alone, relative to tobacco smoking is not in question, nor is its overall safety in

[8] Hon, Lik. China. A non-smokable electronic spray cigarette. Patent CA 218174, published 2004/03/08.
[9] Nicotine Safety and Toxicity. Ed. NL Benowitz. Oxford. OUP. 1998.

absolute terms. Death has been recorded occasionally from accidental poisoning from nicotine (Section 7), but not from medicinal use.

No nicotine poisoning effects have been reported for the Ruyan® e-cigarette. In contrast to the use of alcohol or oral snuff, the very rapid absorption enables the user to become aware of the first effects (light-headedness, queasiness) before serious overdosing can occur.

3.1 Short-term effects

Dose-control. For each puff, "what you inhale is what you get". The smoker is protected from unwanted nicotine by the electronic circuitry shutting off almost immediately after each puff is taken. The smoker controls the size of the puff which determines the nicotine dose. The strength of the dose is immediately and correctly signalled by the irritation to the back of the throat, as no menthol is used to anaesthetise it. Thus the smoker is able to accurately control the dose from puff to puff.

With a zero-nicotine Ruyan® e-cigarette, there is no harshness on the throat, and without such negative feedback, the smoker may puff more frequently, but virtually no nicotine is inhaled. Purchasing 16 mg, 11 mg, 6 mg or 0 mg nicotine strengths of cartridge provides another way in which Ruyan® e-cigarette smokers can pre-regulate their nicotine intake.

Efficiency. No nicotine is wasted in the Ruyan® e-cigarette– over one to four days its nicotine is eventually all inhaled, thus differing from the 12% uptake of nicotine from the tobacco cigarette. In the tobacco cigarette, after combustion, most is lost in side-stream smoke. Of the mainstream smoke some is entrapped in the cigarette filter, while only 1.5 mg (12%) of the cigarette's original nicotine content of 13 mg is inhaled. (Table 1).

In first-time smokers. Acute nicotine toxicity occurs when never-smokers smoke their cigarette (whether tobacco or e-cigarette), becoming light-headed, with nausea and even vomiting, lasting typically for half an hour. Many would-be smokers are thus discouraged from learning to smoke.

Maintenance of steady nicotine blood levels. The experienced smoker of the Ruyan® e-cigarette controls the nicotine intake to maximise pleasure and minimise discomfort. A regular e-cigarette or tobacco cigarette smoker adjusts the size or frequency of each subsequent puff, to maintain nicotine blood levels high enough to avoid unpleasant craving for a cigarette, and low enough to avoid excessive harshness on the back of the throat, or light-headedness due to a high blood level of nicotine.

Self-medication. In a relaxed situation, a smoker may deliberately inhale to achieve the nicotine rush or buzz or light-headed feeling, which will pass within half an hour or so. This is nicotine self-medication, or drug-effect seeking behaviour, which many smokers practice. Inhaling to the point of light-headedness can be harmful for tobacco smokers, tobacco snuff users and e-cigarette smokers who have to drive a car or operate heavy machinery immediately afterwards.

3.2. Long term effects. Thousands of smokers and former smokers have used nicotine in the form of gum for five years with no increase in mortality or hospitalisation.[3]

Longevity The cumulative excess risk of continuing to smoke tobacco cigarettes beyond age 35 years is one in two.[2] As the Ruyan® e-cigarette carries no risk to longevity, the average smoker switching to the Ruyan® e-cigarette before age 35 years will reduce their risk of dying early by one in two.

Cancer and Cardiovascular toxicity. Nicotine is not a cause of cancer. The tendency for nicotine to temporarily increases heart rate and blood pressure flattens out above 8 mg yield per cigarette, so that low doses produce much the same effect as high doses,[6] suggesting that nicotine does not cause cardiovascular toxicity.

3.3 Previous tobacco smoking puts e-cigarette users at risk.

Ruyan® e-cigarette users will be mainly current or past tobacco smokers, and for that reason are at increased risk of heart attack, stroke or lung cancer. Tobacco cigarette smokers have two to three times the annual death rate of non-smokers, and have ten times the risk of sudden cardiac death. Deaths of e-cigarette users may be wrongly blamed on their new e-cigarettes, rather than their past smoking of tobacco.

3.4 Dual use.

Smokers may take some time to switch completely from tobacco to nicotine smoking. As long as they continue to smoke even a few cigarettes a day their risk of dying early remains excessive. (The risk of smoking even 1-4 cigarettes a day carries a 60% excess risk of dying early. Smoking 5-9 cigarettes a day doubles the risk of dying early, compared with never smoking[2]). In particular their excess risk of heart attack will not diminish substantially until they quit tobacco smoking entirely.

4. Nicotine dose, consumption, and labelling

4.1 Correct dose.

Each smoker is accustomed to a certain amount of nicotine each day. This varies greatly between smokers, but for each smoker, varies little from day to day. Heavy tobacco cigarette smokers in the United States smoking an average 36 cigarettes (range 20-62) per day absorb about 37 mg per day (range 10-79 mg)[10].

The Ruyan® e-cigarette cartridge can supply 16 mg nicotine per day. Non-inhalers and smokers of light cigarettes inhale less nicotine. If smoking one cartridge of the 16 mg Ruyan® e-cigarette per day is not able to control cravings, a second e-cartridge for the day might be needed.

Table 4.1 shows that, the 16 mg nicotine Ruyan® e-cigarette cartridge provides nicotine equal to 7 to 10 factory-made tobacco cigarettes. Once the smoker stops smoking tobacco cigarettes, the Ruyan® e-cigarette by itself is unlikely to cause nicotine overdose. Any smoker becoming light headed while smoking an e-cigarette, should stop smoking tobacco.

[10] Benowitz ibid. p.6.

Table 4.1 Nicotine content and delivery or absorption per puff, per smoke, and per day, factory-made tobacco cigarette and Ruyan® e-cigarette compared.

	Content Nicotine in each unburnt tobacco cigarette, or in each Ruyan® e-cigarette cartridge** mg	**Per puff** Nicotine delivery per puff; 99% absorbed## mg	**Per smoke** Nicotine delivery and absorption# per cigarette or Ruyan® e-cigarette smoke' mg	**Per day*** Nicotine delivery and absorption (per 300 puffs from 20 cigarettes or 20 Ruyan® e-cigarette 'smokes' mg
	A	**B****	**C**	**D**
Factory-made cigarettes	A	B=C/15	C	D=C*20
Regular filter cigarettes	13	0.16	1.4 to 2.4 assume 2.0	28 – 48, assume 38
Ruyan ® e-Cigarettes	A	B=A/300***	C=b*15	D=C*20
Ruyan® cartridge Label:**16 mg**	14~ - 16	0.053	0.80	14-16
Ruyan® cartridge Label = **11 mg**	10~ - 11	0.037	0.56	10-11
Ruyan® cartridge Label **6 mg**	6~	0.02	0.3	6
Ruyan® cartridge Label **0 mg**	0-0.5~	0	0	0-0.5

* Ruyan® cartridge lasts one to four days. If it lasts four days, divide Ruyan values in D by 4.
** Assumes 15 puffs per cigarette.
*** Assumes 300 puffs per Ruyan® e-cigarette cartridge. Smokers taking larger puffs may finish the cartridge before 300 puffs. ~ Benchtop test value.
# Nicotine absorbed per cigarette = 1.4 mg (Fagerstrom, for Sweden),[11] 2.4 mg (Djordjevic for USA).[12] The nicotine absorbed from tobacco smoking is much greater than what is printed on cigarette packets.
When nicotine aerosol is inhaled into lungs, approximately 99% of nicotine is retained.[13]
~ ESR Porirua October 2007.

4.2 Nicotine consumption per day. As puffs from the 16 mg nicotine Ruyan® cartridge contain one third to one half the nicotine in a tobacco cigarette puff, and Ruyan® e-cigarette smokers take up to four days to finish a cartridge, smokers are most unlikely to absorb more nicotine from Ruyan® e-cigarettes than previously absorbed from tobacco.

Smokers of the Ruyan® e-cigarette say a cartridge lasts 1 to 4 days, which for a 16 mg cartridge is equal to 4 to 16 mg per day daily or equal to 2.5 to 10 tobacco cigarettes a day unaccompanied by tar or gas toxicants (Table 1). Pure nicotine in this dose is neither excessive nor harmful.

As virtually all cartridge nicotine is eventually inhaled, and over 98% of inhaled nicotine is absorbed[13] the consumption of nicotine cartridges per smoker will reliably establish the level of nicotine absorption per day, provided no tobacco or other nicotine product is being used. This enables clinicians and researchers to estimate nicotine consumption with more precision than is possible with tobacco consumption.

4.3 Nicotine per puff

Method 1) 'Smoke', 35 ml per puff, was drawn from the mouthpiece of the Ruyan e-cgiarette until no more was obtainable. The total puffs per cartridge were thus documented for the manufacturer at a well-known Beijing laboratory.[14]
2) An e-cigarette (0 mg nicotine) was smoked for a total of 80 breaths – 40 shallow, and 40 by deep lung inhalation. The puffing was measured by CreSSmicro interposed between smokers and the e-cigarette. (Table 4.3)

Results.

1) By volume measurement, the manufacturer's estimate was 350 breaths per cartridge. Table 4.1 is based on this estimate.
2) By weighing the decreases per ten puffs taken, (Table 4.3) the average weight of liquid used per puff was 1.5 mg for lung inhalations, and 0.5mg for shallow mouth-throat inhalation. As extractable propylene glycol is approximately 1.0 g, one cartridge should provide 667 lung inhalations.

Conclusion.

These two methods give different results. Further tests in human subjects will clarify how many puffs are obtained by most smokers per cartridge.
If the e-cigarette contained a 16 mg per 1 g of cartridge liquid, instead of the 0 mg cartridge as in Table 2, then, assuming the nicotine was equally concentrated across all puffs, and assuming all breaths are lung inhalations, 1.5 mg of liquid went into the average puff, providing an estimated 1.5 * 16ug nicotine per puff = 24 micrograms of nicotine,. Fifteen puffs would thus supply 360 ug or 0.36 mg of nicotine, that is one fifth of the amount from one cigarette. And 15 shallow puffs would only supply 0.12 mg of nicotine. Volume and weight calculations thus give differing values. Pharmacokinetic testing will show whether smokers obtain sufficient nicotine from the e-cigarette.

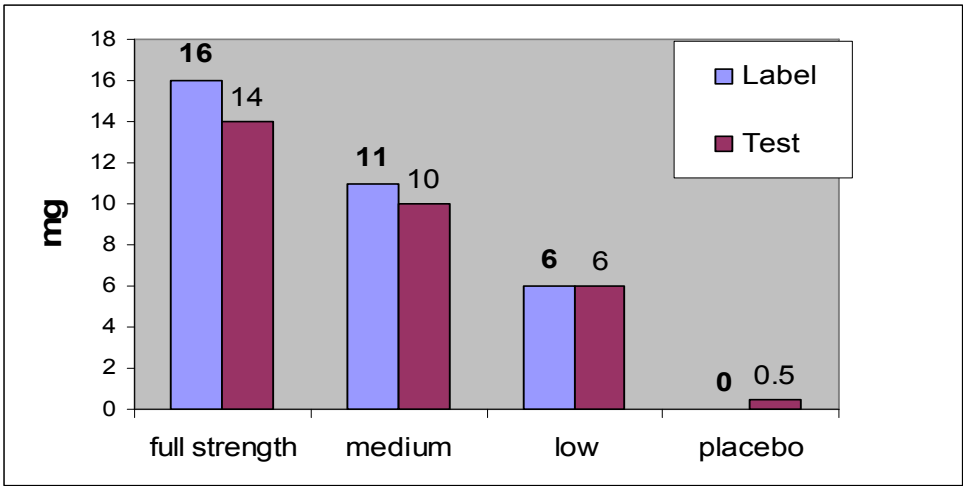
Table 4.3. Weight loss of the 0 mg e-cigarette as a measure of vapourisation of the cartridge liquid

Method	Average puff duration in seconds	Average volume per puff mL	Puff Count	Weight change in e-cigarette Mg	Weight loss per breath mg
Inhaled into mouth and throat (puff volume 21 ml)					
Mouth/throat	0.76	21.1	40	20	0.5
Inhaled into lungs (average puff volume 44 ml)					
Total lung	1.63	43.8	40	60	1.5
Total all	1.20	31.9	80	80	1.0

Lung inhalation results in three times as much cartridge liquid being inhaled, as from shallow inhalation confined to mouth and throat.

4.4 Accuracy of nicotine dose labels

Table 4.4 Ruyan® e-cigarette per cartridge nicotine content by label and by test



The only biologically active ingredient expected in the Ruyan® e-cigarette cartridge liquid is nicotine. On analysis[15], the cartridges labelled as 16 mg actually contained 14.1 mg of nicotine; those labelled 11 mg contained 10.0 mg; those labelled 6 mg contained 5.9 mg; and those labelled 0 mg of nicotine contained 0.5 mg.

In a separate estimation, the nicotine alkaloid β-nicotyrine ($C_{10}H_{10}N_2$) was detected on scan of the headspace in the cartridge by microextraction. The area under the peak was 4% that of nicotine. ($C_{10}H_{12}N_2$). This requires re-analysis once the source of nicotine for the e-cartridge is upgraded.

5. Risk of addiction

5.1 Tobacco versus nicotine addiction.

The extent of the addictive potential of the Ruyan® e-cigarette is not yet known. The frequency of nicotine addiction is lower for all nicotine products so far developed, than for tobacco products, but the e-cigarette represents the first time a pure-nicotine-smoking product is available to be compared with a tobacco cigarette. The illness consequences of addiction to lit tobacco smoke however, are infinitely greater than from addiction to nicotine;without the products of combustion.[3]

Other active substances in tobacco. MAO inhibitor compounds (such as harman and norharman) in tobacco smoke are believed by many to potentiate the effect of the nicotine. If this proves to be a strong factor with respect to tobacco smoke, then the nicotine-only e-cigarette will be much less addictive than smoking tobacco cigarettes. Vapours from the e-cigarette cartridge do not inhibit MAO enzymes. See 8.1.2

Other factors. The cost of buying the e-cigarette, and the need to use a credit card to order it by mail, will likely deter most young people obtaining the e-cigarette for personal

use. If some youths do use it, and develop a taste for nicotine, the price of nicotine refills versus cigarettes will be decisive for many. It also depends on fashion, safety concerns, and whether parents, health groups and doctors approve its use.

5.2 Addiction in smokers

The Ruyan® e-cigarette does not cause nicotine addiction in smokers, as most cigarette smokers are already addicted to nicotine. E-cigarettes are not expected to increase the need for nicotine in smokers, as each smoker needs a certain amount of nicotine each day, and the brain receptor cells cannot distinguish where the nicotine molecule comes from (smoked tobacco, tobacco snuff, or e-cigarette). The e-cigarette does not increase the daily customary dose; from the first day of using the Ruyan® e-cigarette most smokers tend to smoke very few tobacco cigarettes, and surprisingly, seem to use few e-cigarette cartridges in their place. This however is yet to be researched.
Once the daily dose is obtained, the smoker will not reach for another puff from either their tobacco cigarette or their e-cigarette: no pleasure is obtained and there is no craving to relieve.

Further research on quitters is required to find out how many will prefer to continue using the e-cigarette one year after quitting smoking.

Smokers quitting smoking in countries which encourage quitting, are likely to use the e-cigarette to gain control of their nicotine needs, and use it temporarily – for a few weeks only, after stopping smoking. Quitting smoking is often part of a lifestyle change which will often include quitting tobacco and nicotine altogether. By the time smokers are ready to quit cigarettes, many also want to end their nicotine addiction.

The 16 mg, 11 mg nicotine cartridges are expected to satisfy the cravings and maintain the addiction of smokers who wish to stay on nicotine. This is the subject of further tests in 2008.

On the basis of similarity to the rapid action of nicotine nasal spray, we assume that one year after smokers' first using the Ruyan® e-cigarette as a stop smoking aid, no less than 15% would become long term users. (See data for nicotine nasal spray below)..

The 6 mg nicotine cartridge if used up in one day may provide just enough nicotine to maintain addiction. Used over 4 days it would not be sufficient. Very recent quitters using the 6 mg cartridge would likely have cravings for cigarettes and be at risk of smoking tobacco again.

The 0 mg nicotine-labelled cartridge will not maintain addiction. It will provide 0.002 mg nicotine per puff, 0.025 mg per smoke, which at even 300 puffs a day amounts at most to 0.6 mg per day, much less than the estimated 5 mg daily required to sustain addiction[16]. The labels were therefore safe estimates of the dose of nicotine to be expected, and the 0 mg e-cigarette can be used without risk of creating or maintaining dependence on nicotine. Nicotine is not recommended for non-smokers but for smokers already addicted (dependent) to nicotine, who wish to avoid inhaling tobacco smoke.

Tobacco cigarettes Some 84% view their own use of cigarettes as an addiction[17].

Comparison with nicotine medications (Nicotine Replacement Therapy, NRT) Of users of nicotine medications some are still using the medication after one year and assumed to be addicted. (2% for patch, 8% for spray, 9% for gum and 15% for nasal spray) [18].

6. Addiction in young people

Tobacco, tobacco snuff, nicotine snuff (Niconovum) and the e-cigarette can all be expected to induce nicotine addiction in many young people. This involves a subtle loss of autonomy or control over their new habit. Once addicted to nicotine, the concern is that tobacco, snuff and the e-cigarette could be used interchangeably.

The answers to this concern depend on what policies society has put in place to steer young people away from addiction of any kind, and away from tobacco smoking in particular. In 2007, New Zealand smokers could buy an e-cigarette from the internet for the price of a carton of cigarettes. If cigarettes cost much more, more would buy the e-cigarette. Similarly, graphic disease warnings on cigarette packets may persuade smokers to quit or switch to other alternatives such as the e-cigarette which do not require or merit such disease warnings.

Addiction to smoking tobacco cigarettes ensures young smokers remain smokers into adult life and continue to smoke beyond 35 years of age when the risks of smoking deaths begin to increase. Similarly smoking the e-cigarette makes it less likely that the smoker will ever want to smoke tobacco cigarettes again.

Young people may use the e-cigarette as a temporary crutch while stopping smoking and so avoid the future increased mortality risks of smoking. If the e-cigarette was widely available to young people, their cigarette smoking would decrease, life expectancy increase and respiratory health would improve, without any extra mortality from nicotine.

The fate of users of the e-cigarette

Smokers who try the e-cigarette will either:

- Try the e-cigarette experimentally, then revert to tobacco smoking as before.
- Use the e-cigarette as a temporary aid to quitting smoking entirely.
- Switch permanently to e-cigarette (and no longer smoke tobacco) .
- Continue to use both e-cigarette and tobacco cigarettes (See 3.4 above).

First cigarettes The first tobacco cigarettes smoked result in one on four adolescents losing some autonomy (control) over their smoking[19]. Whether some adolescents would soon lose partial control over their use of the Ruyan nicotine e-cigarette is not clear.

Addictive potential The proportion of young people who will prefer the e-cigarette over tobacco, and who use it long term, is unknown. It will vary by country. If government and health groups regard the e-cigarette as almost as dangerous as smoking, e-cigarette

smokers may adopt a "why not" approach to tobacco cigarette smoking, and tobacco cigarette smoking will not be reduced. If, however, society approves the e-cigarette as a cigarette alternative, its users can smoke it openly, without damaging their health. It will be a much safer habit than either smoking tobacco or drinking alcohol.

Graphic and varied health warnings The e-cigarette is not likely to cause addiction any more than cigarettes, which most adolescents can obtain with ease. On the other hand, the e-cigarette supplies safe nicotine, without risk of early death due to lung cancer, heart disease, or emphysema. A simple, truthful warning is therefore suggested below for the e-cigarette.

Graphic warnings on cigarette packets will discourage tobacco smoking.. Better information about the health risks of smoking, and higher prices for tobacco, will mean that as the e-cigarette becomes available, the proportion of young people smoking tobacco should decrease more rapidly.

Possible health warning

This nicotine product is addictive but avoids the other risks of smoking.

Tobacco cigarettes in many countries now warn the smoker "Smoking is addictive". Similar warnings are needed on the e-cigarette packaging, pointing up the difference between the e-cigarette and tobacco cigarettes. Although the manufacturer's pamphlet warns that the e-cigarette is not suitable for young people or non-smoking adults, some may gain access to it.

If young people see graphic disease warnings and high prices on tobacco packets, young people will abstain from tobacco smoking or possibly switch to e-cigarette smoking instead. In due course, fewer will die early from tobacco smoking.

Conclusion.

The invention of the e-cigarette means society must now distinguish between

- Very harmful (tobacco) smoking, and harmless (e-cigarette) smoking; and
- very harmful addiction (associated with smoking) and fairly harmless addiction (associated with the e-cigarette).

Regulators in Western countries are likely to

- prohibit sale of nicotine e-cigarette refills to under-18s, in line with restrictions on cigarette sales to youth
- permit e-cigarette use in most areas where tobacco cigarette smoking is banned
- permit e-cigarette advertising in countries permitting advertising of NRT.
- continue to enforce existing bans on the advertising of smoking tobacco.

7. Risk of accidental ingestion of nicotine

Accidental ingestion of the e-cigarette is theoretically possible, though it has not been mentioned in the English news media in their articles on the Ruyan® e-cigarette from China, where 300,000 units are sold annually since 2004. Poisoning by ingesting tobacco cigarettes is rare, even though children can easily access tobacco cigarettes in the home.

7.1 Ruyan nicotine cartridges, when sold separately are packed in individually sealed child-proof canisters. Without scissors, even adults find them difficult to open. In this packaging, unattended children in car or home are not at risk from the nicotine.

7.2 The nicotine cartridge assembled into the e-cigarette is better child-proofed than a packet of tobacco cigarettes.

- Many Ruyan® smokers keep their e-cigarette close by, reducing risk of child access.
- Once assembled, the join between the e-cigarette mouthpiece/ cartridge, and the metal shell of the middle section is normally difficult even for an adult to pull apart. It is not a screw join.
- If, unusually, this join was loose, it prevents normal use of the e-cigarette, so does not remain loose for long.
- If unusually a child gained access to it and pulled it apart, put the cartridge in the mouth and sucked on it, then the nicotine impregnated in the cartridge could be absorbed through contact with mouth mucosa causing acute toxicity.

Swallowing is less likely, as the mouthpiece-cartridge measures 5 cm in length by 1cm diameter, and requires adult force to separate its two parts.

The highest dose e-cigarette cartridge contains 16 mg of nicotine. The factory-made tobacco cigarette contains 13 mg[20]. The lethal nicotine dose for a child is known to be 10 mg.

8. Safety of the cartridge liquid and inhaled aerosol

Propylene glycol makes up 89-90% of the liquid in the nicotine cartridge that generates the aerosol inhaled by the e-cigarette smoke. (See Appendix 1, Table 2).
Propylene glycol is virtually non-toxic, See Appendix 3.

8.1 Tobacco flavour, Nitrosamines and MAO inhibitor effects

In cartridges dated November and December 2007, the fragrance, odour and taste of tobacco remained. The manufacturer's recipe (Appendix 1) suggests this comes from a flavour base containing tobacco extract weighing 6 mg per cartridge. As we now show, the cartridge liquid does not behave like tobacco:

8.1.1 Tobacco-specific nitrosamines Traces of these nitrosamines, found only in tobacco, were not found in the Ruyan® e-cigarette cartridge liquid except at trace quantity, at a level equal to that reported for medicinal Nicorette gum, at a low level uncharacteristic of tobacco. On this basis, the Ruyan® e-cigarette is a nicotine product, not a tobacco.

The maximum level of tobacco specific nitrosamines of 8 ng TSNAs per gram of cartridge liquid (8 parts per billion or ppb) found in 16 mg nicotine cartridges, compares closely to the 8 ng per gram found in Nicorette gum sold as a nicotine replacement therapy medicine in the United Kingdom[21]. The e-cigarette TSNA content is 200 times less than the amount found in Swedish moist snuff (1000 to 2400 ppb), and 150 times

less than the amount found in unburnt tobacco in the most popular filter cigarette and cigarette tobacco brands (1230 ppb)[22].

Table 8.1 Tobacco specific nitrosamines (TSNAs) in the cartridge liquid of the Ruyan ® e-cigarette, November 2007

Nicotine per Cartridge	Sample ID	NNN (ng/cartridge) Observation	NAT (ng/cartridge) Observation	NAB (ng/cartridge) Observation	NNK (ng/cartridge) Observation	TSNAs Ng/cartridge total
0 mg	073277	BDL	BDL	NQ	0.260	0.260
6 mg	073278	1.42	1.02	BDL	0.628	3.068
11 mg	073279	1.83	1.36	NQ	1.01	4.200
16 mg	073280	3.87	2.16	0.693	1.46	8.183
Labstat 2007[23].					Average TSNAs	3.928
BDL = Below the limit of detection. NQ = Not quantifiable. TSNA = tobacco specific nitrosamines. NAB= nitrosoanabasine NNN= nitrosonornicotine, NAT= nitrosoanatabine, NNK= 4-nitrosomethylamino-1-(3-pyridyl)-1-butanone						

8.1.2 <u>Monoamine oxidase</u>. The cartridge liquid retains a tobacco fragrance or odour. (Appendix 1). Monoamine oxidase (MAO) enzymes both A and B, are strongly inhibited by tobacco smoke extract but the cartridge liquid had no such effect[24]. MAO, found in blood platelets and the brain, has been regarded as a potentiator of the reinforcing (addictive) effects of nicotine. The test results have several implications:

1) The e-cigarette liquid in the cartridge lacks the MAO inhibiting effect of tobacco.

2) Any addictive potential of the e-cigarette is due to nicotine (complemented by nicotine analogues) but the nicotine effect is not reinforced by MAO. This provides a biomedical basis for the e-cigarette to be less addictive than smoking tobacco.

3) If the e-cigarette proves to be no less addictive than the tobacco cigarette, the difference could be explained by less nicotine inhaled from the e-cigarette; or it could be due to MAO in tobacco.

4) The closer the addictive potential of the e-cigarette to that of tobacco cigarettes, the less likely it is that MAO in tobacco is important in reinforcing nicotine's addiction potential.

8.1.3 Benzo(alpha)pyrene The cartridge liquid was tested for benzo(alpha)pyrene, a probable human carcinogen (detectable in tobacco cigarette smoke at 35 nanograms (ng) per cigarette). The value obtained from the e-cigarette liquid was below the method's limit of detection of 1 ng[25]. As the e-cigarette cartridge is equivalent in nicotine to no more than 10 cigarettes, e-cigarette smoking delivers 350 times <u>less</u> benzo(alpha)pyrene than does tobacco cigarette smoking.

8.2 Volatile organic compounds (VOCs)

8.2.1 In e-cigarette 'smoke'.

The yield of VOCs in the "smoke" of the e-cigarette has not been analysed. Volatile organic compounds are small molecules, the products of combustion, and found in all tobacco smoke. The e-cigarette generates no flame or fire; and does not heat up the e-cigarette. The very high temperatures of a burning cigarette (combustion) are not achieved in e-cigarette smoke.

Analysis of VOCs is planned before the next and final version of this report is issued.

8.2.2 In the e-cigarette cartridge liquid.

A) By SIFT-MS (Selected Ion Flow Tube and Mass Spectrograph) method

Aim To test the headspace of liquid from freshly opened (un-smoked) cartridges by SIFT-MS method, and incubate for one hour at 37 deg C.

Method Ruyan e-Cigarette cartridges (16 mg nicotine; batch 20071228) had their wisp removed and one was placed in each of two 500-mL glass Schott bottles, which were then capped with pierceable septa. Duplicate blank samples of laboratory air were also analysed for comparison. Bottles were then incubated at 37 °C for approximately 60 minutes prior to analysis.

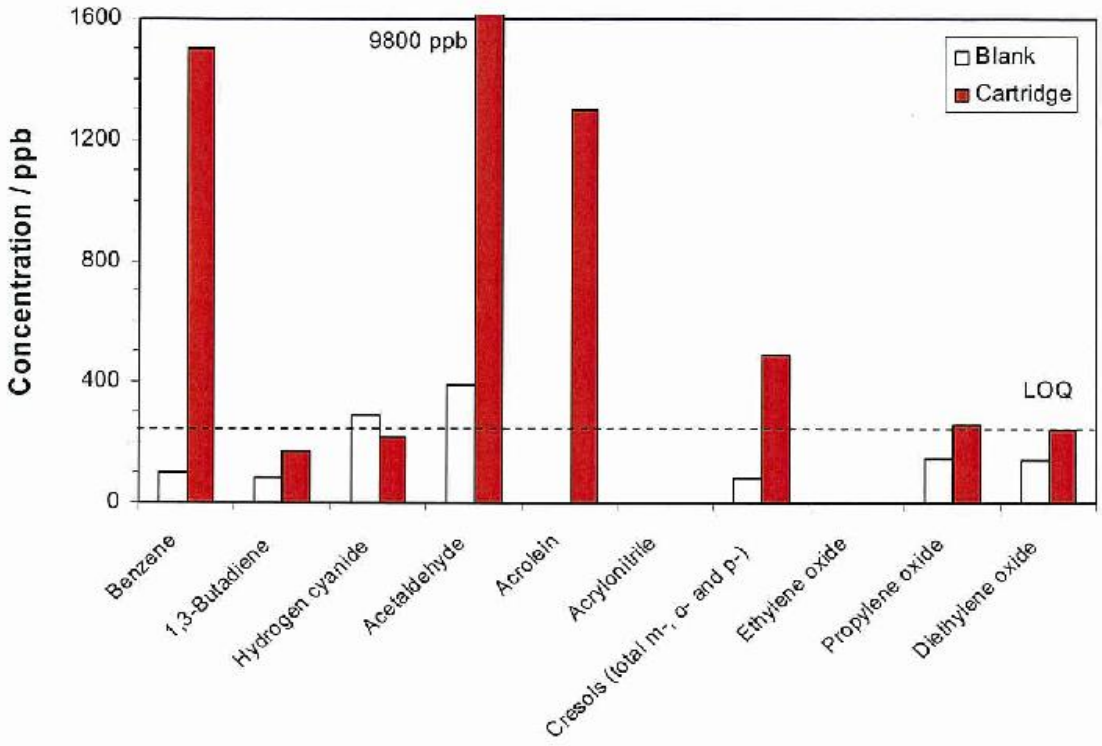
Method
SIFT-MS analyses gas samples for volatile organic compounds (VOCs) and certain inorganic compounds.[1] Typically it can accurately detect and quantify these compounds in real time at very low concentrations (usually to parts-per-trillion {ppt} levels), even at breath humidity. SIFT-MS does not employ chromatographic separation and hence cannot perform well when high levels of organic solvents are present. A Syft Technologies Voice100^{TM} instrument was used for this work. It was operated in two modes- selected ion mode (SIM) or Full Scan Mode (FSM).

Results
The results of the analysis are shown in Figure 8.2.2a and Table 8.2.2b. High levels of ethanol were found in the cartridges (identified from the full scans). This meant that the SIFT-MS instrument had to be run at reduced sensitivity for the analysis presented here, with a degraded limit of quantification (LOQ = 300 ppb). Consequently, some target compounds could not be reported, as all their available ion products suffered significant interference; and for the toxicants reported, the results represent an upper limit to the true concentration in the wisp.

- Using SIFT-MS, (Figure 8.2.2a), due to interference from alcohol in the Ruyan cartridge, ethylene oxide could not be separated from acetaldehyde. Meantime, using HS SPME method (below) ethylene oxide was not detected in the headspace of the Ruyan cartridge, and therefore the 9500 ppb seen in Figure 1 is all due to acetaldehyde.
- Acrylonitrile does not register in the graph: no response was obtained. Although below the level of quantitation of 0.3 ppm, it suggests that acrylonitrile is absent.

Figure 8.2.2a: SIFT-MS headspace analysis of the Ruyan® e-cigarette cartridge (mean of two replicates), showing the instrument's estimated limit of quantitation.

Figure 1: *SIFT-MS headspace analysis of the Ruyan e-Cigarette cartridge (mean of two replicates), showing the instruments estimated limit of quantitation in this case.*



"The results presented here are preliminary, due to interferences caused by ethanol, which is present at very high concentrations in the wick. The results represent an upper limit. However the measurements do show definitively that a number of tobacco-related toxicants are not present at significant levels in the e-Cigarette, such as hydrogen cyanide, 1,3-butadiene and acrylonitrile. For toxicants that appear to have concentrations above the limit of quantitation (LOQ), it is recommended that other techniques (for example, GC-MS or LC-MS) be used for more definitive analysis."

Accordingly, on this recommendation we used GC-MS analysis (See 8.2.2B below).

Table 8.2.2b: SIFT-MS headspace analysis of the Ruyan® e-cigarette cartridge (mean of two replicates). "<LOQ" = less than the limit of quantitation.

Toxicant	Concentration in blank (parts per billion; ppb)	Concentration in headspace of cartridge (parts per billion; ppb)
Acetaldehyde	<LOQ	9500
Benzene	<LOQ	1500
1,3-Butadiene	<LOQ	<LOQ
Hydrogen cyanide	<LOQ	<LOQ
Acrolein	<LOQ	1300
Acrylonitrile	<LOQ	<LOQ
Cresols (total m-, o- and p-)	<LOQ	490
Propylene oxide	<LOQ	<LOQ
Diethylene oxide	<LOQ	<LOQ

Langford 2008[26]

B) Volatile Profile of the Sample Ruyan® e-cigarette by using HS-SPME and GC-MS[27]

Introduction

Head Space Solid-Phase Micro-Extraction (HS-SPME) was the sampling technique used to sample the headspace volatiles emitted from the sample upon heating. This involved exposing a conditioned fibre into the headspace of a sealed vial and allowing the volatile compounds in the headspace to absorb onto the fibre surfaces. These volatile compounds were then introduced into the GCMS by exposing the fibre inside the GC injection port where they were stripped off at a high temperature.

The compounds detected by the mass spectrometer were Qualified only, i.e. identified by comparison with a mass spectral library and their relative abundances reported. Concentrations for these compounds were not obtained using this technique. In order to obtain concentration information the protocol used would need to be changed to include the use of standards, both internal and external.

Method

Samples were analysed using a Shimadzu GCMS-QP2010 gas chromatograph mass spectrometer fitted with a Restek Rtx-WAX fused silica capillary column (30.0m x 0.25mmi.d. x 0.50µm film thickness) coupled in series with a Restek Rtx-1ms fused silica capillary column (15m x 0.25mm id x 0.25µm film thickness).

Sample preparation involved placing the ecigarette into a 20 ml SPME sample vial where it was then quickly capped. Using a CTC-Combi PAL auto sampler (Shimadzu AOC-5000), samples were incubated for 60 min at 37ºC with their enclosed headspace

exposed to a 2 cm long DVB/CAR/PDMS combination SPME fibre (Supelco). During this exposure period the headspace volatiles were absorbed onto the fibre.

Desorption of these volatiles occurred when the SPME fibre was inserted (by the Atuosampler) into the heated (250 deg C) injection port of the Shimadzu GCMS-QP2010 gas chromatograph–mass spectrometer. The injection port was then used in Splitless mode operating with a Helium carrier gas linear flow of 25.9cm/s (column flow). The GC columns were held initally at 35 deg C for 5mins, ramped to 100 deg C at 7 deg C/min where it was then ramped to 200 deg C at 3 deg C/min, and then finally ramped to 250 deg C at 7 deg C /min and held for 10mins.

During the elution of the compounds the GC–MS was operated in scan mode at a detector voltage of 1.2kV and electron impact ionisation voltage of 70 eV. All compounds detected were identified by matching their mass spectra with the spectra of reference compounds found in the NIST EPA/NIH Mass Spectral Library database (National Institute of Standards and Technology, NIST05).

Results

Table 8.2.2c. Screening of headspace vapour of a just-opened Ruyan® e-cigarette cartridge by different methods- SIFT-MS (Selected Ion Flow Tube with Mass Spectrometry), Solid phase microextraction (HS-SPME), and exhaled CO.

Compound	Toxicology *	**MRLs** Minimal Risk Levels non-cancer effects) ppm**#	**PELs** Permissible Exposure Levels of OSHA) ppm***	Detected in headspace vapour of Ruyan® e-cigarette cartridge Detected YES or NO	
				SIFT-MS Mass Screen ppm, 37deg C	HS-SPME 37deg C
Acetaldehyde	CA?, R.	Not listed	200	YES <9.5ppm	YES
Acetone	N	13 Chronic	1000	Not tested	YES
Acrolein	R	0.00004 I	0.1	YES < 1.3	NO
Acrylonitrile	CA, R	0.1 Acute	Not listed	NO. <<0.3	YES
Benzene	CA, CVD	0.003 Chronic	10	YES < 1.5	NO
1,3, Butadiene	CA	Not listed	1-5	NO <0.3	NO.
m-, o-, p- Cresols	CVD	Not listed	5	YES <0.495	NO
Carbon monoxide	CVD^	Exhaled.breath	50	15 puffs do not raise CO	
Ethylene oxide	CA	0.09 ppm I	Not listed	Not reported.	NO
Hydrogen cyanide	CVD	Not listed	10	NO < 0.3	NO
Propylene glycol	Not toxic	0.009 ppm I	None listed	YES	YES
Styrene	? CA	0.2 chronic	100	Not tested	YES
Xylenes	N	0.05 chronic	100	Not tested	YES

* CA= carcinogen, CVD= cardiovascular toxicant, N= neurological toxicant, R= respiratory toxicant.

^CVD risk for increased risk of ventricular fibrillation begins at 33 ppm (COHb=5%) and above. http://www.atsdr.cdc.gov/interactionprofiles/IP-12/ip12-a.pdf
**Minimum Risk Levels for hazardous substances.US Public Health Serivce, Agency for Toxic Substances and Disease Registry. Nov. 2007.http://www.atsdr.cdc.gov/toxpro2.html
***Permissible Exposure Levels. OSHA. Sept. 2007.
http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992

Acute effect = 1-14 days, I=Intermediate effects = 14-364 days, Chronic effect = 365 days or longer.
< LOQ= below the limit of quantitation. ppm = at 37 degrees Centigrade.

Summarising Table 8.2.2c above, the volatile organic compounds detected had either

- High permitted level for chronic exposure, as for acetone, acetaldehyde, styrene or xylene. (10 to 1000 ppm), but not yet quantified, or
- No listing under OSHA, but not exceeding 0.3 ppm on SIFT-MS, or
- No listing under OSHA, lack of proven toxicity. Example: propylene glycol, Present in ample quantity.

Table 8.2.2d. Toxicants ranked by Permitted Exposure Levels,* and whether present in Ruyan® e-cigarette cartridge vapour as detected by HS-SPME and exhaled CO.

Permitted Exposure Level PEL, ppm*	Compound Ppm	Detection by HS-SPME	SIFT-MS	CO Monitor, Exhaled breath	Remarks
< 1 ppm	Acrolein	NO	1.3 ppm		Need to quantify further
10 or less	HCN, butadiene	NO	<LOQ		Major toxicants
50	Carbon monoxide			NO, Not increased	
100 100 200 1000	Styrene Xylene Acetaldehyde Acetone	YES YES YES YES	9.5 ppm		OSHA permits higher levels in air for chronic exposure to these gases
Not listed by OSHA	Propylene glycol	YES	YES		Not considered toxic
	Acrylonitrile	YES	<<0.3 ppm, virtually zero.		Need recheck and quantify by a GC-MS method
	Ethylene oxide	NO			

***Permissible Exposure Levels**. OSHA. Sept. 2007 for weighted average exposures during an 8 hour shift.
http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992

For a graphic of the run result, see www.healthnz.co.nz/Portland2008ECIG.pdf

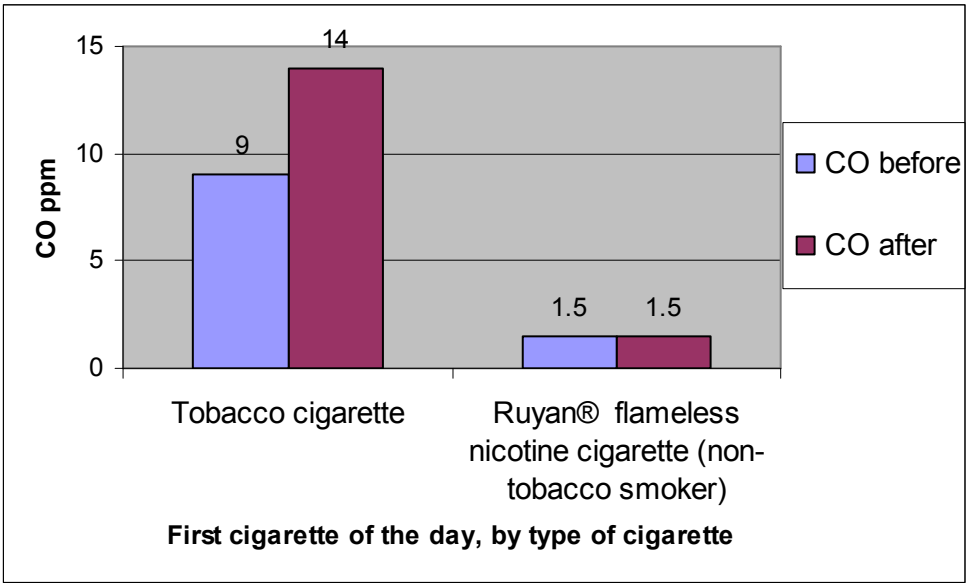
8.2.3 Analysis of the exhaled breath after using the Ruyan® e-cigarette

Carbon monoxide is a product of combustion and therefore can distinguish between the smoke produced by burning tobacco versus flameless cigarettes.

Method
Five minutes after their final puff of their first cigarette of the day, 17 smokers exhaled into a MicroMedical CO analyzer.[28] A non-tobacco smoker with a smokefree home and workplace, was similarly tested after 20 lung inhalations from of the Ruyan® e-cigarette.

Results

Table 8.2.3 Carbon monoxide in exhaled breath, before and after the first cigarette of the day, tobacco versus Ruyan® e-cigarette



The tobacco cigarette boosted CO in exhaled breath by an average of 5 ppm, but did not increase it in the non-smoker inhaling from the flameless Ruyan® e-cigarette

8.3 Impurities

8.3.1 In Propylene glycol. Impurities might arise in the manufacture or storage of propylene glycol.

Propylene oxide and ethylene oxide (a carcinogen) were not detected above the limit of detection 16.75 ug/ml and 42.5 ug/ml respectively on GCMS (gas chromatograph, mass spectrograph) testing.[29]. Some interference (matrix effect) prevented accurate quantification. However neither compound was detected by the HP-SPME scan, suggesting their levels if present were likely to be under 1 ppm.

8.3.2 Heavy metal traces. Heavy metals such as chromium, arsenic, and nickel can cause cancer, and lead is a neuro-toxicant. The liquid was tested for heavy metals (Arsenic, Antimony, Cadmium, Chromium, Cobalt, Copper, Lead, Manganese and Nickel), and the concentrations in each case were less than 1 part per million.
No hazardous effects are expected from heavy metals at this concentration[2] .

9. Risk of cross-infection from use

9.1 Risk of contamination from the mouthpiece. Public health agencies typically advise smokers not to share drinking glasses or cigarettes, due to the risk of cross-infection from lip saliva on the mouth end, with the risk of meningitis. This advice holds true for any electronic cigarette.

9.2 Risk of micro-organisms in the cartridge liquid. Another risk would be if the liquid in the cartridge acted as a culture medium for micro-organisms. The 5% alcohol content of the cartridge liquid (See Appendix 1) might be expected to inhibit growth of micro-organisms.
Environmental Science Research tested one used and one unused Ruyan® cartridge for the presence of the three main classes of micro-organism (aerobic, anaerobic and Legionella)[30]. None was found.
We conclude there is no inherent tendency in the design of the Ruyan® e-cigarette towards contamination from growth of organisms in the cartridge liquid. Nevertheless, instructions to users (and to tobacco cigarette smokers) should discourage cigarette sharing because of the risk of transfer of meningococcal meningitis, tuberculosis and other infectious diseases.

10. Safety of Ruyan® e-cigarette 'smoke' for bystanders.

Because inhaled nicotine is over 98% absorbed[6], the exhaled 'smoke' is propylene glycol minus the nicotine, and any exhaled PG mist dissipates within seconds. Without the gaseous products of combustion, the 'smoke' is not harmful to bystanders. The 'smoke' or mist is not tobacco smoke, and not from combustion – no flame is lit – and is not defined as environmental tobacco smoke. and e-cigarette "smoking" would be permitted under New Zealand's Smoke free Environments Act[31].

11. Further safety testing

Analyses have been requisitioned for further testing for possible impurities in the cartridge liquid.

Also, in January to March 2008, as part of a further trial of safety and efficacy, Clinical Trials Research Unit, University of Auckland independently monitored the use of the e-cigarette by some 50 subjects, over the course of one day, and recorded any adverse effects. These results are not yet available, and so will form the basis of a separate report to be published later in 2008.

Appendix 1. Safety of cartridge liquid in the Ruyan® e-cigarette

Summary:
Based on the manufacturer's information, the composition of the cartridge liquid is not hazardous to health, if used as intended.

Table 1.1: Chemical compositions (quantity) released from each Ruyan® cartridge

Chemical content released from each cartridge	Cartridge Specification, named by nicotine content			
	16mg	11mg	6mg	0mg
Water (mg)	40	40	40	40
Alcohol (mg)	50	50	50	50
Propylene glycerol (mg)	888	893	898	904
Nicotine (mg)	16	11	6	0
Flavor Base (mg) *	6	6	6	6
Total (mg)	1000	1000	1000	1000

Source: Manufacturer's data

Table 1.2: Chemical compositions (percentage w/w) released from each cartridge

Chemical content released from each catridge	Cartridge Specification, named by nicotine content.			
	16mg	11mg	6mg	0mg
Water	4%	4%	4%	4%
Alcohol	5%	5%	5%	5%
Propylene glycerol***	88.8%	89.3%	89.8%	90.4%
Nicotine	1.6%	1.1%	0.6%	0.0%
Flavour base *	0.6%	0.6%	0.6%	0.6%
Total	100%	100%	100%	100%

Source: Table 1.1.

*** See Appendix 3. Safety of Propylene Glycol.

***Safety Evaluation: 4-hydroxy-2,5-dimethyl-3(2H)-furanone and Acetyl pyrazine**

1). **4-hydroxy-2,5-dmethyl-3(2H)-furanone**
4-Hydroxy-2,5-dmethyl-3(2H)-furanone (FEMA 3174, CoE 536) is naturally occurring in various foods and plays an important role in the flavor of numerous fruits as well as in roasted products. 4-hydroxy-2,5-dmethyl-3(2H)-furanone has the odor and taste of fruity, caramelized pineapple-strawberry and is widely used in fresh bread, butter, chocolate, chocolate cocoa, coffee, meat roasted and nut almond.

Over 90% of annual production volume of tetrahydrofuran and furanone flavoring agents is 4-hydroxy-2,5-dmethyl-3(2H)-furanone. The estimated daily *per capita* intake is 5300 μg in Europe and 5200μg in the USA. Due to the large consumption, the safety of 4-hydroxy-2,5-dmethyl-3(2H)-furanone is extensively investigated. The oral LD_{50} for

mouse is 1,608mg/kg. Genotoxicity is observed at high dose, but it is related to a mechanism involving reactive oxygen species, rather than the generation of an active metabolite. A 2-year study in which rat were given a dose up to 400mg/kg bw from diet daily showed no evidence of carcinogenicity. Considering the fact that NOEL of 200mg/kg bw in rat is >2300 times the daily intake as a flavoring agent, the WHO Committee on Food Additives concludes that "the safety of this agent would not be a concern at the estimated current intake"[1].

2)**. Acetyl pyrazine**

Acetyl pyrazine (2-acetyl pyrazine, FEMA 3126, CoE 2286) is found in beef, coffee, popcorn, sesame seed, almond, wheat bread, cocoa, peanut, pork and potato chips, etc. According to the documentation from tobacco industry, acetyl pyrazine is added to cigarettes to give a pop-corn-like flavor and aroma to the tobacco.

Acetyl pyrazine belongs to a group of 41 flavoring agents consisting of pyrazine and pyrazine derivatives. Among them, acetyl pyrazine is detected naturally and its daily intake threshold for humans is 540mg/day. The estimated annual consumption of acetyl pyrazine is 920kg in the USA, corresponding to 120μg/person per day. In Europe, the intake of acetyl pyrazine is 14μg/person per day. The consumption of the parent substance pyrazine from food is about 36,000 times greater than its intake as a flavoring agent[2]. Compared to the 540mg/day human intake threshold, the amount is much lower and it is not a safety concern[3].

Toxicity data support the above conclusion. In an acute toxicity test on rat, LD_{50} through gavage was >3,000mg/kg. A group of 32 Wistar rats were maintained on diets containing acetyl pyrazine 8.2mg/kg bw for 90 days. Control group was given basic diet. At the end of experiment, measurements of growth rate, food intake, haematological and clinical chemical parameters, organ weights, and gross and histopathological appearance showed no differences between test and control animals[4].

Conclusion. Based on the manufacturer's information, the composition of the cartridge liquid is not hazardous to health, if used as intended.

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Appendix 2. Ruyan® e-cigarette. New Zealand testing to date, as of 9 April 2008

Topic	Name of test	Purpose	Status	Result
Toxicology	Nicotine content of liquid in cartridges	Confirm labelling states contents correctly	Completed	Generally around 90% of label.
	Benzo-alpha-pyrene in liquid	Whether liquid carcinogenic	Completed	None found
	Heavy metal traces in cartridge liquid	Whether liquid carcinogenic	Completed	Less than one part per million
	Tobacco specific nitrosamines in cartridge liquid	Whether liquid carcinogenic	Completed	Same as in Nicorette gum
	MAO inhibitors found in tobacco	Whether tobacco like effect found.	Completed	MAO effect not detected.
	Headspace tests for volatile organic compounds	To detect any impurities in cartridge liquid	Completed ,	Some detected and need quantifying.
	Draw-over 'smoke' tests	for quantifying gases detected	Booked for April 2008	Available May 2008
	Test for bacteria	To rule out infectivity. Whether bacteria grow in used and unused cartridges.	Completed	No growth of aerobic, anaerobic bacteria or legionella
Adverse effects	50 smokers to use each product for one day	Note how adverse events compare.	February-March 2008	Expected May 2008
Satis-faction ratings	50 smokers to use 16 mg Ruyan® e-cigarette for one day; and on other days use 0 mg Ruyan® e-cigarette, 10 mg Nicorette inhaler and own cigarette.	Rate satisfaction with product at end of day.	February March 2008	Expected May 2008
Efficacy Effect on urge to smoke (cigarette cravings)		Compare urge to smoke before are many times after using each product.	February-March 2008	Expected May 2008
Efficacy Pharmaco-kinetic study	Blood nicotine taken before and after using Ruyan® e-cigarette. (12 tobacco smokers)	Test and compare increase in blood nicotine after use of each product over two hours.	February-March 2008	Expected May 2008

Appendix 3. Safety of Propylene Glycol

Summary: Propylene glycol (PG) is virtually non-toxic.

Properties and uses. Propylene glycol $C_3H_8O_2$ is a completely water soluble liquid, and is prepared by hydrolysis of propylene oxide under pressure at high temperature without a catalyst. It is used in pharmaceuticals, as a drug vehicle (for example as an FDA approved solvent for intravenous diazepam) and preservative. It is used also in personal lubricants. It is used in semi-moist pet food and as a humectant for tobacco. In the food industry it is used as a solvent, humectant and preservative. Its mist is used in theatrical stage productions.[2]

Animal studies

In a study of rats exposed for 60 hours over two weeks, the highest concentration tested, 1800 mg/m(3), which was the highest concentration that could practically be generated, was the no-observed-effect level (NOEL). PG does not appear to pose a significant hazard via inhalation of either the vapor or a vapor/aerosol mixture.[3]

Addition of propylene glycol at 2.2% w/w tobacco does not increase the toxicity of cigarette tobacco.[4] In rats PG levels in plasma and lung are super-imposable with half an hour. A mild cumulative build up (30% or less) occurred after 28 days.[5]

Propylene glycol in humans
The toxicology website http://toxnet.nlm.nih.gov/ was searched for PG, using terms such as human, aerosol, NOEL, carcinogenicity, inhalation.
A review of PG has concluded it is safe for use in cosmetics at concentrations up to 50%.[6]
Absorption PG vapour has 100% deposition efficiency in human airways.[7]
It is partly absorbed on inhalation. PG is absorbed completely from the gastrointestinal tract and partly via the skin and the lungs.

Metabolism. It is metabolized to lactic acid and pyruvic acid, and further oxidized to glycogen or carbon dioxide and water. In man, approximately 20 - 25% of the PG is eliminated unchanged via the kidney.
Toxicity The website www.pneumotox.com devoted to inhalational toxicology, registers one case report of bronchospasm[8] but no other adverse effects.
Since PG is less efficiently absorbed following dermal and inhalation exposure compared to oral exposure, it is likely to have a low acute toxicity by these routes of exposure. CNS depression causing mortality has been described in premature infants after repeated exposure to medication containing PG.[9]

Carcinogenicity. There is no evidence that PG is a carcinogen.
PG exposure per puff of the Ruyan® e-cigarette The cartridge of the Ruyan® e-cigarette contains approximately 1g of PG, of which 0.9 g is extractable from the pad. The concentration of PG in the mouth from one drag of the Ruyan® e-cigarette (900 mg per cartridge, 300 puffs = 3mg) is 3 mg per mouthful).

PG exposure per day of using Ruyan® e-cigarette If the cartridge lasts 2-3 days as expected, then the inhaled dose is 0.3 to 0.45 g per day, and if used more intensively, could result in 0.9 g of PG inhaled and probably absorbed.

Absorption PG is absorbed rapidly and completely when taken orally. Humans have been given 40 g per 12 hours for 3 days to establish a steady state. After 3 days blood levels reached maximum one hour after administration of the PG dose.[2] We could find no data on the proportion of PG absorbed by inhalation. However the proportion is expected to be high, as it is highly soluble.

No-observed-effects level (NOEL) and RfD (reference dose) for humans for sub-chronic (less than a lifetime) and chronic inhalational exposure to PG is estimated by US EPA at 116 mg per 70 Kg human. This level, derived from rat studies, allows a safety factor of 100, 10 for inter-species extrapolation, and 10 to allow for susceptible individuals.[2] This NOEL, however, is artificially low - an artefact of the vapour pressure, as the researchers could not ensure higher concentrations of PG into the air breathed by the rats.

Inhalational Minimal Risk Levels (MRLs) No MRLs for acute- or chronic-duration inhalation exposure to propylene glycol were derived because data are insufficient.[10]

Inhalation threshold. The USEPA has developed no inhalation threshold value for it, nor has Cal/EPA. Inhalation toxicity is not an issue.

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Public Health England

Protecting and improving the nation's health

E-cigarettes: a new foundation for evidence-based policy and practice

Introduction

Smoking rates in England are in long-term decline. However, tobacco use remains one of the country's major public health challenges with the harm increasingly concentrated in more disadvantaged communities. Over recent years, e-cigarettes have risen in popularity to become the number one quitting aid used by smokers.[1] This consumer-led phenomenon has attracted considerable controversy within public health and beyond, with the unfortunate consequence of confusion among the general public about the relative risks of nicotine, e-cigarettes and smoked tobacco.

Public Health England (PHE) has a key role in mobilising the evidence base to protect public health and reduce inequalities. Our response to the uncertainty and controversy associated with e-cigarettes has been to establish a sound evidence base. In our first year we commissioned independent evidence reviews from leading UK researchers Professor John Britton[2] and Professor Linda Bauld.[3] These were published in May 2014 to coincide with our national symposium on e-cigarettes and tobacco harm reduction.

Together with Cancer Research UK we have set up the UK Electronic Cigarette Research Forum to discuss new and emerging research, develop knowledge and understanding, enhance collaboration among researchers interested in this topic, and inform policy and practice.

This latest comprehensive review of the up-to-date evidence on e-cigarettes, commissioned from Professor Ann McNeill and Professor Peter Hajek, synthesises what is now a substantial international peer-reviewed evidence base on e-cigarettes. It provides a firm foundation for policy development and public health practice in the context of new regulations for e-cigarettes to be introduced in the UK from May 2016 under the revised EU Tobacco Products Directive (currently under consultation).

Main findings of the evidence review

The report details the steady increase in the use of e-cigarettes in England over recent years (fig 1). This increase has taken place in the context of continued long-term declines in smoking prevalence among adults (fig 2) and youth (fig 3).

Figure 1

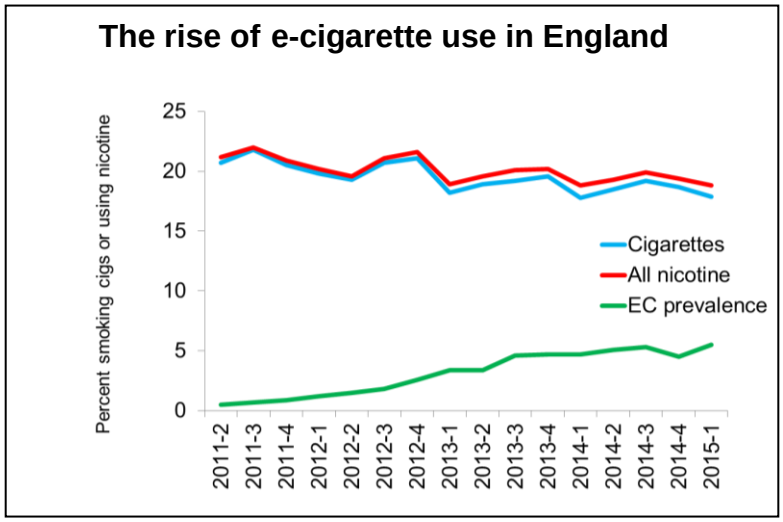


Figure 2

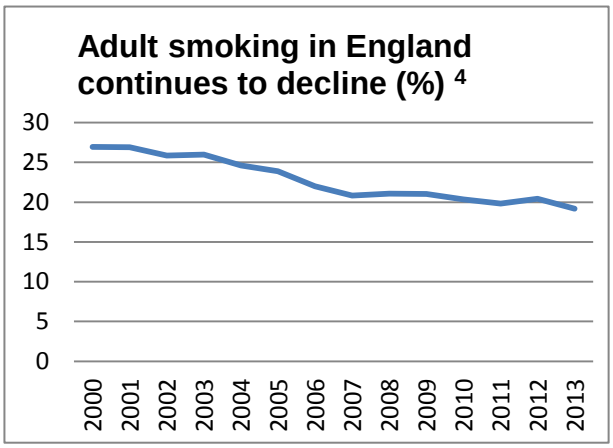
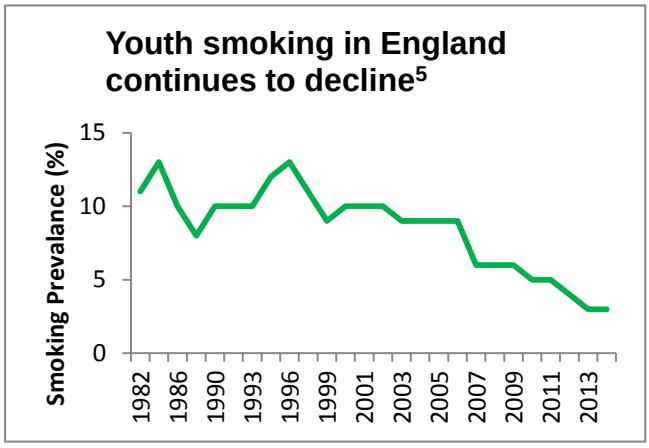


Figure 3



The authors find that among adults and youth, regular use of e-cigarettes is found almost exclusively among those who have already smoked. The highest rates of e-cigarette use are found among adult smokers. E-cigarettes have rapidly become the most widely used quitting aid in England (fig 4).

Figure 4

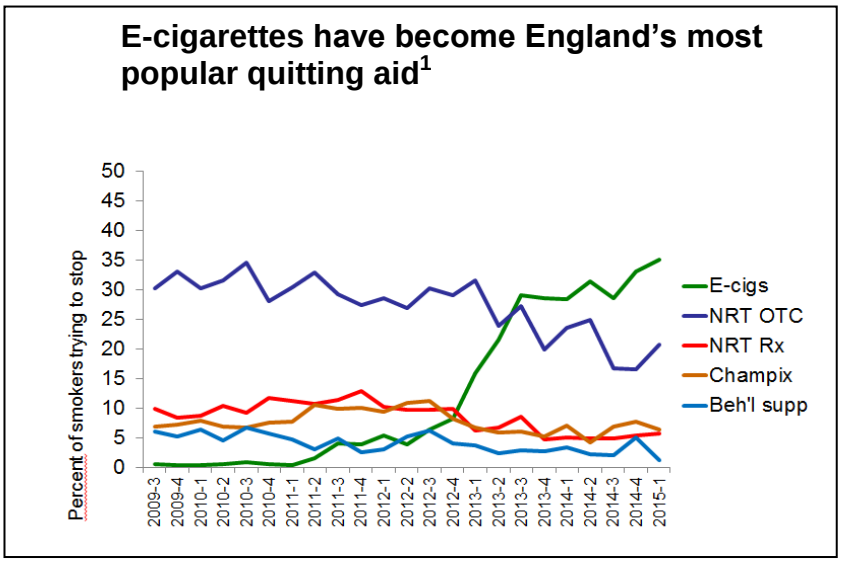
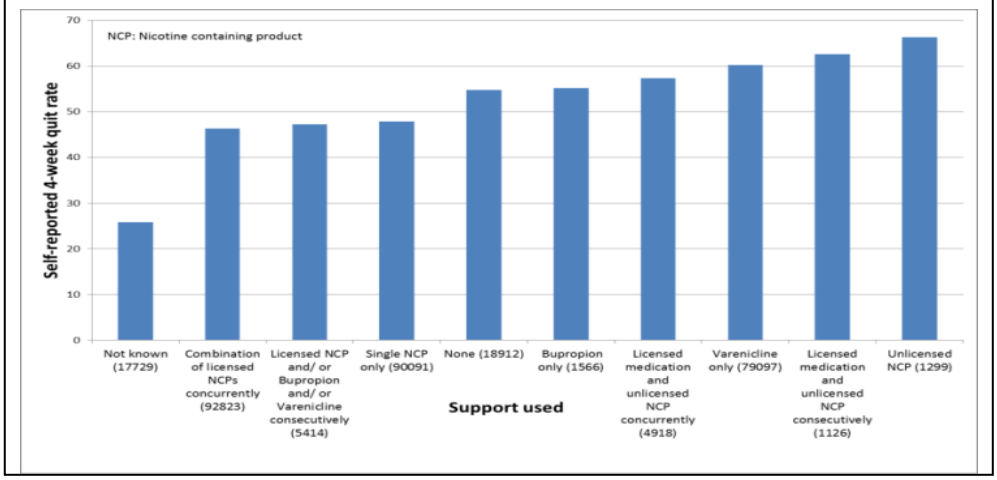


Figure 5

Smokers using EC with expert support to quit enjoy high levels of success[6]

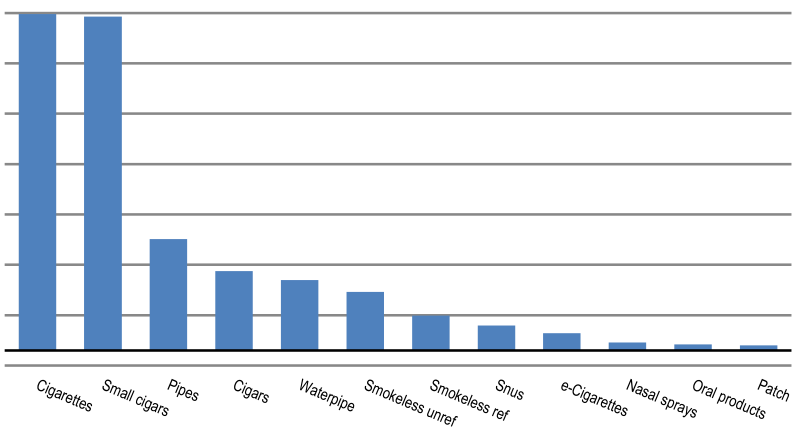


Recent studies support the Cochrane Review[7] findings that e-cigarettes can be effective in helping people to quit smoking. In local stop smoking services across England the relatively small number of smokers who have combined e-cigarettes with expert support have had high rates of success (fig 5).

Under the current regulatory system individual e-cigarette products vary considerably in quality and specification. We also do not yet have data on their long-term safety. However, the current best estimate by experts is that e-cigarette use represents only a fraction of the risk of smoking (fig 6).

Figure 6

Experts estimate e-cigarettes carry a fraction of the risk of smoking[7]



Safety and the perception of risks

It is important that the public be provided with balanced information on the risks of e-cigarettes, so that smokers understand the potential benefits of switching and so non-smokers understand the risks that taking up e-cigarettes might entail:

- when used as intended, e-cigarettes pose no risk of nicotine poisoning to users, but e-liquids should be in 'childproof' packaging. The accuracy of nicotine content labelling currently raises no major concerns
- the conclusion of Professor John Britton's 2014 review for PHE, that while vaping may not be 100% safe, most of the chemicals causing smoking-related disease are absent and the chemicals present pose limited danger, remains valid. The current best estimate is that e-cigarette use is around 95% less harmful to health than smoking
- e-cigarettes release negligible levels of nicotine into ambient air with no identified health risks to bystanders
- over the last year, there has been an overall shift among adults and youth towards the inaccurate perception of e-cigarettes as at least as harmful as cigarettes

Implications of the evidence for policy and practice

Based on the findings of the evidence review PHE also advises that:

- e-cigarettes have the potential to help smokers quit smoking, and the evidence indicates they carry a fraction of the risk of smoking cigarettes but are not risk free
- e-cigarettes potentially offer a wide reach, low-cost intervention to reduce smoking in more deprived groups in society where smoking is elevated, and we want to see this potential fully realised
- there is an opportunity for e-cigarettes to help tackle the high smoking rates among people with mental health problems, particularly in the context of creating smokefree mental health units
- the potential of e-cigarettes to help improve public health depends on the extent to which they can act as a route out of smoking for the country's eight million tobacco users, without providing a route into smoking for children and non-smokers. Appropriate and proportionate regulation is essential if this goal is to be achieved

- local stop smoking services provide smokers with the best chance of quitting successfully and we want to see them engaging actively with smokers who want to quit with the help of e-cigarettes
- we want to see all health and social care professionals providing accurate advice on the relative risks of smoking and e-cigarette use, and providing effective referral routes into stop smoking services
- the best thing smokers can do for their health is to quit smoking completely and to quit for good. PHE is committed to ensure that smokers have a range of evidence-based, effective tools to help them to quit. We encourage smokers who want to use e-cigarettes as an aid to quit smoking to seek the support of local stop smoking services
- given the potential benefits as quitting aids, PHE looks forward to the arrival on the market of a choice of medicinally regulated products that can be made available to smokers by the NHS on prescription. This will provide assurance on the safety, quality and effectiveness to consumers who want to use these products as quitting aids
- the latest evidence will be considered in the development of the next Tobacco Control Plan for England with a view to maximising the potential of e-cigarettes as a route out of smoking and minimising the risk of their acting as a route into smoking

Next steps for PHE

PHE's ambition is to secure a tobacco-free generation by 2025. Based on the evidence, we believe e-cigarettes have the potential to make a significant contribution to the endgame for tobacco. With opportunity comes risk, and a successful approach will be one that retains vigilance and manages these risks, while enabling a flourishing and innovative market with a range of safe and effective products that smokers want to use to help them quit.

From October this year, new regulations prohibiting the sale of e-cigarettes to under-18s and purchase by adults on behalf of under-18s will provide additional protection for young people.The government is consulting on a comprehensive array of regulations for e-cigarettes under the revised EU Tobacco Products Directive, for introduction from May 2016.

As part of our ongoing work to build an evidence-based consensus to support policy and practice on e-cigarettes, PHE will:

- continue to monitor the evidence on uptake of e-cigarettes, health impact at individual and population levels, and effectiveness for smoking cessation as products and technologies develop

- hold a second national symposium on e-cigarettes and harm reduction in spring 2016 to present the latest evidence and discuss its implications for policy and practice
- provide the public with clear and accurate information on the relative harm of nicotine, e-cigarettes and smoked tobacco. Nearly half the population don't realise e-cigarettes are safer than smoking, and studies have shown that some smokers have avoided switching in the belief that e-cigarettes are too dangerous
- publish framework advice to support organisations in developing evidence-based policies on use of e-cigarettes in enclosed public places and workplaces. This follows an engagement exercise conducted with public health partners and the wider stakeholder community to discuss the evidence and invite their input on its implications
- commission the National Centre for Smoking Cessation and Training to provide training and support to stop smoking practitioners to improve their skills and confidence in advising clients on the use of e-cigarettes
- monitor tobacco industry involvement in the evolving e-cigarettes market and exercise continuing vigilance to ensure we meet our obligations under Article 5.3 of the Framework Convention on Tobacco Control to protect public health policy from commercial and other vested interests of the tobacco industry

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8 September 2009

E-cigarettes: harmless inhaled or exhaled

No second hand smoke

CHEMICALS IN SMOKE and E-cigarette MIST

Leading chemicals only	Cigarette SMOKE	E-cigarette MIST
Nicotine per puff	YES 0.1 mg/puff	YES 0.01 mg/puff
Propylene glycol	NO 0 mg/puff	YES 0.7 mg/puff
Carbon monoxide	YES	NONE
Acrolein	YES	NONE
Hydrogen cyanide	YES	NONE
CARCINOGENS	1,3-Butadiene and 20+ others:	Trace amounts of a few only:
Acetaldehyde	YES	TRACE
Acrylonitrile	YES	NONE
Arsenic	YES	NONE
Benzalphapyrene	YES	NONE
Benzene	YES	NONE
Cadmium	YES	NONE
NNN, NNK (nitrosamines)	YES	TRACE

Second hand *cigarette* smoke is a mixture of mainstream and sidestream smoke. It contains the same toxicants as mainstream smoke, but at reduced levels. It is responsible for about 8% of the deaths caused by direct smoking.

Second hand mist from an *e-cigarette* is not smoke at all, and does not contain any substance known to cause death, short or long term, in the quantities found. It becomes invisible within a few seconds, and is not detectable by smell**.**

Exhaled breath after e-cigarette use has been tested for CO only. No increase in CO was found.

The e-cigarette does not create side-stream smoke. Exhaled breath after e-smoking contains even less nicotine per puff, as much of the nicotine inhaled is absorbed. Similarly, propylene glycol is largely absorbed and little is exhaled.

No harm found in e-cigarette mist

Nicotine is not harmful in the quantities mentioned.[1]

Propylene glycol is harmless – it is used in making theatrical fog and as an ingredient in soaps, personal lubricants and intravenous medicines.

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Some smokers need satisfying replacement products to help them quit smoking

Public Health England

Protecting and improving the nation's health

E-cigarettes: an evidence update

A report commissioned by Public Health England

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About Public Health England

Public Health England exists to protect and improve the nation's health and wellbeing, and reduce health inequalities. It does this through world-class science, knowledge and intelligence, advocacy, partnerships and the delivery of specialist public health services. PHE is an operationally autonomous executive agency of the Department of Health.

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Contents

Foreword

The role and impact of electronic cigarettes has been one of the great debates in public health in recent years and we commissioned this independent review of the latest evidence to ensure that practitioners, policy makers and, most importantly of all, the public have the best evidence available.

Many people think the risks of e-cigarettes are the same as smoking tobacco and this report clarifies the truth of this.

In a nutshell, best estimates show e-cigarettes are 95% less harmful to your health than normal cigarettes, and when supported by a smoking cessation service, help most smokers to quit tobacco altogether.

We believe this review will prove a valuable resource, explaining the relative risks and benefits of e-cigarettes, in terms of harm reduction when compared with cigarettes and as an aid to quitting.

We will continue to monitor the position and will add to the evidence base and guidance going forward.

Duncan Selbie, Chief Executive, PHE

Key messages

1. Smokers who have tried other methods of quitting without success could be encouraged to try e-cigarettes (EC) to stop smoking and stop smoking services should support smokers using EC to quit by offering them behavioural support.

2. Encouraging smokers who cannot or do not want to stop smoking to switch to EC could help reduce smoking related disease, death and health inequalities.

3. There is no evidence that EC are undermining the long-term decline in cigarette smoking among adults and youth, and may in fact be contributing to it. Despite some experimentation with EC among never smokers, EC are attracting very few people who have never smoked into regular EC use.

4. Recent studies support the Cochrane Review findings that EC can help people to quit smoking and reduce their cigarette consumption. There is also evidence that EC can encourage quitting or cigarette consumption reduction even among those not intending to quit or rejecting other support. More research is needed in this area.

5. When used as intended, EC pose no risk of nicotine poisoning to users, but e-liquids should be in ‘childproof' packaging. The accuracy of nicotine content labelling currently raises no major concerns.

6. There has been an overall shift towards the inaccurate perception of EC being as harmful as cigarettes over the last year in contrast to the current expert estimate that using EC is around 95% safer than smoking.

7. Whilst protecting non-smoking children and ensuring the products on the market are as safe and effective as possible are clearly important goals, new regulations currently planned should also maximise the public health opportunities of EC.

8. Continued vigilance and research in this area are needed.

Executive summary

Following two previous reports produced for Public Health England (PHE) on e-cigarettes (EC) in 2014, this report updates and expands on the evidence of the implications of EC for public health. It covers the EC policy framework, the prevalence of EC use, knowledge and attitudes towards EC, impact of EC use on smoking behaviour, as well as examining recent safety issues and nicotine content, emissions and delivery. Two literature reviews were carried out to update the evidence base since the 2014 reports and recent survey data from England were assessed.

EC use battery power to heat an element to disperse a solution of propylene glycol or glycerine, water, flavouring and usually nicotine, resulting in an aerosol that can be inhaled by the user (commonly termed vapour). EC do not contain tobacco, do not create smoke and do not rely on combustion. There is substantial heterogeneity between different types of EC on the market (such as cigalikes and tank models). Acknowledging that the evidence base on overall and relative risks of EC in comparison with smoking was still developing, experts recently identified them as having around 4% of the relative harm of cigarettes overall (including social harm) and 5% of the harm to users.

In England, EC first appeared on the market within the last 10 years and around 5% of the population report currently using them, the vast majority of these smokers or recent ex-smokers. Whilst there is some experimentation among never smokers, regular use among never smokers is rare. *Cigarette* smoking among youth and adults has continued to decline and there is no current evidence in England that EC are renormalising smoking or increasing smoking uptake. Instead, the evidence reviewed in this report point in the direction of an association between greater uptake of EC and reduced smoking, with emerging evidence that EC can be effective cessation and reduction aids.

Regulations have changed little in England since the previous PHE reports with EC being currently governed by general product safety regulations which do not require products to be tested before being put on the market. However, advertising of EC is now governed by a voluntary agreement and measures are being introduced to protect children from accessing EC from retailers. Manufacturers can apply for a medicinal licence through the Medicines and Healthcare products Regulatory Agency (MHRA) and from 2016, any EC not licensed by the MHRA will be governed by the revised European Union Tobacco Products Directive (TPD).

A summary of the main findings and policy implications from the data chapters now follows.

Summary of Chapter 3: UK policy framework

The revised TPD will introduce new regulations for EC or refill containers which are not licensed by the MHRA. The cap on nicotine concentrations introduced by the TPD will take high nicotine EC and refill liquids off the market, potentially affecting heavier smokers seeking higher nicotine delivery products.

The fact that no licensed EC are yet on the market suggests that the licensing route to market is not commercially attractive. The absence of non-tobacco industry products going through the MHRA licensing process suggests that the process is inadvertently favouring larger manufacturers including the tobacco industry, which is likely to inhibit innovation in the prescription market.

Policy implications

- From May 2016, following the introduction of the revised TPD, ECs will be more strictly regulated. As detailed elsewhere in the report, the information we present does not indicate widespread problems as a result of EC. Hence, the current regulatory structure appears broadly to have worked well although protecting non-smoking children and ensuring the products on the market are as safe and effective as possible are clearly important goals. New regulations currently planned should be implemented to maximise the benefits of EC whilst minimising these risks.

- An assessment of the impact of the TPD regulations on the UK EC market will be integral to its implementation. This should include the degree to which the availability of safe and effective products might be restricted.

- Much of England's strategy of tobacco harm reduction is predicated on the availability of medicinally licensed products that smokers want to use. Licensed ECs are yet to appear. A review of the MHRA EC licensing process therefore seems appropriate, including manufacturers' costs, and potential impact. This could include a requirement for MHRA to adapt the processes and their costs to enable smaller manufacturers to apply, and to speed up the licensing process. The review could also assess potential demand for the EC prescription market and what types of products would be most appropriate to meet that demand.

Summary of Chapter 4: Prevalence of e-cigarette use in England/Great Britain

Adults: Around one in 20 adults in England (and Great Britain) use EC. Current EC users are almost exclusively smokers (~60%) or ex-smokers (~40%), that is smokers who now use EC and have stopped smoking altogether. EC use among long-term ex-smokers is considerably lower than among recent ex-smokers. Current EC use among

never smokers is very low, estimated to be 0.2%. The prevalence of EC use plateaued between 2013-14, but appeared to be increasing again in 2015.

Youth: Regular EC use among youth is rare with around 2% using at least monthly and 0.5% weekly. EC use among young people remains lower than among adults: a minority of British youth report having tried EC (~13%). Whilst there was some experimentation with EC among never smoking youth, prevalence of use (at least monthly) among never smokers is 0.3% or less.

Overall, the adult and youth data suggest that, despite some experimentation with EC among never smokers, EC are attracting few people who have never smoked into regular use.

Trends in EC use and smoking: Since EC were introduced to the market, cigarette smoking among adults and youth has declined. In adults, overall nicotine use has also declined (not assessed for youth). These findings, to date, suggest that the advent of EC is not undermining, and may even be contributing to, the long-term decline in cigarette smoking.

Policy implications

- Trends in EC use among youth and adults should continue to be monitored using standardised definitions of use.
- Given that around two-thirds of EC users also smoke, data are needed on the natural trajectory of ‘dual use’, ie whether dual use is more likely to lead to smoking cessation later or to sustain smoking (see also Chapter 6).
- As per existing NICE guidance, all smokers should be supported to stop smoking completely, including ‘dual users’ who smoke and use EC.

Summary of Chapter 5: Smoking, e-cigarettes and inequalities

Smoking is increasingly concentrated in disadvantaged groups who tend to be more dependent. EC potentially offer a wide reach, low-cost intervention to reduce smoking and improve health in disadvantaged groups.

Some health trusts and prisons have banned the use of EC which may disproportionately affect more disadvantaged smokers.

Policy implications

- Consideration could be given to a proactive strategy to encourage disadvantaged smokers to quit smoking as quickly as possible including the use of EC, where appropriate, to help reduce health inequalities caused by smoking.

- EC should not routinely be treated in the same way as smoking. It is not appropriate to prohibit EC use in health trusts and prisons as part of smokefree policies unless there is a strong rationale to do so.

Summary of Chapter 6: E-cigarettes and smoking behaviour

Recent studies support the Cochrane Review findings that EC can help people to quit smoking and reduce their cigarette consumption. There is also evidence that EC can encourage quitting or cigarette consumption reduction even among those not intending to quit or rejecting other support. It is not known whether current EC products are more or less effective than licensed stop smoking medications, but they are much more popular, thereby providing an opportunity to expand the number of smokers stopping successfully. Some English stop smoking services and practitioners support the use of EC in quit attempts and provide behavioural support for EC users trying to quit smoking; *self-reported* quit rates are at least comparable to other treatments. The evidence on EC used *alongside smoking* on subsequent quitting of smoking is mixed.

Policy implications

- Smokers who have tried other methods of quitting without success could be encouraged to try EC to stop smoking and stop smoking services should support smokers using EC to quit by offering them behavioural support.

- Research should be commissioned in this area including:
  - longitudinal research on the use of EC, including smokers who have not used EC at the beginning of the study
  - the effects of using EC while smoking (temporary abstinence, cutting down) on quitting, and the effects of EC use among ex-smokers on relapse
  - research to clarify the factors that i) help smokers using EC to quit smoking and ii) deter smokers using EC from quitting smoking, including different EC products/types and frequency of use and the addition of behavioural support, and how EC compare with other methods of quitting which have a strong evidence base

- It would be helpful if emerging evidence on EC (including different types of EC) and how to use EC safely and effectively could be communicated to users and health professionals to maximise chances of successfully quitting smoking.

Summary of Chapter 7: Reasons for use and discontinuation

A number of surveys in different populations provide evidence that reducing the harm from smoking (such as through cutting down on their cigarette consumption or helping with withdrawal during temporary abstinence) and the desire to quit smoking cigarettes are the most important reasons for using EC. Curiosity appears to play a major role in experimentation. Most trial of EC does not lead to regular use and while there is less evidence on why trial does not become regular use, it appears that trial due to curiosity is less likely to lead to regular use than trial for reasons such as stopping smoking or reducing harm. Dissatisfaction with products and safety concerns may deter continued EC use.

Policy implications

- Smokers frequently state that they are using EC to give up smoking. They should therefore be provided with advice and support to encourage them to quit smoking completely.

- Other reasons for use include reducing the harm from smoking and such efforts should be supported but with a long-term goal of stopping smoking completely.

Summary of Chapter 8: Harm perceptions

Although the majority of adults and youth still correctly perceive EC to be less harmful than tobacco cigarettes, there has been an overall shift towards the inaccurate perception of EC being at least as harmful as cigarettes over the last year, for both groups. Intriguingly, there is also some evidence that people believe EC to be less harmful than medicinal nicotine replacement therapy (NRT).

Policy implications

- Clear and accurate information on relative harm of nicotine, EC and tobacco cigarettes is needed urgently (see also Chapter 10).

- Research is needed to explore how health perceptions of EC are developed, in relation to tobacco cigarettes and NRT, and how they can be influenced.

Summary of Chapter 9: E-cigarettes, nicotine content and delivery

The accuracy of labelling of nicotine content currently raises no major concerns. Poorly labelled e-liquid and e-cartridges mostly contained less nicotine than declared. EC used

as intended pose no risk of nicotine poisoning to users. However, e-liquids should be in 'childproof' packaging.

Duration and frequency of puffs and mechanical characteristics of EC play a major role in determining nicotine content in vapour. Across the middle range of nicotine levels, in machine tests using a standard puffing schedule, nicotine content of e-liquid is related to nicotine content in vapour only weakly. EC use releases negligible levels of nicotine into ambient air with no identified health risks to bystanders. Use of a cigalike EC can increase blood nicotine levels by around 5 ng/ml within five minutes of use. This is comparable to delivery from oral NRT. Experienced EC users using the tank EC can achieve much higher blood nicotine levels over a longer duration, similar to those associated with smoking. The speed of nicotine absorption is generally slower than from cigarettes but faster than from NRT.

Policy implications

- General labelling of the strength of e-liquids, along the lines used for example indicating coffee strength, provides sufficient guidance to consumers.

- Regulatory interventions should ensure optimal product safety but make sure EC are not regulated more strictly than cigarettes and can continue to evolve and improve their competitiveness against cigarettes.

Summary of Chapter 10: Safety of e-cigarettes in light of new evidence

Two recent worldwide media headlines asserted that EC use is dangerous. These were based on misinterpreted research findings. A high level of formaldehyde was found when e-liquid was over-heated to levels unpalatable to EC users, but there is no indication that EC users are exposed to dangerous levels of aldehydes; stressed mice poisoned with very high levels of nicotine twice daily for two weeks were more likely to lose weight and die when exposed to bacteria and viruses, but this has no relevance for human EC users. The ongoing negative media campaigns are a plausible explanation for the change in the perception of EC safety (see Chapter 8).

None of the studies reviewed above alter the conclusion of Professor Britton's 2014 review for PHE. While vaping may not be 100% safe, most of the chemicals causing smoking-related disease are absent and the chemicals which are present pose limited danger. It has been previously estimated that EC are around 95% safer than smoking. This appears to remain a reasonable estimate.

Policy implications

- There is a need to publicise the current best estimate that using EC is around 95% safer than smoking.
- Encouraging smokers who cannot or do not want to stop smoking to switch to EC could be adopted as one of the key strategies to reduce smoking related disease and death.

Summary of Chapter 11: Other health and safety concerns

There is a risk of fire from the electrical elements of EC and a risk of poisoning from ingestion of e-liquids. These risks appear to be comparable to similar electrical goods and potentially poisonous household substances.

Policy implications

- The risks from fire or poisoning could be controlled through standard regulations for similar types of products, such as childproof containers (contained within the TPD but which are now emerging as an industry standard) and instructions about the importance of using the correct charger.
- Current products should comply with current British Standard operating standards.
- Records of EC incidents could be systematically recorded by fire services.

Summary of Chapter 12: International perspectives

Although EC use may be lower in countries with more restrictions, these restrictions have not prevented EC use. Overall, use is highest among current smokers, with low numbers of non-smokers reporting ever use. Current use of EC in other countries is associated with being a smoker or ex-smoker, similar to the findings in the UK. EC use is frequently misreported with experimentation presented as regular use. Increases in youth EC trial and use are associated with decreases in smoking prevalence in all countries, with the exception of one study from Poland.

Policy implications

- Future research should continue to monitor and evaluate whether different EC policies across countries are related to EC use and to smoking cessation and smoking prevalence.
- Consistent and agreed measures of trial, occasional and regular EC use among youth and adults are urgently needed to aid comparability.

1. Introduction

Despite the decline in smoking prevalence observed over the last few decades, there remain over eight million smokers in England. Most of these are from manual and more disadvantaged groups in society, including those with mental health problems, on low income, the unemployed and offenders. In some such population groups, the proportion who smoke is over two or three times higher than that in the general population, a level of smoking observed in the general population over 40 years ago. For those who continue to smoke regularly, much of their lives will be of lower quality and spent in poorer health than those who don't smoke, and they will have a one in two chance of dying prematurely, by an average of 10 years, as a direct result of their smoking. Smoking is therefore the largest single contributor to health inequalities as well as remaining the largest single cause of preventable mortality and morbidity in England.

Moving forward, it is therefore important to maintain and enhance England's comprehensive tobacco control strategy in order to motivate and support *all* smokers in society to stop smoking as quickly as possible, and prevent the recruitment of new smokers. Harm reduction guidance, published by the National Institute for Health and Care Excellence in England in 2013, recognised that some smokers struggled to quit abruptly and that cigarettes were a lethal delivery system for nicotine [1]; it is widely accepted that most smokers smoke for the nicotine but die from the other smoke constituents. Harm reduction has been identified as one of the more promising policy options to reduce smoking induced inequalities in health [2]. All experts agree that a well-resourced comprehensive strategy, involving cessation, prevention and harm reduction should make the goal of a smoke-free society in England quickly achievable.

However, the advent of electronic cigarettes (EC) over recent years has caused controversy. In 1991, Professor Michael Russell, a leading English smoking cessation expert from the Institute of Psychiatry, argued that *"it was not so much the efficacy of new nicotine delivery systems as temporary aids to cessation, but their potential as long-term alternatives to tobacco that makes the virtual elimination of tobacco a realistic future target",* and he recommended that "*tobacco should be rapidly replaced by cleaner, less harmful, sources of nicotine"* [3]. Professor Russell was one of the first to recognise the critical role that nicotine played in tobacco use and he identified that whilst there were good ethical and moral reasons not to promote nicotine addiction in society, the harm caused by nicotine was orders of magnitude lower than the harms caused by cigarette smoke. Professor Russell was also a pioneer of new treatments for smoking cessation, in particular, nicotine replacement therapies (NRT). Since then, the number of NRT products has proliferated such that there are now several different delivery routes and modes and countless different dosages and flavours. However, even with a relaxation of the licensing restrictions which increased their accessibility, NRT products have never become popular as an alternative to smoking.

In 2004, the first EC was marketed in China, and EC started to appear in England in 2006/7. The subsequent three years saw a rapid rise in their use. Whilst Professor Russell died in 2009, predating the arrival of these products in England, proponents of EC similarly recognised their potential to contribute towards making a smoke-free society more rapidly achievable [4]. Those against EC, however, believed that they were at best a distraction, at worst a means of undoing decades of progress in reducing smoking [5].

Any new tobacco control strategy for England must therefore incorporate a nicotine strategy, which should include recommendations and an appropriate regulatory framework for EC. This report attempts to inform that strategy by reviewing recent evidence and surveys relating to the **use** of EC and how they **impact smoking behaviour.** The focus is England, although we also draw on evidence from elsewhere in the UK and internationally.

Description of e-cigarettes

EC use battery power to heat an element to disperse a solution that usually contains nicotine. The dispersion of the solution leads to the creation of an aerosol that can be inhaled by the user. The heated solution typically contains propylene glycol or glycerine, water, nicotine, and flavourings. EC do not contain tobacco, do not create smoke and do not rely on combustion. Whilst EC 'smoke' is technically an aerosol, throughout this report we use the established terminology of vapour, vaping and vaper.

There is substantial heterogeneity between different types of EC and the speed with which they are evolving making them difficult to categorise. ECs available in England can be classified into three basic types: (1) EC that are either (a) disposable or (b) use pre-filled cartridges that need to be replaced once emptied. We will refer to these using their most common name, 'cigalikes'. Most cigalikes resemble cigarettes, although it is important to note that some do not; (2) EC that are designed to be refilled with liquid by the user. We will refer to these using their common name 'tank systems'. (3) Finally, some EC products, mostly tank systems that allow users to regulate the power delivery from the batteries to the atomizer. These we refer to as mods or 'variable power EC'.

In the UK, the most prominent brands of cigalikes are now owned by the tobacco industry. To the authors' knowledge only one tobacco company sells a tank model in the UK, with the rest of the market consisting of non-tobacco industry companies. Some products have also been introduced by the tobacco industry that could be referred to as 'hybrids' such that they use pre-filled nicotine cartridges but look like tank models. Additionally, a few EC that are similar to cigalikes in function are also sold that use cartridges that can be refilled, and some users will puncture holes/remove the ends of cigalike cartridges to refill them instead of buying new cartridges.

Studies have validated the ability of EC to deliver nicotine to the user. Blood plasma nicotine concentrations increase after inhalation of EC aerosol [6, 7], and cotinine, a biomarker for nicotine, has been detected in the saliva of EC users [8, 9]. Information about the overall and relative risks of EC in comparison with smoking has also been developing. Using a multi-criteria decision analysis (MCDA) model, the Independent Scientific Committee on Drugs selected experts from several different countries to compare a variety of nicotine products on variables of harm identified by the UK Advisory Council on the Misuse of Drugs [10]. EC were identified as having 4% of the relative harm of cigarettes overall (including social harm) and 5% of the harm to users, although it was acknowledged that there was a lack of hard evidence for the harms of most of the nicotine products on most of the criteria.

Structure of report

Following Chapter 2 on methodology, Chapter 3 assesses the current and future policy framework for EC. Chapters 4 and 5 assess trial and usage in England among adults and youth as well as different socioeconomic groups where evidence permits. Chapter 6 examines the evidence for the impact of EC on smoking behaviour including the use of EC in quit attempts as well as alongside smoking. Chapter 7 assesses reasons for trying and discontinuing EC and Chapter 8 perceptions of relative harms of EC and smoking. Chapter 9 discusses nicotine content and emissions of EC as well as nicotine uptake in users. Chapters 10 and 11 assess different aspects of safety drawing on recent published studies as well as national statistics. Chapter 12 examines international perspectives of EC policies and usage.

2. Methodology

For the present report we have included: (1) a synthesis of recent evidence (published since the two PHE 2014 EC reports) with the earlier evidence in the earlier PHE reports drawing on both national and international literature; and (2) *where feasible*, an analysis of any relevant national unpublished data available to PHE, KCL and partner organisations from England, Great Britain or the UK, including: i) Smoking Toolkit Study (UCL); ii) Action on Smoking and Health (ASH) Smokefree GB (adult and youth) surveys; iii) Internet Cohort GB survey; iv) Smokers' surveys 2014 commissioned by ASH from YouGov; and v) the International Tobacco Control (ITC) policy evaluation project.

For the evidence review (1) above, given the short timeframe for this report, a systematic review of the literature was not possible. However, we followed systematic review methods where possible and searched PubMed for studies from 2014 onwards using the following search terms: (("2014/01/01"[Date - Publication] : "3000"[Date - Publication])) AND (((((((e-cigarette) OR Electronic cigarettes) OR e-cig*) OR electronic cig*) OR ENDS) OR electronic nicotine delivery systems) OR electronic nicotine delivery system) OR ((Nicotine) AND Vap*)).

The term ENDS was used as some studies have referred to e-cigarettes as Electronic Nicotine Delivery Systems (ENDS). This search returned 3,452 records. The titles of all records were screened and 798 articles were identified as potentially relevant to the report. The full papers of abstracts considered relevant by two reviewers were retrieved and reviewed as identified in Appendix A.

We wanted to ensure we included the most up-to-date information on EC use and impact in England. In order to do this we used routine national data sources to retrieve measures of EC use prevalence, fires, poisoning and other adverse events. Specifically for (2) above, we assessed, in addition to published papers, unpublished national survey data relevant to this work, identifying where findings are peer reviewed/published. The methods of the surveys that we have accessed are as follows:

Smoking Toolkit Study (STS, University College London)

The STS consists of monthly **cross-sectional household interviews** of adults (aged 16 and over) in England that has been running since November 2006. Each month involves a **new nationally representative sample** of about 1,800 respondents. Since 2009, all respondents who smoked in the last year have been asked questions on EC; since November 2013 all respondents complete questions on EC. For more information, see www.smokinginengland.info

ASH Smokefree GB (adult and youth) surveys

Adult: ASH has conducted **cross-sectional internet surveys** of adults (aged 18 and over) in Great Britain (GB) since 2007. These surveys cover a wide range of tobacco control policies and smoking behaviour and are carried out on ~12,000 adults each year. Questions on EC were included first in 2010, with new EC questions added in each subsequent survey (2012, 2013, 2014, 2015).

Youth: ASH has conducted **cross-sectional surveys of British youth** (aged 11-18) three times to date (2013, 2014, 2015). **Younger** participants are recruited, **online,** through the adult YouGov participants with **older** participants contacted **directly**. It has been used to give a more contemporaneous and comprehensive snapshot of youth attitudes towards smoking and their behaviours (and includes a breakdown of trial and more prolonged use of EC) than UK Government national surveys have been able to.

Internet Cohort GB survey (King's College London, University College London)

A unique longitudinal internet survey of smokers and recent ex-smokers in GB (aged 16 and over) surveyed first in 2012 and then again in December 2013 and 2014. Of the 5,000 respondents in the initial sample, 1,031 respondents (20.7%) used EC at all at the time of the survey in 2012. The prevalence of past-year smoking in this baseline sample was similar to that identified through the STS (which, as stated above, recruited representative samples of the population in England), over a comparable period.

In 2013, 2,182 of the 5,000 were followed up and in 2014, 1,519 were followed up. EC use was 32.8% (n=717) in 2013 and 33.2% (n=505) in 2014. The study sample was recruited from an online panel managed by Ipsos MORI who were invited by email to participate in an online study and were screened for smoking status. The survey included questions on smoking and quitting behaviour and stress and general health as well as detailed questions on EC usage.

ASH GB Smokers' survey 2014

This is an online survey carried out by YouGov for ASH specifically to assess more detailed attitudinal measures concerning nicotine containing products. The 2014 survey involved 1,203 adult smokers and recent ex-smokers selected from the ASH Smokefree adult survey to have roughly equal numbers of smokers who had (n=510) and had not (n=470) tried EC and a smaller number of ex-smokers who had tried EC (n=223).

ITC Policy Evaluation project

A longitudinal cohort survey of smokers and recent ex-smokers (aged 18 and over), surveyed by telephone and internet. The ITC UK survey started in 2002 and surveys

have been conducted approximately annually since that time. Probability sampling methods are utilised through telephone surveys using random digit dialling, but in more recent survey waves participants could opt to complete surveys on the internet. The ITC UK study benefits from parallel cohort surveys in Australia, Canada and the United States, enabling comparisons across countries with different tobacco and EC policies. Each wave of the survey includes approximately 1,500 UK respondents. EC questions were added to the last three waves. Data from the last wave (in 2014) were not available for inclusion in this report, but published papers from earlier waves are included. More details of the methodology are available at www.itcproject.org

3. UK policy framework

E-cigarette regulations in England: current and proposed

Regulations have changed little in England since the previous PHE reports. Currently EC are governed by general product safety regulations (UK and EU) which do not require that the products be tested before being put on the market. However, manufacturers can apply for a medicinal licence through the Medicines and Healthcare products Regulatory Agency (MHRA) [11] and from next year any EC not licensed by the MHRA will be governed by the revised European Union Tobacco Products Directive (TPD)[12]. Both the MHRA licensing and the TPD regulatory routes are described below. The TPD regulations are extensive and will have a significant impact on the EC market.

One change from the previous PHE report, which was introduced by the Advertising Standards Authority in October 2014, is that until the TPD comes into force, advertising of EC is governed by a voluntary agreement. This agreement indicates, inter alia, that advertising must be socially responsible, not promote any design, imagery or logo that might be associated with a tobacco brand or show the use of a tobacco product in a positive light, make clear that the product is an EC and not a tobacco product, not undermine quit tobacco messaging, and must not contain health or medicinal claims unless the product is licensed. These guidelines will be reviewed in October 2015 and when more is known about the application of the TPD the role of the Code will be clarified.

A further recent change is the introduction of measures to protect children from EC: an age of sale lower limit of 18 years of age (in line with tobacco cigarettes) is being introduced and a ban on proxy purchasing of EC.

EU Tobacco Products Directive (TPD) route

The revised TPD will introduce new regulations for EC or refill containers (referred to below as products) which are not licensed by the MHRA. We have listed these in detail below because they are wide-ranging and will impose a significant step change for manufacturers, importers and Member State (MS) authorities:

- **notification**: Manufacturers must inform competent authorities of the MS six months before placing new products on the market. For those already on the market by 20 May 2016, the notification needs to be submitted within six months of this date. Each substantial modification of the product requires a new notification
- **reporting obligations** (for which manufacturers/importers might be charged) include:

    - details (including quantification) on all the ingredients contained in, and emissions resulting from the use of, the product, by brand name
    - toxicological data regarding ingredients and emissions, including when heated, with reference particularly to health of consumers when inhaled including any addictive effect
    - information on nicotine doses and uptake when consumed under normal or reasonably foreseeable conditions
    - description of the product components, including where appropriate opening and refill mechanisms of product or refill containers
    - description of the production process and declaration that it conforms with the TPD
    - declaration that manufacturer/importer bear full responsibility for the quality and safety of the product when placed on market and used under normal or reasonably foreseeable conditions
- **nicotine-containing liquid** restrictions:
    - EC must not contain more than 20 mg/ml of nicotine
    - nicotine-containing liquid must be in dedicated refill containers not exceeding 10ml volume, and cartridges or tanks do not exceed a volume of 2ml
    - additives are not prohibited but the nicotine-containing liquids cannot contain additives that are otherwise prohibited by the other Articles in the TPD
    - high purity ingredients must be used and substances other than those declared should only be present in trace quantities which are unavoidable during manufacture
    - ingredients must not pose a risk to health either when heated or not heated
    - nicotine doses must be delivered at consistent levels under normal conditions of use
- products are required to be child and tamper proof, protected against breakage and leakage and have a mechanism that ensures refilling without leakage
- products must include a **leaflet with information** on:
    - instructions for use and storage of the product, including a reference that the product is not recommended for use by young people and non-smokers
    - contra-indications
    - warnings for specific groups
    - possible adverse effects
    - addictiveness and toxicity
    - contact details of manufacturer/importer and a legal or natural contact person within the EU
- **outside packaging of products** must include:
    - list of all ingredients contained in the product in descending order of the weight
    - an indication of the nicotine content and delivery per dose
    - batch number
    - recommendation to keep the product out of reach of children

    - no promotional element or feature or such that suggests the product is harm reducing (or other features described in Article 13 of the Directive)
- **health warnings:**
    - One of the following must be shown:
        - 'This product contains nicotine which is a highly addictive substance. It is not recommended for use by non-smokers' or
        - 'This product contains nicotine which is a highly addictive substance'
    - Member States shall determine which health warning to use
    - health warnings must comply with regulations concerning specific provisions on position and size
- cross-border **advertising** and promotion, sponsorship etc of products will be prohibited (unless trade information)
- **cross-border sales** of products may be prohibited or subject to a registration scheme
- manufacturers/importers of products to submit an **annual submission** on their products to competent authorities in MS which should include:
    - comprehensive data on sales volumes, by brand name and product type
    - information on preferences of various consumer groups, including young people, non-smokers and the main types of current users
    - mode of sale of the products
    - executive summaries of any market surveys carried out in respect of the above, including an English translation thereof products
- MS shall monitor the market developments concerning products, including any evidence that their use is a gateway to nicotine addiction and ultimately traditional tobacco consumption among young people and non-smokers. This information to be made publicly available on a website although the need to protect trade secrets should be taken into account
- MS should on request, make all information relevant to this Article available to the Commission and other Member States who will respect confidential information
- MS shall require manufacturers, importers and distributors of products to establish and maintain a system for collecting information about all of the suspected adverse effects on human health
- **corrective action** should be taken immediately if economic operators consider or have reason to believe that products are not safe or of good quality or not conforming to the Directive, ensuring conformity or withdrawal or recall from the market. In such cases, operators are required to inform immediately market surveillance authorities of the MS giving details of risk to human health and safety, corrective action taken and results of such corrective action. MS may request additional information from the economic operators on safety and quality aspects or any adverse effect of products
- the Commission will submit a report to the European Parliament and the Council on potential risks to public health by 20 May 2016 and as appropriate thereafter

- where a competent authority believes specific products could pose a serious risk to human health it should take appropriate provisional measures, immediately inform Commission and competent authorities of other MS of measures taken and communicate any supporting data. The Commission will determine whether provisional measure is justified informing the MS concerned of its conclusions to enable appropriate follow-up measures to be taken
- the Commission can extend any prohibition to other MS if such an extension is justified and proportionate
- the Commission is empowered to adapt wording of health warnings and ensure factual
- the Commission will give a common format for notification and technical standard for the refill mechanism outlined above

The exact date of implementation in England is yet to be specified but full compliance is likely to be necessary by 2017. One UK company, Totally Wicked, has challenged the UK's intention to transpose the Directive into UK law. The case rests on whether the TPD was properly made and has been referred to the European Court of Justice for a preliminary ruling. This is expected in late 2015/early 2016.

During implementation, government will need to undertake an impact assessment for the UK market on the final proposals as set out in the Directive and this will be consulted upon. The TPD certainly raises the barrier for bringing EC products to market or continuing to market existing products, and will undoubtedly constrain the EC market. Understanding any unintended consequences of the EU TPD as well as intended ones will be important. For example, the cap on nicotine concentrations introduced by the TPD will take high nicotine EC and refill liquids off the market, potentially affecting heavier smokers seeking higher nicotine delivery products.

Medicines and Healthcare products Regulatory Agency (MHRA) licensing route

Following a consultation in 2010, the UK MHRA introduced a mechanism for the licensing of EC and other nicotine containing products as medicines requiring medicinal purity and delivery standards. Such a licence would be required for products to be prescribed on the NHS. As with other licensed nicotine containing products, advertising controls would be applied and VAT of 5% would be imposed.

The licensing process has been described by the MHRA [11]. This regulation was described initially as 'light touch' recognising a product that delivered nicotine could be effectively used for harm reduction or cessation purposes, thus implying a relatively speedy route to licensing. This was subsequently changed to 'right touch' as it was apparent that the process was more lengthy and costly than originally envisaged. We understand that the MHRA estimated costs for a one-off application of between £252K and £390K with an annually recurring cost of between £65K and £249K, for each

product. This does not include the costs of making manufacturing facilities and products MHRA compliant – estimated at several million pounds.

At the time of writing one non-EC nicotine inhaler product, Voke, developed by Kind Consumer, and to be marketed by British American Tobacco (BAT), had received a medicinal licence, although it is not yet being marketed in England. A further BAT product (an EC) is currently going through the application process. Other EC products are currently in the pipeline with the MHRA but it is not clear at what stage the applications are or what types of products, eg cigalikes or tank models, are involved.

The absence of a licensed product, five years after the MHRA's consultation took place, suggests that this route to market is not commercially attractive. The fact that the only product at the application stage is a BAT product suggests that the process is very resource intensive. As well as cost, other possible reasons include complexity, a lack of desire to engage with medicinal licensing or the MHRA, the entrepreneurial nature of the EC manufacturers and a possible lack of perceived benefits to acquiring a licence. This could be problematic when the EU TPD is implemented, which is likely to constrain the over-the-counter market. Additionally, having a diverse range of EC on prescription is likely to be beneficial (similar to nicotine replacement tobacco (NRT) products – when new products are introduced, evidence suggests that they do not cannibalise the existing NRT product market but instead expand the use of medications). This means that small manufacturers, particularly non-tobacco industry manufacturers, who may be producing a greater variety or more satisfying EC, will not compete with larger corporations such as the tobacco industry in the prescriptions market. There are several consequences of this which should be explored. These could include an inhibition of innovation and damage public health. Alternatively, given the demand for prescribed EC products is as yet unknown, particularly in the population groups where smoking prevalence is elevated, the medicinal route may not impact public health. The appeal of EC may rest in the fact that they are not medicines. A review of the MHRA licensing process for EC, and its likely impact, is recommended.

Summary of findings

The revised TPD will introduce new regulations for EC or refill containers which are not licensed by the MHRA. The cap on nicotine concentrations introduced by the TPD will take high nicotine EC and refill liquids off the market, potentially affecting heavier smokers seeking higher nicotine delivery products.

The fact that no licensed EC are yet on the market suggests that the licensing route to market is not commercially attractive. The absence of non-tobacco industry products going through the MHRA licensing process suggests that the process is inadvertently favouring larger manufacturers including the tobacco industry, which is likely to inhibit innovation in the prescription market.

Policy implications

- From May 2016, following the introduction of the revised TPD, ECs will be more strictly regulated. As detailed elsewhere in the report, the information we present does not indicate widespread problems as a result of EC. Hence, the current regulatory structure appears broadly to have worked well although protecting non-smoking children and ensuring the products on the market are as safe and effective as possible are clearly important goals. New regulations currently planned should be implemented to maximise the benefits of EC whilst minimising these risks.

- An assessment of the impact of the TPD regulations on the UK EC market will be integral to its implementation. This should include the degree to which the availability of safe and effective products might be restricted.

- Much of England's strategy of tobacco harm reduction is predicated on the availability of medicinally licensed products that smokers want to use. Licensed ECs are yet to appear. A review of the MHRA EC licensing process therefore seems appropriate, including manufacturers' costs, and potential impact. This could include a requirement for MHRA to adapt the processes and their costs to enable smaller manufacturers to apply, and to speed up the licensing process. The review could also assess potential demand for the EC prescription market and what types of products would be most appropriate to meet that demand.

4. Prevalence of e-cigarette use in England/Great Britain

This chapter assesses the use of EC by adults and young people in England by drawing on recent surveys carried out in England and Great Britain (GB). A later chapter discusses EC prevalence internationally.

Measures used

One of the main issues in measuring EC use is the lack of consistent and appropriate terminology, for example some studies equate ever having used EC with current use of EC which is clearly inappropriate. We recommend that definitions of usage categories should be standardised similar to those used in smoking surveys. Appendix B lists the different measures used in surveys focused on in this report, and gives definitions used in the other studies included in this review.

Use of e-cigarettes by adults

First, we assess e-cigarette use in the adult population in England. We summarise various data sources to provide an overview of EC use among the general population, and then specifically smokers, recent and long-term ex-smokers, and never-smokers. The two main surveys used in this chapter are the Smoking Toolkit Study (STS) and the ASH Smokefree GB surveys. However, in addition to these surveys, findings from the Office for National Statistics Opinions and Lifestyle Survey (ONS survey), a randomised probability sample omnibus survey in GB, have also been included in this section although the exact question used is not available [13]; preliminary released data from Q1 2014 are reported here in advance of the complete data due for publication later in 2015.

Population use of e-cigarettes

Of the available datasets, just two – the Smoking Toolkit Study (STS, England) and the ASH Smokefree GB adult surveys – provide information on population prevalence (Table 1). Using the STS, it is estimated that 5.5% of the adult population of England used EC in the first quarter of 2015 indicating a marked rise from 0.5% in 2011. The measure of use in the STS is compiled from four survey questions and assesses *current use for any reason* (Appendix B). A very similar estimate is obtained for GB using the 2015 ASH survey, with 5.4% of the population estimated to be current (defined as *tried EC and still use* them, see Appendix B) EC users. This translates to about 2.6 million EC users in GB in 2015 [14](for comparison there are about nine million tobacco

smokers in GB and as discussed later, most EC users are smokers or ex-smokers). The ASH survey also assessed trial and about 17% of the adult GB population was estimated to have tried EC.

Table 1: Adult EC current use[1]

Source (date of data collection)	Population Prevalence	Never smokers	Ex-smokers	Smokers ('Dual users')
ASH Smokefree GB adult survey *(2015 - March)*	5.4%	0.2%	6.7%	17.6%
Office for National Statistics *(2014 - Q1)*	N/A	0.1%	4.8%	11.8%
Smoking Toolkit Study *(2015 – Q1)*	5.5%	0.2%[2]	3.3%[2]	21.2%

[1]For definitions of current use please see Appendix B. The ONS question is unavailable.
[2]Figures for never and long-term ex-smokers are derived from n=22489 never and long-term ex-smokers surveyed between November 2013 and March 2015

Never smokers and long-term ex-smokers

All three surveys estimate *current* EC use among adult *never* smokers to be very rare at 0.2% or less, and between 3% and 7% among *ex*-smokers – the latter estimates may vary because in the STS recent ex-smokers (last-year) are not included in this category (Table 1). Prevalence of current EC use among recent ex-smokers in the STS was around 40% in the first quarter of 2015 [15].

The ASH survey estimated that around 1.5% of *never* smokers and 16% of *ex*-smokers had *ever tried* EC.

Smokers

Recent surveys estimate that *current* EC use among smokers, sometimes referred to as 'dual users' of cigarettes and e-cigarettes, is between 12 and 21% (Table 1). The prevalence of EC use among last-year smokers (defined as smokers and recent ex-smokers) using the STS in England is estimated at 22.9% for *any* use of EC and 14.9% for *daily* EC use. The ASH 2015 survey indicated that 17.6% of current smokers use EC currently (18% of occasional and 17% of daily smokers); the same survey indicated that a small majority of smokers (59%) have now tried EC.

The Q1 2014 ONS Survey data estimates for current use are considerably lower, suggesting that just under 12% of current smokers used EC in early 2014. The survey question/s used to determine this is/are not available to assess whether different ways of assessing use may be a reason for this discrepancy in findings.

The ASH survey indicates that about 60% of current EC users are current smokers, and about 40% are ex-smokers. The proportion of EC users among never smokers remains negligible.

Summary

Around one in 20 of the general adult population in England (and GB) use EC. Current EC users are almost exclusively smokers or ex-smokers. EC use among long-term ex-smokers is considerably lower than among recent ex-smokers.

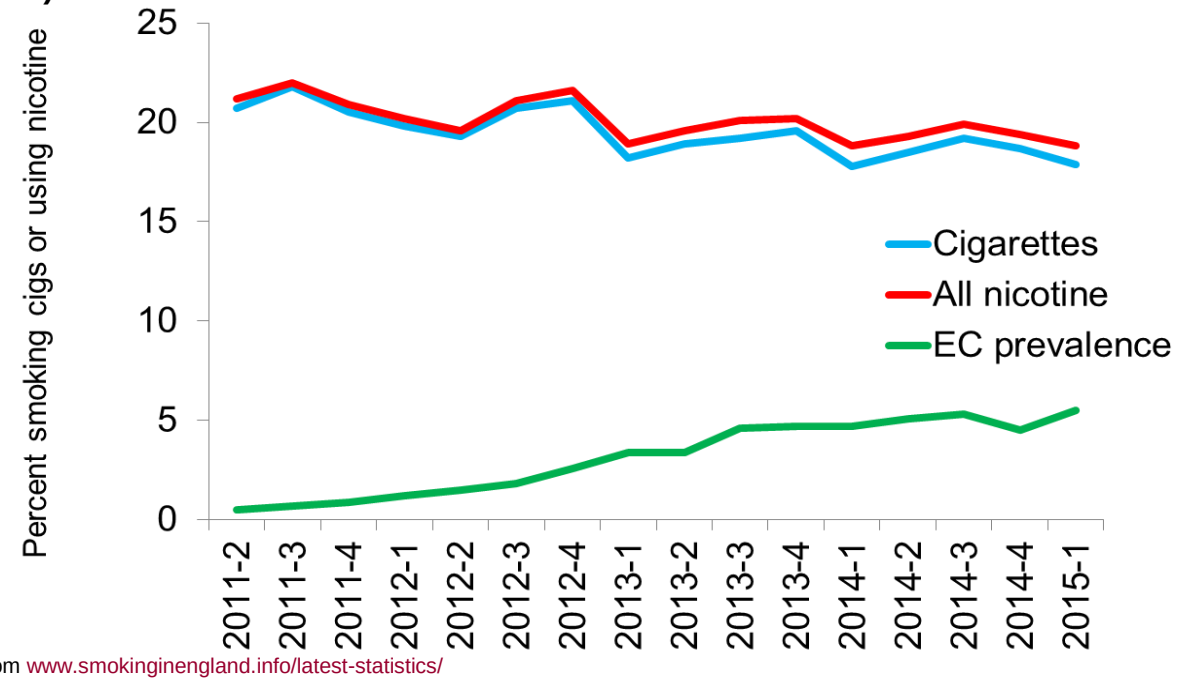
Trends in e-cigarette use among adults

Both the STS and ASH surveys demonstrate that there was a steady increase in EC use in the population from 2011 to 2013.

Smoking Toolkit Study (STS) data

The STS data indicate that this increase slowed down, even declining at the end of 2014 from 5.3% in Q3 to 4.5% in Q4 (Figure 1). However, as Q1 data from 2015 show a recent upswing to 5.5%, this decline may have been temporary. The STS data show that alongside the increase in EC use, smoking of tobacco cigarettes declined. Overall nicotine use, ie any consumption via cigarette smoking, NRT use or EC use, has also declined.

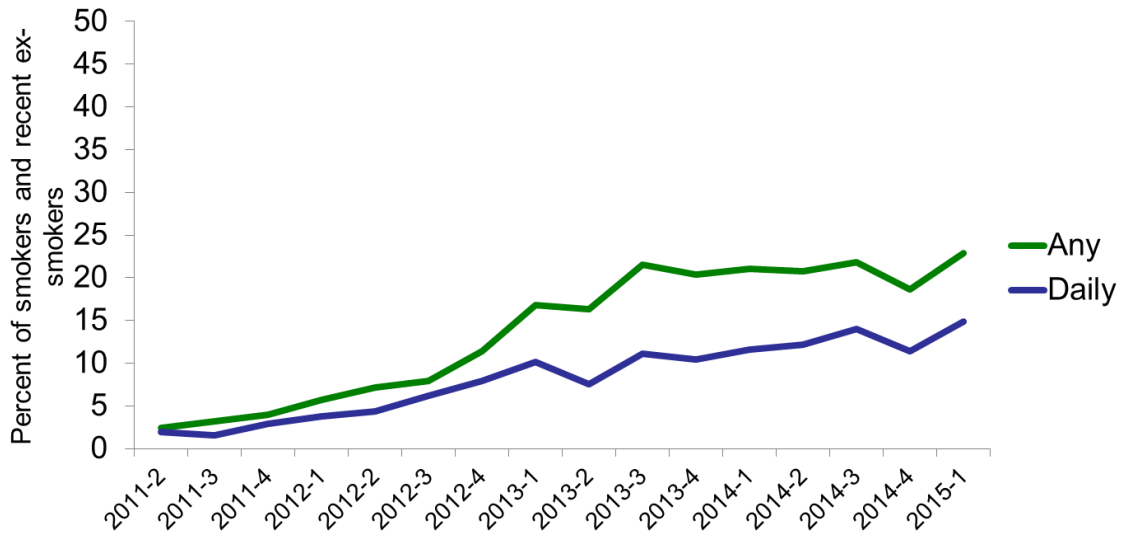
Figure 1: Prevalence of smoking and e-cigarette use among the adult English population (STS)



From www.smokinginengland.info/latest-statistics/

The overall pattern of EC use in the population is mirrored among last year smokers for whom EC prevalence increased from 2011, but declined from 22% for *any* use and 14% for *daily* use in Q3 2014, to 19% and 11% respectively in Q4 2014; however, any and daily use increased again to 23% and 15% respectively in Q1 2015 (Figure 2).

Figure 2: Prevalence of e-cigarette use among last year smokers (STS)



From www.smokinginengland.info/latest-statistics/

ASH Smokefree GB adult survey

The ASH surveys indicated a slowing down in the increase of EC use in the population between 2014 and 2015 and use among current smokers in 2015 remained at the 2014 level (17.6% of smokers in 2014 and 2015). Use among ex-smokers increased from 1.1% in 2012, to 4.5% in 2014 and 6.7% in 2015, whereas no increase in use was observed among never smokers over the last few years, remaining at 0.2% since 2013. **This means that the increase in EC use observed overall was accounted for by an increase in use by ex-smokers.** It is not clear to what extent this is due to smokers stopping smoking using EC or ex-smokers taking up ECs.

Summary

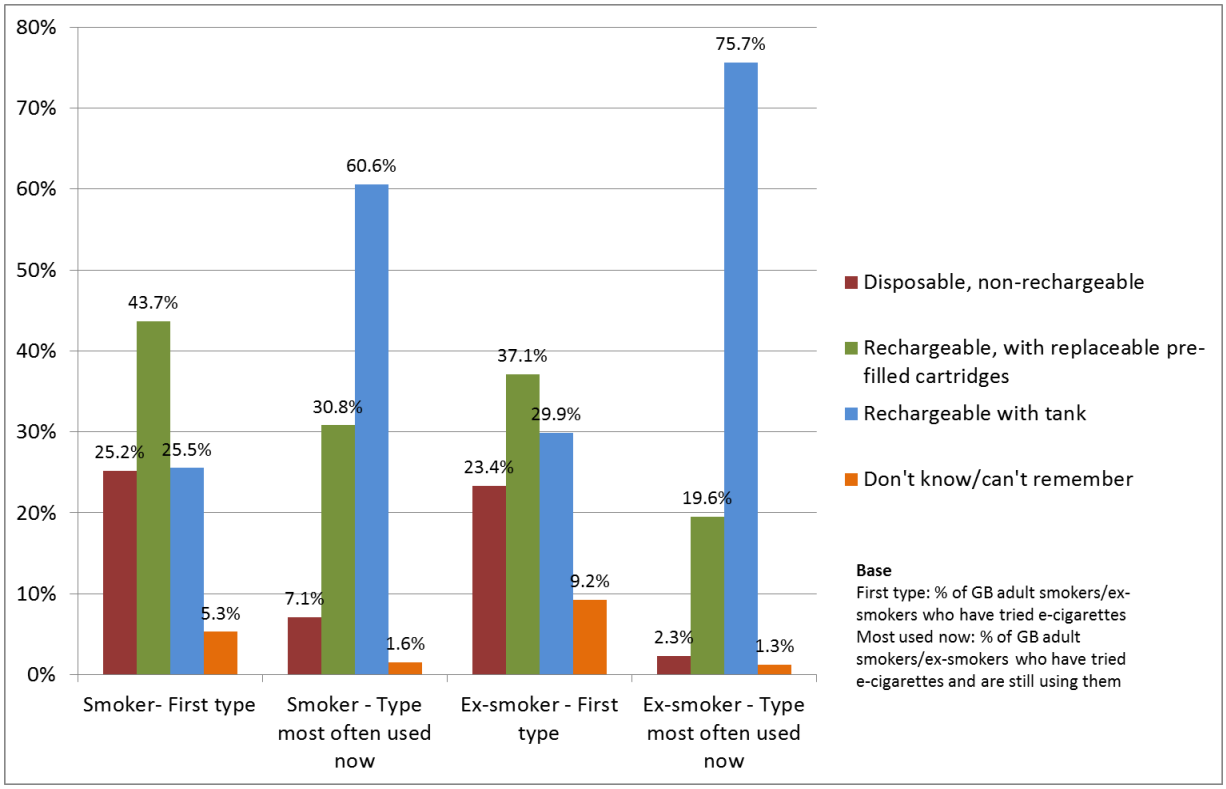
The prevalence of EC use among adults has plateaued. Most of the recent increase in use appears to be among ex-smokers. Cigarette smoking has declined over the period when EC use increased and overall nicotine use has also declined. These findings suggest that the advent of EC is not undermining and may be contributing to the long-term decline in cigarette smoking.

Types and flavours of e-cigarettes used among adults

When those who had tried EC in the 2015 ASH survey were asked about which EC *they used first*, 24% reported a disposable, 41% a rechargeable with replaceable pre-filled cartridges and 28% rechargeable with tank/reservoir filled with liquids (7% didn't know/couldn't remember). The different types were in the same order of popularity for first use regardless of smoking status (Figure 3).

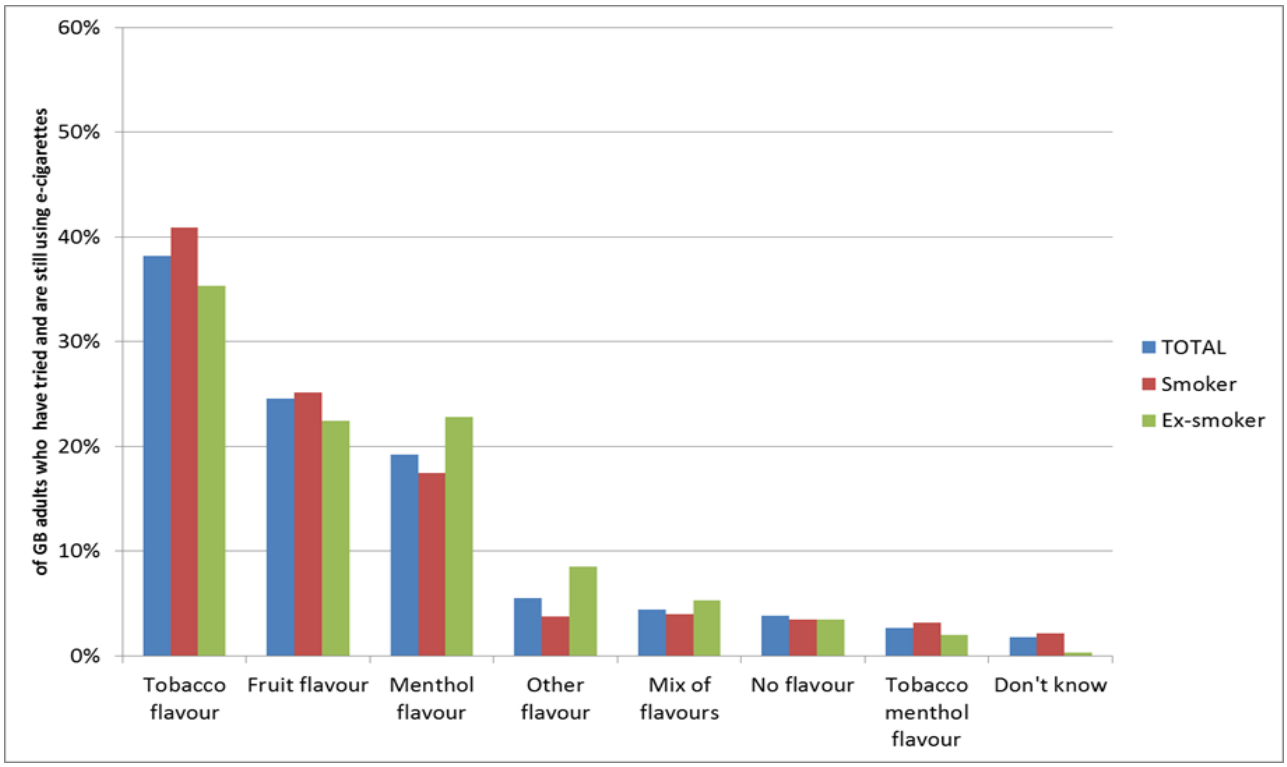
For those *still using EC* from the same survey, only 5% were *now mostly* using a disposable, 26% a rechargeable with replaceable pre-filled cartridges and 66% rechargeable with tank/reservoir filled with liquids (2% didn't know/couldn't remember). **This suggests that a considerable proportion of those who continue to use EC over time switch to the tank models.** Among EC users, ex-smokers were particularly likely to use tank models mostly and very few ex-smokers were using disposables (Figure 3). This is in agreement with findings reported in Chapter 6 of this report, where tank models were found to be associated with having quit smoking [16].

Figure 3: Type of e-cigarettes first used and currently used (ASH Smokefree GB data 2015)



The ASH Smokefree GB 2015 adult survey also shows that the most popular flavour was tobacco flavour, followed by fruit and menthol flavours (Figure 4).

Figure 4: Use of different flavoured e-cigarettes (ASH Smokefree GB data 2015)



Use of e-cigarettes among young people

The main source for estimating *smoking* prevalence in England among youth is the '*Smoking, drinking and drug use among young people'* surveys [17], however, EC use was first assessed in 2014 and these data are not yet available. This section therefore draws on the ASH Smokefree GB youth surveys to assess EC usage in young people, supplemented by a study in the North West of England, two cross-sectional national surveys in Wales and one national survey in Scotland. The measures used are detailed in Appendix B.

In 2015, the ASH survey found that 12.7% of 11 to 18-year olds reported *having tried EC;* of these, 80.9% had only used one once or twice (10.2% of all respondents). Current EC use was considerably lower: 0.7% had used an EC sometimes but not more than once a month; 1.2% more than once a month but not weekly; and 0.5% weekly (Table 2). **The prevalence of EC use (2.4% overall)** among people aged between 11 and 18 was therefore lower than among the general population. In comparison, 21% of all 11 to 18-year olds reported having tried cigarettes, of whom 54% only tried once (11.4% of all respondents). Current smoking was reported by a total of 6.7%; 2.7% smoked less than weekly and 4% at least weekly.

Experimentation increased with age: 2.9% of 11-year olds and 20.2% of 18-year olds had tried EC. In comparison, among 11-year olds, 3.9% had tried cigarettes (0.7% current smokers), whereas 40.9% of 18-year olds had tried cigarettes (14.3% current smokers).

Use of EC was very closely linked with smoking status. Among never smokers, 0.3% used EC monthly or more often, compared with 10.0% of ever smokers and 19.1% of current smokers. The majority of EC users had tried tobacco cigarettes first (Table 2).

Table 2: E-cigarette use among young people

Source	Ever tried	Use more than /at least once a month	Use more than once a week	Use (at least monthly) in *never* smokers	Those using e-cigarettes who had tried tobacco first
ASH Smokefree GB youth survey (11-18 years) [1] *(2015 – March)*	12.7%	1.9%	0.5%	0.1%	63.7%
Health Behaviour in School-aged Children, Wales (11-16 years) *(Nov 2013 – Feb 2014)* **[18]** [2]	12.3%	1.5%	Not reported	0.3%	Not reported
CHETS Wales survey (10—11 year olds)[19] 2014	5.8%	Not reported	Not reported	Not reported	Not reported
SALSUS Scotland survey (15 and 13 year olds)[20] 2013/2014	12%	0.4%	0%	0%	Not reported

[1]For question on e-cigarette categories please see Appendix B. Use more than/ at least once a month excludes those using more than once a week who are reported separately
[2] N=9055, use defined as at least monthly

Similar findings have been observed in Scotland. A national survey carried out in 283 schools across Scotland in late 2013/early 2014 involved more than 33,000 schoolchildren aged 13 and 15 years old [20]. Seven per cent of 13-year olds, and 17% of 15-year olds, had ever used an EC. Trial was associated with smoking status – 4% of never smokers had tried EC (3% trying them once and 1% having tried a few times) compared with 24% of ever smokers, 39% of ex-smokers, 46% of occasional smokers and 66% of regular smokers. Eleven per cent of regular smokers and 6% of occasional smokers reported using e-cigarettes at least monthly.

Very similar findings have been reported from a survey in Wales (Table 2). A survey of secondary schoolchildren was carried out under the auspices of the Health Behaviour of

School Children (HBSC) study and more than 9,000 participants aged 11–16 from 82 schools were included [18]. Overall, 12.3% had tried EC, 1.5% were monthly users, compared with 12.1% reporting ever having smoked and 5.4% current smokers (reported smoking less than once a week or more frequently). Whilst many *experimental* EC users had never smoked, most *regular* EC users had also smoked tobacco. The authors commented that *"the very low prevalence of regular use…suggests that e-cigarettes are unlikely to be making a significant direct contribution to adolescent nicotine addiction".*

Additionally, around 1,500 **10 to 11-year olds** were surveyed in Wales, from 75 schools in the CHETS Wales study [18, 19] (Table 2). Overall, 5.8% (n=87) had ever used an EC; most reported only using once (3.7%, n=55 overall) and only 2.1% (n=32) reported using them more than once. Again, EC use was associated with smoking. Just under half (47.6%) of those who reported having used tobacco had ever used an EC compared with 5.3% of never smokers. Controlling for other variables associated with EC use, parental use of EC and peer smoking remained significantly associated with having ever used an EC. Having ever used an EC was associated with weaker anti-smoking intentions. **Parental EC use was not associated with weakened anti-smoking intentions whereas parental smoking was [19].** This study, published prior to the one above, concluded that EC represented a new form of experimentation with nicotine that was more common than tobacco usage. It also commented that the findings added *"some tentative support for the hypothesis that use of e-cigarettes may increase children's susceptibility to smoking"*. However, as this was a cross-sectional survey, causal connections cannot be inferred. It is possible that children who had used EC would have smoked cigarettes in their absence and this could explain the relationship between intentions and EC usage (see below).

An additional survey of schoolchildren has been carried out in England. Trading Standards in the North West of England have been running biennial surveys of schoolchildren since 2005. The 2013 findings on EC, smoking and alcohol were published [21]. The survey was not designed to be representative (no compliance or completion rates were collected) but instead *"to provide a broad sample of students from a range of community types".* More than 100 schools participated and more than 16,000 participants aged 14–17 years of age were included in the analyses. It is important to acknowledge that the question about EC was "*Have you ever bought or tried electronic cigarettes?*", and this study cannot therefore add to knowledge on current usage. Around one in five of the sample had accessed EC, with access being higher in those who had experience of smoking. Around 5% of those who had *never* smoked cigarettes reported accessing EC; around half of *ex-smokers* and over two thirds of *regular smokers* had accessed them. Parental smoking and alcohol use were also associated with EC access.

Summary

Regular use of EC among youth is rare with around 2% using at least monthly and 0.5% weekly. A minority of British youth report having tried EC (national estimates suggest around 12%). Whilst there was some experimentation with EC among never smokers, **nearly all those using EC regularly were cigarette smokers.**

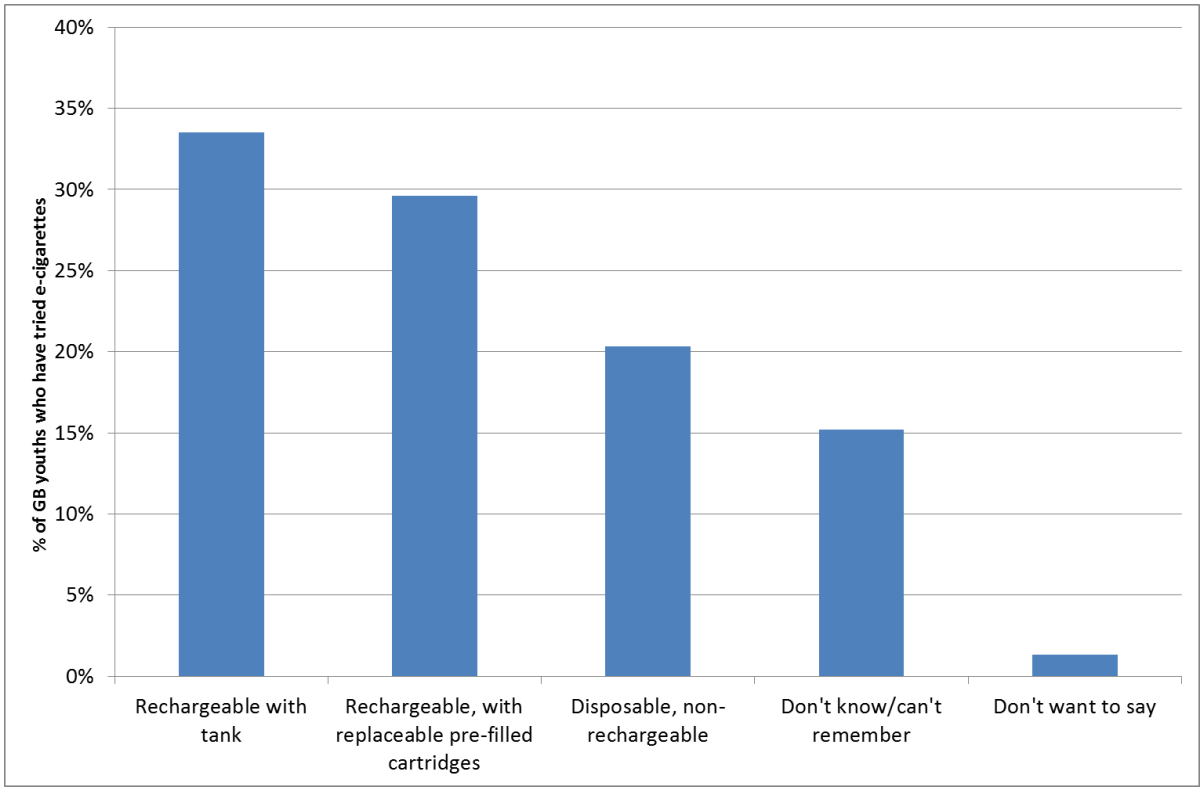
Trends in e-cigarette use among young people (ASH Smokefree GB youth)

The ASH Smokefree GB youth surveys indicate that awareness of EC has increased markedly, with the proportion of individuals who had *never heard* of EC falling from 33.1% in 2013 to 7.0% in 2015*. Ever having tried* EC also increased, from 4.5% in 2013, to 8.1% in 2014, and to 12.7% in 2015. However, the proportion using an EC monthly or more frequently remained virtually unchanged from 2014 (1.6%) to 2015 (1.7%). Over the same period, the proportion of regular smokers (at least weekly) remained at around 4% (2013: 4%, 2014: 3.6%, 2015: 4%).

Type and flavour among youth

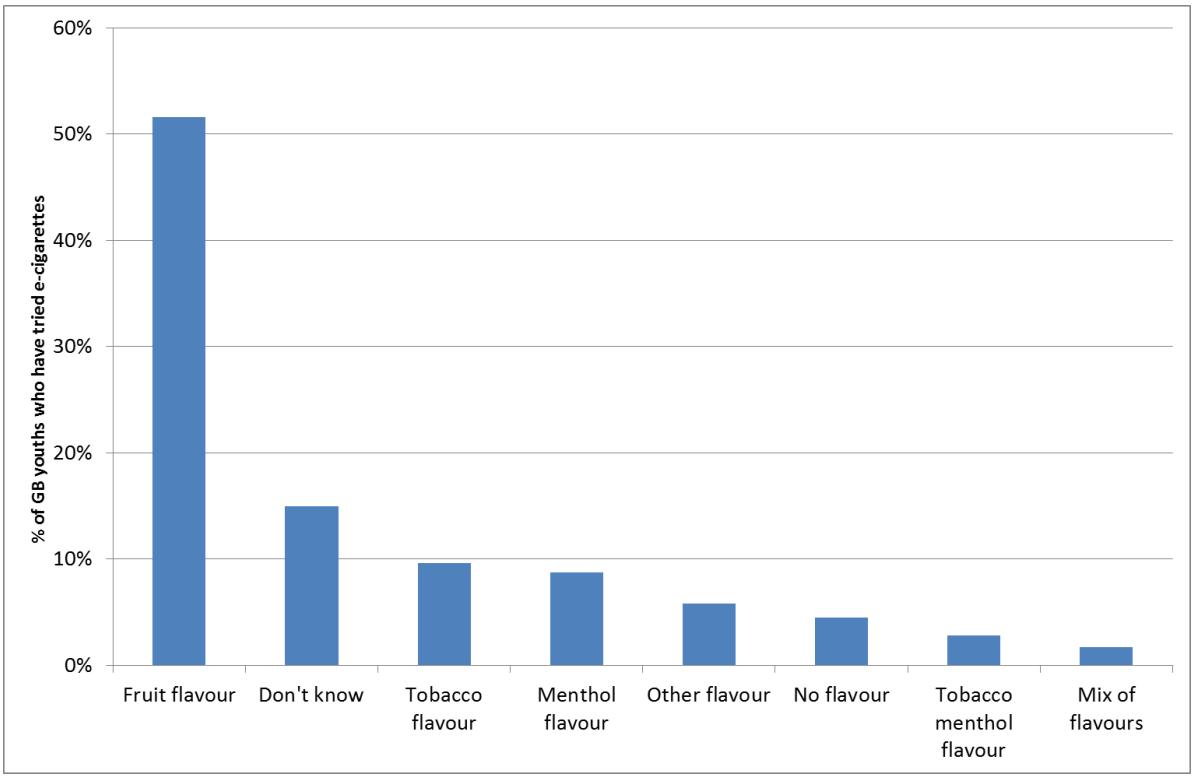
The proportion of youth reporting current use was too small to assess the most frequently used types or flavours in current users, so Figures 5 and 6 include everyone *who had tried* an EC. One third had first used a tank model and the most popular flavours among triers by far were fruit flavours. The responses for adults and youth are not directly comparable given flavours were assessed for adult current EC users, but in the latter group, fruit flavours were less popular than tobacco flavours.

Figure 5: First type of e-cigarette tried by youth, ASH Smokefree GB youth survey, 2015



Note: The proportion of youth reporting current use was too small to assess the most frequently used types.

Figure 6: Last flavour tried by youth, ASH Smokefree GB youth survey, 2015



Note: The proportion of youth reporting current use was too small to assess flavours in current users.

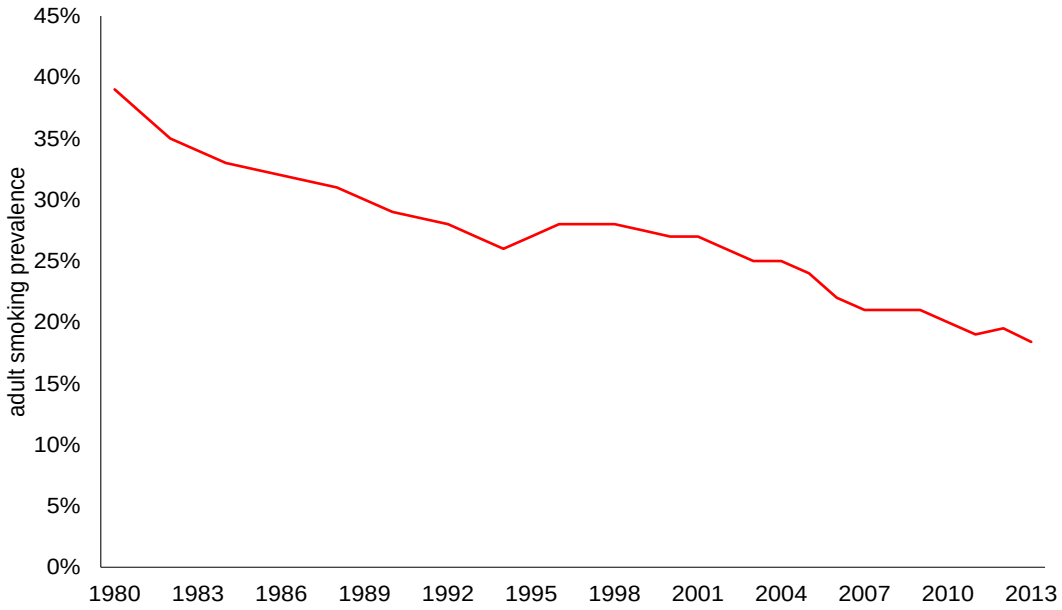
Concerns about impact of e-cigarette use on smoking

Three main concerns raised about EC use are that they might 1) renormalise smoking 2) reduce quitting and 3) act as a 'gateway' to smoking or nicotine uptake. An ultimate test for the first concern, and to some extent all three concerns, is the impact of EC use on smoking prevalence nationally which is explored first below. Evidence for effectiveness of EC on quitting smoking is explored in more detail in Chapter 6. Whilst other concerns have been raised such as renormalising the tobacco industry, we are only able to comment on issues pertaining to the objectives of our report.

Recent trends in smoking prevalence

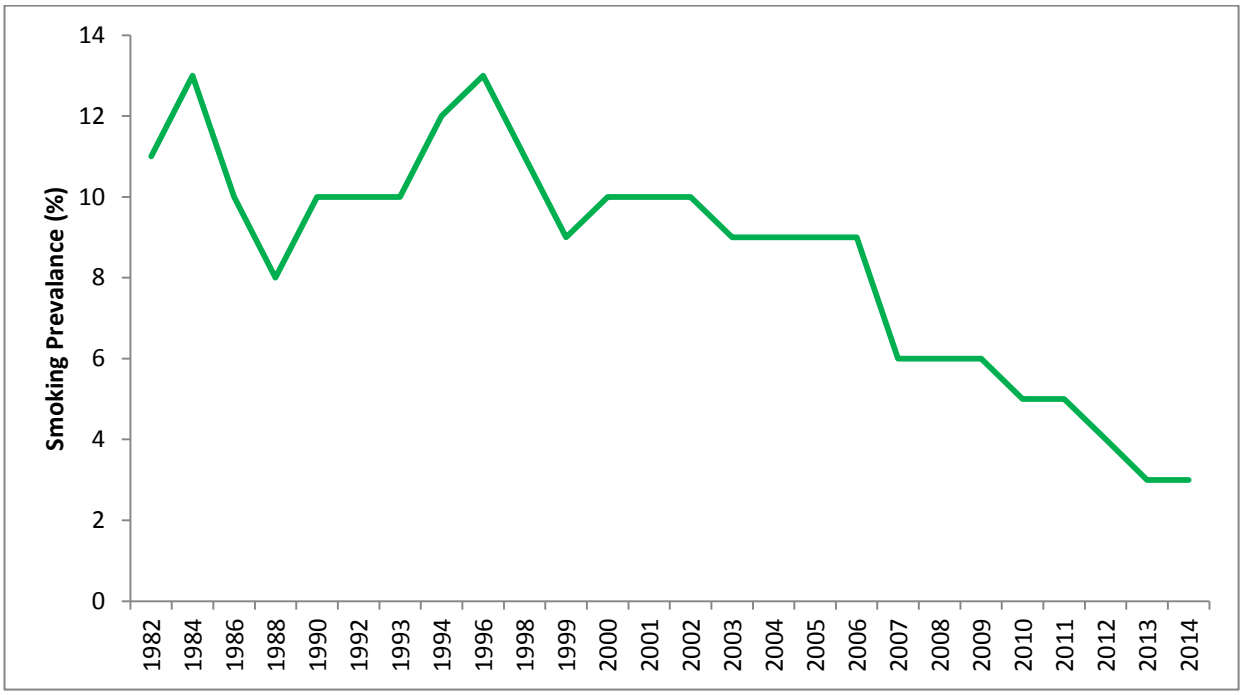
Since EC arrived on the market in England, smoking prevalence has continued to decline among both adults and youth (Figures 1, 7 and 8). Evidence to date therefore conflicts with any suggestion that EC are renormalising smoking. Whilst other factors may be contributing to the decline in smoking, it is feasible that EC may be contributing to reductions in smoking over and above any underlying decline.

Figure 7: Adult smoking prevalence in England 1980–2013[1]



[1] General Lifestyle Survey aged 16+(1980-2010); Integrated Household Survey aged 18+ (2011). Diagram courtesy of ASH.

Figure 8: Prevalence of regular smoking among 11–15 year olds in England 1980–2014[2]



Please note: decimal places were not used in the published data.

Gateway

The gateway theory or hypothesis is commonly invoked in addiction discourse, broadly to suggest that the use of one drug (sometimes a legal one such as tobacco or alcohol) leads to the use of another drug (sometimes an illegal one) but its definition is contested. No clear provenance exists and its origin appears to derive from lay, academic and political models [22]. It is apparent that discussions about the natural progression of drug use observed in longitudinal studies of young people appear to have morphed into implicit conclusions on causality without any evidential backing. Some have argued that the effect could be causal if the use of one drug, biochemically or pharmacologically, sensitises the brains of users to the rewarding effects of other drugs [23] making the dependent use of these other drugs more likely. However, there are many plausible competing hypotheses for such a progression [24] including i) shared networks and opportunities to purchase the drugs; and ii) individual characteristics such as genetic predispositions or shared problematic environment. Academic experts have stated that the gateway concept "*has been one of the most controversial hypotheses…in part because proponents and opponents of the hypothesis have not always been clear about what the hypothesis means and what policies it entails*" [24]. Indeed, a recent analysis of gateway concluded *"Although the concept of*

[2] Smoking drinking and drug use among young people in England surveys. Health and Social Care Information Centre, 2014.

the gateway theory is often treated as a straightforward scientific theory, its emergence is rather more complicated. In effect, it is a hybrid of popular, academic and media accounts – a construct retroactively assembled rather than one initially articulated as a coherent theory" [22].

Despite these serious and fatal flaws in the arguments, the use of the term 'gateway' is commonplace both in the academic literature and the lay press, particularly in relation to EC use and whether EC are a gateway to smoking. Some have suggested that if EC use increases at the same time as smoking increases then EC are acting as a gateway to smoking. Similarly, it's been argued that if someone uses an EC first and then initiates smoking, EC are a gateway. These arguments are clearly erroneous. To give one example of the misuse of the gateway concept, a BMJ news item on the Moore et al., 2014 [18] *cross-sectional* study discussed above commented that "[EC} *could be a gateway into smoking*" [25].

Kandel recently argued that evidence from mice offers a biological basis for the sequence of nicotine to cocaine use in people [26], but there is limited evidence for this. In reality, the gateway theory is extremely difficult to test in humans. For example, a clean test of the gateway hypothesis in relation to EC and smoking would require randomising people to an environment with EC and one without, and then following them up over a number of years to assess uptake of EC and smoking.

We strongly suggest that use of the gateway terminology be abandoned until it is clear how the theory can be tested in this field. Nevertheless, the use of EC and smoking requires careful surveillance in young people. The preferred option is that young people do not use EC but it would be preferable for a young person to use an EC instead of smoking, given the known relative risks of the EC and smoking cigarettes [10].

Summary

Since EC were introduced to the market, smoking prevalence among adults and youth has declined. Hence there is no evidence to date that EC are renormalising smoking, instead it's possible that their presence has contributed to further declines in smoking, or denormalisation of smoking. The gateway theory is ill defined and we suggest its use be abandoned until it is clear how it can be tested in this field. Whilst never smokers are experimenting with EC, the vast majority of youth who regularly use EC are smokers. Regular EC use in youth is rare.

Summary of findings

Adults: Around one in 20 adults in England (and Great Britain) use EC. Current EC users are almost exclusively smokers (~60%) or ex-smokers (~40%), that is smokers

who now use EC and have stopped smoking altogether. EC use among long-term ex-smokers is considerably lower than among recent ex-smokers. Current EC use among never smokers is very low, estimated to be 0.2%. The prevalence of EC use plateaued between 2013-14, but appeared to be increasing again in 2015.

Youth: Regular EC use among youth is rare with around 2% using at least monthly and 0.5% weekly. EC use among young people remains lower than among adults: a minority of British youth report having tried EC (~13%). Whilst there was some experimentation with EC among never smoking youth, prevalence of use (at least monthly) among never smokers is 0.3% or less.

Overall, the adult and youth data suggest that, despite some experimentation with EC among never smokers, EC are attracting few people who have never smoked into regular use.

Trends in EC use and smoking: Since EC were introduced to the market, cigarette smoking among adults and youth has declined. In adults, overall nicotine use has also declined (not assessed for youth). These findings, to date, suggest that the advent of EC is not undermining, and may even be contributing to, the long-term decline in cigarette smoking.

Policy implications

- Trends in EC use among youth and adults should continue to be monitored using standardised definitions of use.
- Given that around two-thirds of EC users also smoke, data are needed on the natural trajectory of ‘dual use’, ie whether dual use is more likely to lead to smoking cessation later or to sustain smoking (see also Chapter 6).
- As per existing NICE guidance, all smokers should be supported to stop smoking completely, including ‘dual users’ who smoke and use EC.

5. Smoking, e-cigarettes and inequalities

Smoking and inequalities

Whilst smoking prevalence overall has been declining over the past 50 years, smoking has become increasingly concentrated in more disadvantaged groups in society. Over the last decade, the gap between smoking in the different social groups has not narrowed (Figure 9) and some of the most disadvantaged groups in society (such as people with serious mental illness or prisoners) have shown no change in smoking prevalence over time (e.g. Figure 10). Furthermore, among smokers, the level of nicotine dependence increases systematically as deprivation increases [2]. A key challenge in tobacco control is therefore how to encourage smokers from disadvantaged groups to stop smoking.

Whilst quitting cigarettes and all nicotine use should remain the main goal across all social groups, EC are of interest because, as with other cleaner nicotine delivery systems, they potentially offer a wide reach, low-cost, intervention to reduce smoking and improve health in these more deprived groups in society where smoking is elevated [2]. It is therefore important to examine the potential impact of EC on inequalities.

Figure 9: Smoking trends by socioeconomic group status (GHS data)

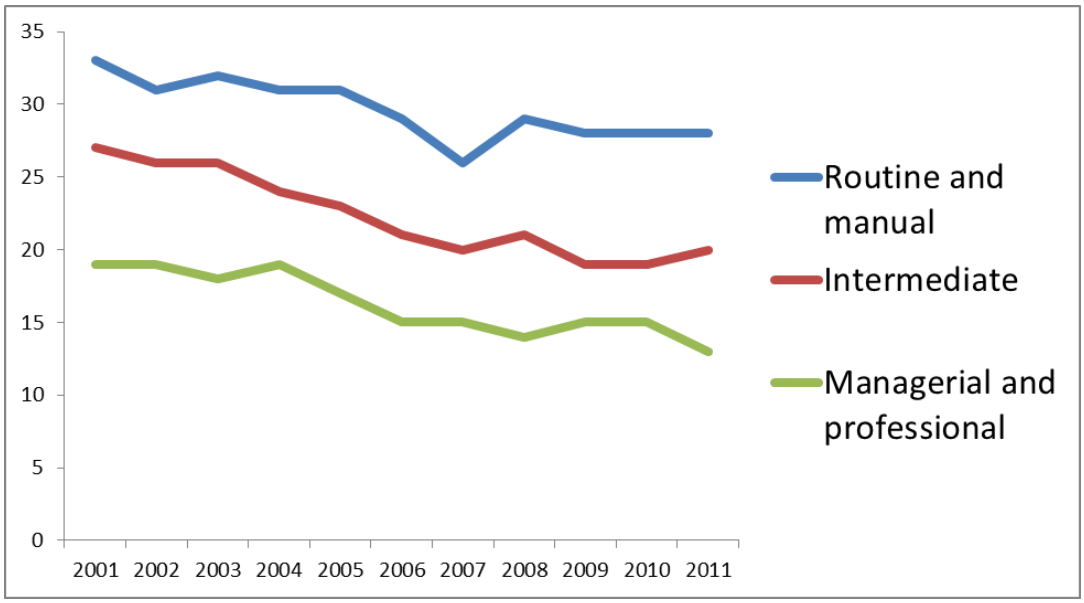
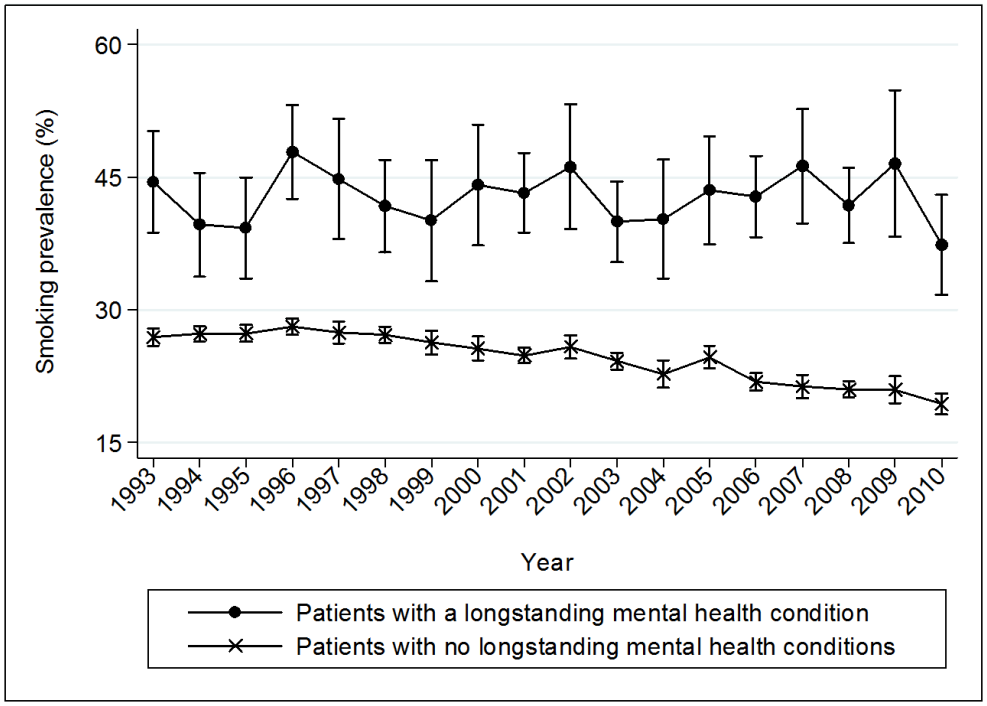


Figure 10: Smoking trends and mental health [27]

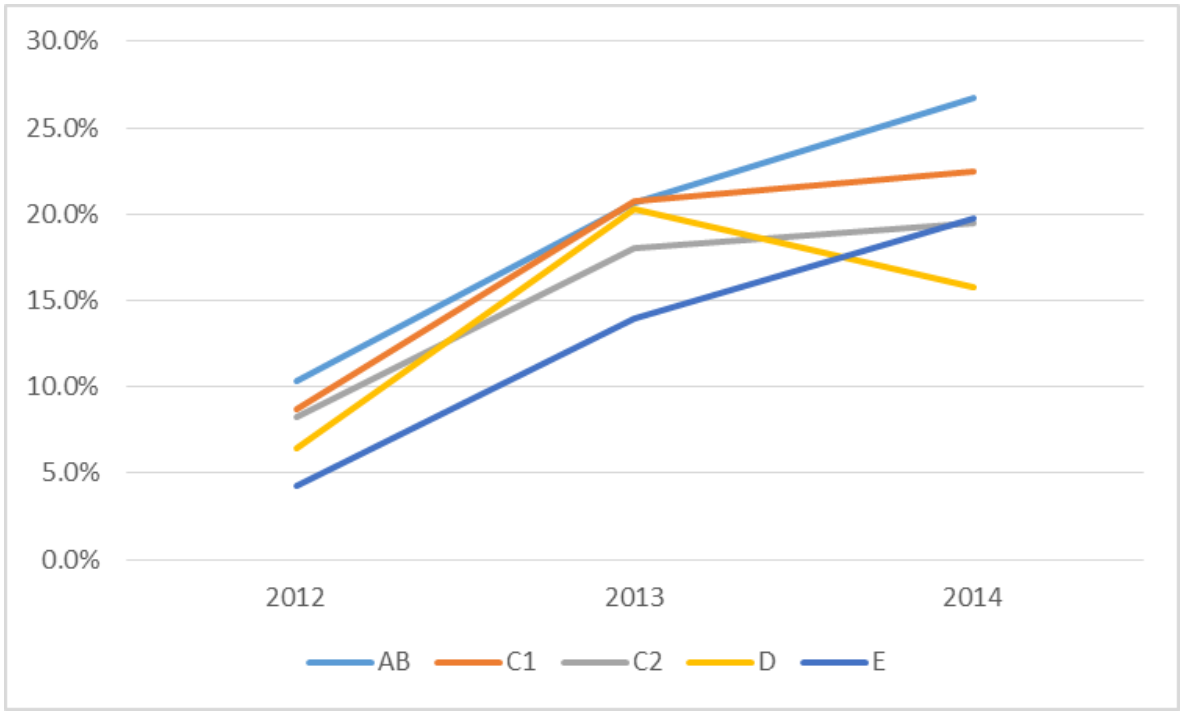


E-cigarette use and different social groups

Earlier surveys in GB and internationally suggested a social gradient in the use of EC, with smokers of higher income and education being more likely to have used and tried [28, 29]. However, the 2015 ASH Smokefree GB adult 2015 survey indicated only small differences across groups, with lower socioeconomic groups slightly more likely to have tried and be using EC. At the population level, 14.4% of ABC1 groups ('non-manual' occupational groups) had tried EC compared with 19.4% in C2DE groups ('manual' occupational groups); 4.6% of ABC1 were still using EC compared with 6.3% of C2DE groups. Nevertheless, given the higher prevalence of smoking in C2DE groups, when examined within the smoker population by social class, 20.0% of ABC1 smokers compared with 16.0% of C2DE smokers were EC current users.

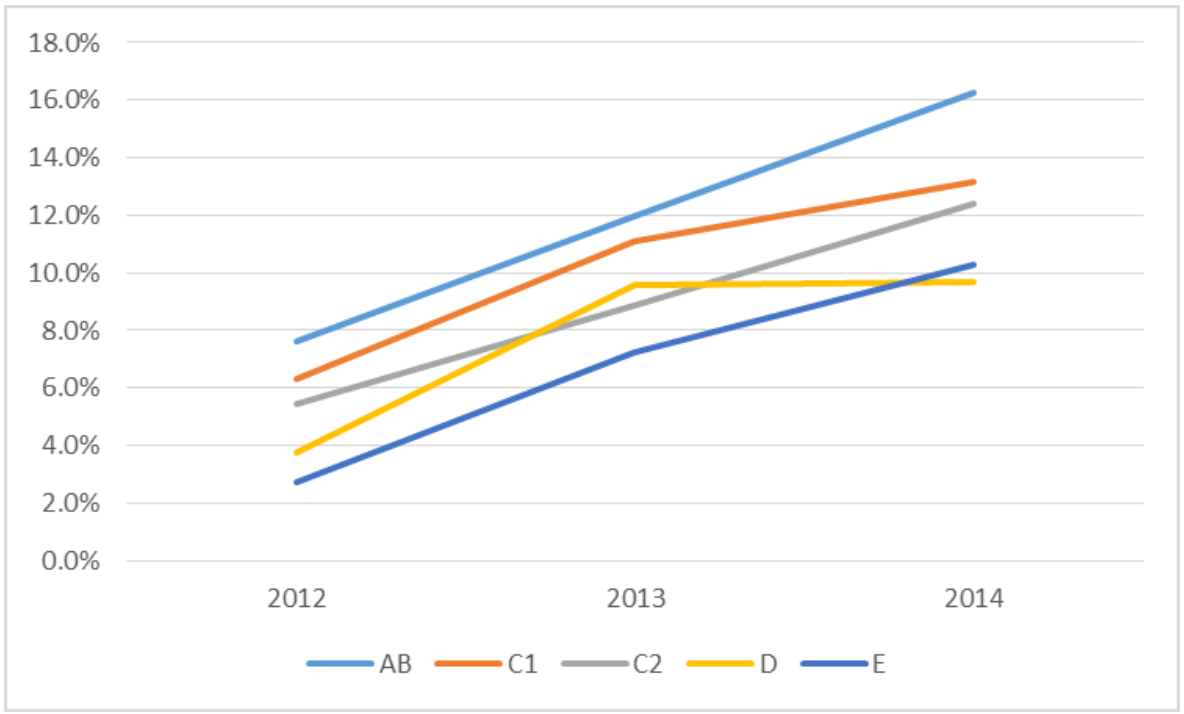
The STS data surveys show an increase in EC use in all social groups between 2012 and 2014 (Figures 11 and 12) but at a relatively similar rate such that socioeconomic differences are still apparent both for current and daily use of EC.

Figure 11: *Current* use of e-cigarettes by social class among last year smokers (STS data)



From www.smokinginengland.info/latest-statistics/

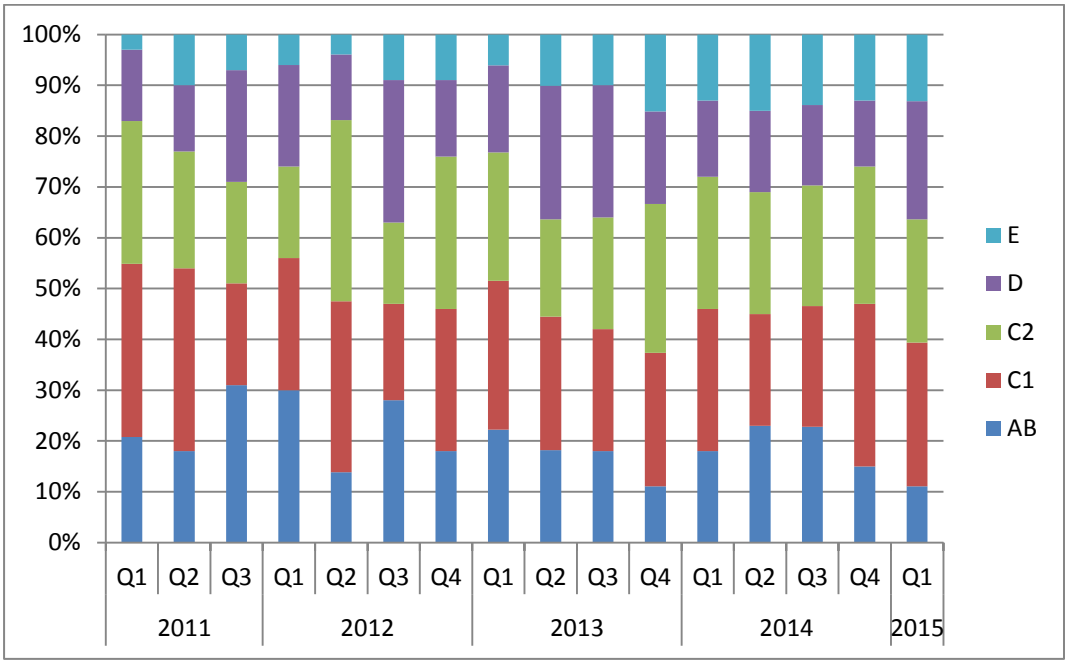
Figure 12: *Daily* use of e-cigarettes by social class among last year smokers (STS data)



From www.smokinginengland.info/latest-statistics/

Nevertheless, EC are penetrating the lower socioeconomic groups. Figure 13 shows the social class breakdown of EC users by quarter over time, also derived from STS data.

Figure 13: E-cigarette use by social class over time (STS data)



From www.smokinginengland.info/latest-statistics/

E-cigarette use in other disadvantaged groups

There are no GB data, to our knowledge, on EC use among groups where smoking prevalence is known to be very high, such as offenders and people with serious mental illness. There is emerging evidence on the effectiveness of EC in people with mental illness (see Chapter 6). However, to some extent, usage among these groups will be dependent on EC policies being introduced in prisons and mental health settings.

Recent NICE guidance on smoking cessation in secondary care settings [30] recommended the implementation of smokefree policies in these settings, alongside advice to stop smoking and nicotine dependence treatment. Trusts are now implementing this guidance but many prohibit EC usage as well as cigarettes. The rationale for such prohibition is unclear.

The South London and Maudsley NHS Foundation Trust (SLaM) was the second NHS mental health trust to go comprehensively smoke free in England. It has developed an EC policy alongside the smokefree policy which allows EC to be used in private spaces or grounds, although EC are not to be offered as first line treatment or replace tobacco cigarette smoking and can only be used as part of a care treatment pathway [31]. Currently, the use of disposable products or rechargeable models with cartridges is allowed (the latter only under supervision), but tanks are prohibited because of fears

that they might be used for new psychoactive substances (sometimes also known as ‘legal highs’). The basis for this fear is being assessed and the use of tank models may be assessed in a restricted pilot shortly. During the first six months of the policy, the EC policy has been implemented smoothly.

A more general concern has been raised that EC can be used as a vehicle for other drugs. This concern needs exploring and is not something that should be promoted. Nevertheless, if true, EC are likely to offer a less harmful delivery route for the drugs than smoking which could be the subject of research.

Prisons are likely to introduce comprehensive smokefree policies over the next few years [32]. Similar to mental health trusts, it would seem inappropriate to prohibit EC and disposable EC are currently being piloted in at least three prisons [33]. Consideration should also be given to the use of other models of EC in pilots. The use of EC in prisons has been considered in other jurisdictions which should also be informative [34].

Summary of findings

Smoking is increasingly concentrated in disadvantaged groups who tend to be more dependent. EC potentially offer a wide reach, low-cost, intervention to reduce smoking and improve health in disadvantaged groups.

Some health trusts and prisons have banned the use of EC which may disproportionately affect more disadvantaged smokers.

Policy implications

- Consideration could be given to a proactive strategy to encourage disadvantaged smokers to quit smoking as quickly as possible including the use of EC, where appropriate, to help reduce health inequalities caused by smoking.

- EC should not routinely be treated in the same way as smoking. It is not appropriate to prohibit EC use in health trusts and prisons as part of smokefree policies unless there is a strong rationale to do so.

6. E-cigarettes and smoking behaviour

Introduction

Studies examining the relationship between EC use and smoking behaviour have focused on two main questions to date: (1) do EC help people to quit when used on a quit attempt, and, (2) what is the effect of using EC while smoking, on reductions in smoke intake, cigarettes per day, quit attempts, and stopping smoking? Because EC use is a relatively new phenomenon and the products are constantly changing with technological innovation, the studies examining these questions to date are heterogeneous. As mentioned earlier, studies vary in their definitions of EC use, including ever use, which could include one puff, to studies that discriminate between daily and non-daily use. Additionally, it is evident that many of the studies were not originally designed to study the effects of EC use on smoking behaviour due to the absence of rigour and omitted/unmeasured variables.

Current recommendations for use of e-cigarettes to quit

The National Centre for Smoking Cessation and Training (NCSCT) has published current recommendations for practice regarding the use of EC for stopping smoking [35]. The NCSCT recommends that practitioners be open to EC use among smokers trying to quit, particularly if they have tried other methods of quitting and failed. The NCSCT also provides more detailed guidelines for smokers wanting to use EC to quit, including differences in puffing on EC versus regular cigarettes, the need to try different types of EC to find one that works for them, and that multi-sessional behavioural support is likely to improve their success of quitting. Some services have welcomed smokers who wish to stop with the help of EC [36].

The NICE guidelines for tobacco harm reduction cover recommendations for the use of *licensed* EC for quitting, cutting down (reduction in cigarettes per day), and temporary abstinence [1], similar to NRT. Use for both cutting down and temporary abstinence have been shown to be precursors to quitting among smokers using NRT. As discussed in Chapter 3, no licensed EC are currently available.

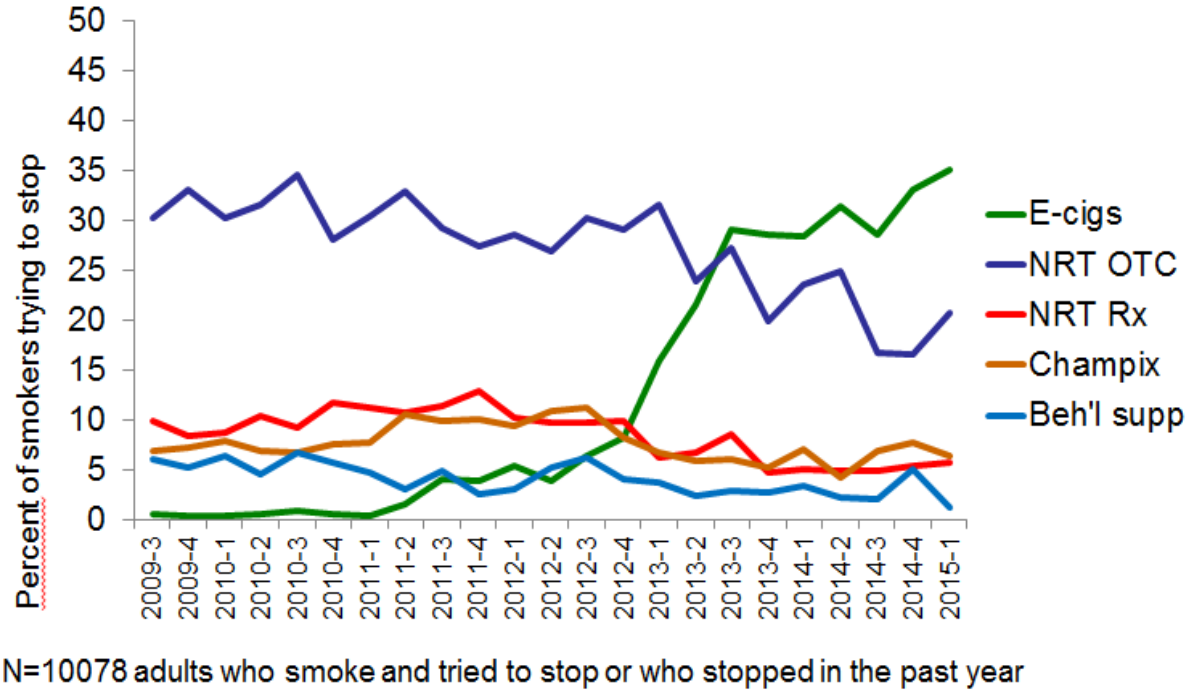
Use of e-cigarettes for stopping smoking

STS data have shown that EC have quickly become the most common aid that smokers in England use to help them stop smoking (Figure 14). The rise in the use of EC as a stop smoking aid is occurring despite the fact that no licensed EC are available. Although the most effective way for stopping smoking, currently supported by the research literature [37, 38] is a combination of behavioural support (NHS in Figure 14)

and medication (NRT on prescription or Champix), the problem is that few smokers access these services, limiting their impact on population health.

This section reviews the evidence regarding the use of EC for stopping smoking that has been published since the Cochrane Review [39] on the use of EC for smoking cessation and reduction (cutting down). The Cochrane Review is briefly summarised below.

Figure 14: Support used in quit attempts



From: smokinginengland.info/latest-statistics

Randomised controlled trials

To date, two randomised controlled trials (RCTs) have tested the efficacy of EC for stopping smoking, one among smokers wanting to stop and the other among smokers not intending to quit within the next month [40, 41]. Both were among highly dependent smokers. A recent Cochrane Review of these RCTs [39] concluded that they demonstrated that EC with nicotine help smokers reduce their cigarette consumption and stop smoking compared with no nicotine EC (placebo). However, the authors cautioned that there was uncertainty in the findings, and gave their findings a 'low' confidence rating using GRADE standards. The Cochrane Review also considered observational studies of EC use and cessation. They concluded that these observational studies were generally consistent with the findings of RCTs. Since the Cochrane Review, one RCT[41], and a secondary analysis of one of the RCTs in the Cochrane Review[42] have been published and are discussed below.

O'Brien et al., 2015 [42] conducted a secondary analysis of the RCT data from Bullen et al., 2013 [43] to examine the effectiveness of EC with and without nicotine compared to the nicotine patch among individuals with mental illness (MI). They identified 86 participants among the original 657 participants (all motivated to quit) using secondary data from the trial on reported use of any medications associated with MI. Overall, when compared to participants without MI, there were no significant differences for those with MI on the primary outcomes of smoking reduction and smoking cessation. One exception was that the six-month quit rate was higher among participants with MI in the patch condition compared to those without MI. Although not a primary outcome, there was evidence of a greater rate of relapse among participants with MI. In the analysis that only included participants with MI, there were no significant differences in quit rates across the three conditions, however participants allocated to 16mg EC showed greater smoking reduction than those allocated to patch. **The authors concluded that EC appear to be equally effective for smoking cessation among individuals with and without MI**, building on other promising research involving EC and people with MI.

Adriaens et al., 2014 [41] conducted an eight-week RCT in Belgium with control where they randomised 48 smokers **who did not want to quit** to one of two conditions: (1) use of tank model EC, and training on how to use, with no encouragement to quit, and (2) no use of EC. Both groups attended similar periodic lab sessions over an eight-week period where measurements of craving, withdrawal, saliva cotinine, and expired-air CO levels were taken. Adriaens found that after eight weeks of use 34% of those given EC had quit smoking compared to 0% of those not given EC, the EC group also showed substantially greater cigarette reduction. After eight weeks, the group which did not receive EC at baseline was given EC, but no training on how to use the products. At the final eight-month follow-up, 19% of the original EC group and 25% of the control group (given EC at week eight) had quit smoking. Significant reductions in cigarette consumption were also found.

Population studies

One problem with RCTs is that because of the time taken to set up and implement trials, the EC used in the trials are often no longer available for sale by the time the research is published. This is problematic because many new EC enter onto the market and it is possible they may be more effective at delivering nicotine than the products used in the trial, and possibly more effective for smoking cessation. Additionally, the controlled environment of RCTs is unable to provide evidence of the effectiveness of EC in the real world where use is much more subject to external forces, such as availability, price and social norms around use. RCTs also reveal little about the attractiveness of the products and thus likely uptake of the products used and what happens after a successful or failed attempt to stop smoking with an EC in the long-term.

Observational and natural history studies are therefore important. Only one population-based survey has examined the effectiveness of EC used during quit attempts. A large cross-sectional study of 5,863 English smokers who attempted to quit in the past year without using professional support [29] found that those who used EC on their last quit attempt were more likely to quit than those who used over the counter NRT – (the most common help sought by smokers after EC, see Figure 14), or no quit aid, controlling for factors related to quitting. This study was, however, unable to explore prospective predictors of quitting, including pre-quit nicotine dependence. Still, this study offers some of the best evidence to date on the effectiveness of EC for use in quit attempts.

Other recent population studies [16, 44, 45] have also examined the association between EC use and quitting. However, because these studies (1) included smokers who were already using EC at baseline, and (2) did not examine the use of EC during a specific quit attempt, we discuss them below in the section on use of EC while smoking.

Pilot studies

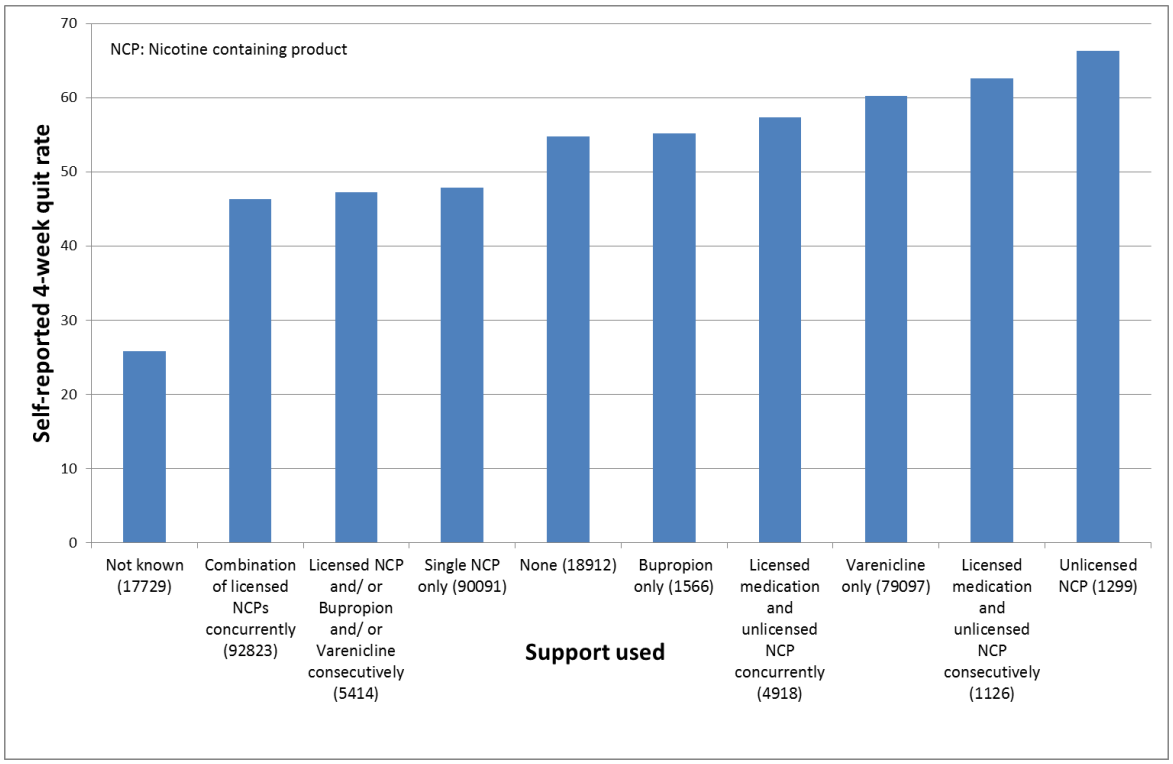
Polosa et al., 2014 [46] conducted a six-month pilot study of tank-type EC users with no control group among 72 smokers **who did not want to quit (smokers were enrolled after rejecting participation in smoking cessation program at a hospital)**. At six months, they found significant 50% and 80% reductions in cigarette consumption, and a quit rate of 36% [46]. Another study by Polosa et al., 2014 [47] followed 71 vape shop customers (seven different shops) after their first visit to the shop. The first visit included instructions on how to use EC and encouragement to use their EC of choice to reduce their smoking, along with a telephone number they could call for help. At six and twelve months after their initial visit they found that the smokers reported significant 50% and 80% reductions in cigarettes per day at six and twelve months, and that at six and twelve months, 42.2% and 40.8% had quit smoking.

E-cigarettes and stop smoking services

Some English stop smoking services and practitioners support the use of EC in quit attempts [48], and provide behavioural support for EC users trying to quit smoking. The most recent monitoring data from the stop smoking services show the self-reported success rates for different medications and nicotine-containing products used (Figure 15). Data are not given by validated success rates but overall, 69% of those who self-report stopping smoking are carbon-monoxide validated [49]. Hence, there are limitations with these data as they are self-reported success rates and it is possible that they may vary by treatment used. Additionally, the data are not adjusted for other factors, such as dependence, known to influence success rates, and it is likely that they emanate from a limited number of services who record unlicensed nicotine-containing products and who might therefore be more supportive of their use. Nevertheless, the

evidence is consistent with evidence from trials and other observational data that e-cigarettes are likely to support successful quitting.

Figure 15: Support used and stop smoking service self-reported quit rates[3]



Note: Figures in brackets represent the number of quit attempts in which each type of support was used. The number of clients with recorded e-cigarette use is very small in comparison to those recorded to have used other types of support.

Use of e-cigarettes while smoking

Population studies

Two studies using data drawn from a longitudinal population sample of more than 1,500 smokers in GB recently examined the impact of EC use on quitting, considering the effects of frequency of EC used and type of EC. Brose et al., 2015 [45] found that respondents who used EC daily at baseline were more likely to make a quit attempt one year later, but were no more or less likely to quit than those who did not use EC. Daily EC use at follow-up was found to be associated with reduced cigarette consumption since baseline. No effects of non-daily EC use on quit attempts, quitting, or reduction in consumption were found. Using data from the same Internet Cohort GB study, Hitchman et al., 2015 [16] found differences in quitting between baseline and follow-up

[3] Taken from Health and Social Care Information Centre. Statistics on NHS Stop Smoking Services in England - April 2014 to December 2014.Publication date: April 23, 2015 Source: Ref 47. http://www.hscic.gov.uk/catalogue/PUB17302

depending on the type and frequency of EC used at follow-up: compared to no EC use, non-daily cigalike users were less likely to have quit smoking since baseline, daily cigalike or non-daily tank users were no more or less likely to have quit, and daily tank users were more likely to have quit. Overall, the two studies showed that daily use of EC does not lead to lower cessation, and is associated with making quit attempts, cigarette reduction, and if tank-type EC is used, is associated with smoking cessation. Non-daily use of EC is not associated with quit-related outcomes, and may, if cigalike-type EC are used, be associated with lower cessation.

Supporting these findings, using data from a longitudinal population study of smokers in two metropolitan areas in the US, Biener et al., 2015 [44] measured use and intensity of EC use at *follow-up* in a longitudinal sample of smokers at baseline from two US cities. Biener also found that it was only intensive EC users (used daily for at least one month) that were more likely to quit, less intensive EC users were no more likely to quit than those not using EC.

There are limitations with these studies. For example, an unavoidable methodological problem is that only people who currently smoke are included in these studies meaning that smokers who switched completely to EC and stopped smoking are excluded. The efficacy of EC is thus invariably underestimated.

A longitudinal telephone survey reported by Al-Delaimy et al., 2015 [50] among a sample of 368 current smokers from California at baseline (2011) investigated the relation between '*ever have used*' versus *'never will use'* EC, and making a quit attempt, a 20% reduction in cigarettes per month, and quitting for more than one month at follow-up (2012). Al-Delaimy included smokers at baseline who at both baseline and follow-up reported the same EC status: never will use EC at both baseline and follow-up OR ever have used EC at both baseline and follow-up, excluding anyone who gave different responses. Also excluded were respondents who said they might use EC in the future at baseline or follow-up, and respondents who had never heard of EC, reducing sample size from n=980 to n=368. Al-Delaimy concluded that compared to smokers who reported they never will use EC, respondents who had ever used EC were significantly less likely to have reduced their cigarette consumption and quit at follow-up, with no differences reported of quit attempts at follow-up. This study has serious methodological problems that make its conclusions uninterpretable, first, the measure of EC use is 'ever use', which could include even a puff on an EC and second, they applied several exclusion criteria that are not clearly justified.

Studies of smokers enrolled in smoking cessation programs

Two recent studies have examined the use of EC among smokers enrolled in smoking cessation programmes in longitudinal studies [51, 52]. Pearson et al., 2015 [51] examined the relation between reporting using an EC for quitting at follow-up and

smoking cessation (30-day abstinence) in a sample of smokers enrolled in a web-based cessation programme in the US with three-month follow-up. Pearson illustrated how the relation between using EC to quit and successful smoking cessation depended on the factors that were adjusted for and how the data were analysed, finding that under some conditions EC use was related to being less likely to quit and in others there was no relationship. The authors concluded that caution needs to be exerted when interpreting observational studies of the effects of EC use on smoking cessation.

Borderud et al., 2014 [52] examined whether any use of EC in the past 30 days was related to smoking cessation outcomes in a group of cancer patients enrolled in a smoking cessation programme in the US. When treating all smokers who dropped out of the study as smoking cessation failures, the authors found that any use of EC in the last 30 days was related to being less likely to quit; however, this treatment of the data may have been problematic because more EC users than non-users dropped out of the study. No relationship between EC use in the last 30 days and smoking cessation was observed when drop-outs were excluded from the analyses. One potential problem with this study is the measure of any EC use in the last 30 days, as this could range from using an EC once in the last 30 days to using an EC daily for the past 30 days. As illustrated [16, 44, 45] and discussed in previous studies [51], measurements of EC use that do not fully capture frequency of use may influence the relation between EC use and smoking cessation. As with studies in the previous section, the Borderud study started with smokers who had tried EC but did not stop smoking. This, of course, seriously reduces the chance of detecting a positive effect.

Summary of findings

Recent studies support the Cochrane Review findings that EC can help people to quit smoking and reduce their cigarette consumption. There is also evidence that EC can encourage quitting or cigarette consumption reduction even among those not intending to quit or rejecting other support. It is not known whether current EC products are more or less effective than licensed stop-smoking medications, but they are much more popular, thereby providing an opportunity to expand the number of smokers stopping successfully. Some English stop smoking services and practitioners support the use of EC in quit attempts and provide behavioural support for EC users trying to quit smoking; *self-reported* quit rates are at least comparable to other treatments. The evidence on EC used *alongside smoking* on subsequent quitting of smoking is mixed.

Policy implications

- Smokers who have tried other methods of quitting without success could be encouraged to try EC to stop smoking and stop smoking services should support smokers using EC to quit by offering them behavioural support.

- Research should be commissioned in this area including:
  - longitudinal research on the use of EC, including smokers who have not used EC at the beginning of the study
  - the effects of using EC while smoking (temporary abstinence, cutting down) on quitting, and the effects of EC use among ex-smokers on relapse
  - research to clarify the factors that i) help smokers using EC to quit smoking and ii) deter smokers using EC from quitting smoking, including different EC products/types and frequency of use and the addition of behavioural support, and how EC compare with other methods of quitting which have a strong evidence base

- It would be helpful if emerging evidence on EC (including different types of EC) and how to use EC safely and effectively could be communicated to users and health professionals to maximise chances of successfully quitting smoking.

7. Reasons for use and discontinuation

Reasons for using e-cigarettes

Reasons for using EC have been assessed for adult smokers and ex-smokers in a number of different ways. Across different populations, help to quit smoking and harm reduction were the top reasons endorsed for using EC [44, 53-57].

In the Internet Cohort GB survey, the list of possible reasons for using EC was extended after the first year (the survey was carried out in 2012, 2013 and 2014). Nevertheless, the most frequently endorsed reasons were health, to cut down and to quit smoking. These were endorsed by approximately 80% of current users at all three time points. The biggest change over time was recorded for '*they are cheaper'* which appeared to be more popular in 2014 than 2013 (Table 3). Because of the way the question is phrased, a user endorsing a reason does not indicate that current use is for this particular reason, for example, 80% of current users agree that e-cigarettes may help you quit, but this does not mean that 80% of all users were using them in a quit attempt.

Table 3: Internet cohort GB survey, reasons for using e-cigarettes (in order of frequency of endorsement in 2014)

Which of the following were reasons for your using electronic cigarettes? (multiple responses possible)	2012 (n=1031)	2013 (n=717)	2014 (n=505)
They may make it easier for you to cut down the number of cigarettes you smoke	81.0	78.1	79.4
They may not be as bad for your health	81.7	79.8	79.2
They might help you quit	81.8	79.9	79.0
No tobacco smoke	not asked	70.9	71.3
They are cheaper	not asked	36.1	65.5
The smell or cleanliness	not asked	65.4	65
So you can use them in places where smoking regular cigarettes is banned	67.2	66.5	61
They may be more socially acceptable	not asked	55.8	54.3
Because I enjoy it	not asked	38.6	48.7
They taste better	28.5	26.1	34.1
Friends or family use them	not asked	37.0	33.3
The technology	not asked	34.2	30.3
A health professional advised you to do so	not asked	16.7	16.4

The ASH Smokefree GB survey similarly found that EC users who were ex-smokers most frequently endorsed that they used or had used EC to help them stop smoking entirely (Table 4). Among smokers, this was the second most frequently endorsed reason, with curiosity being the most frequent reason. Smokers also often reported use to help them cut down on smoked tobacco, which was rarely reported by ex-smokers.

Table 4: Reasons for use, ASH Smokefree GB adult survey, 2015 (weighted)

I use/used electronic cigarettes…	Smokers	Ex-smokers
Just to give it a try	35%	29%
To help me stop smoking tobacco entirely	30%	44%
To help me reduce the amount of tobacco I smoke, but not stop completely	29%	9%
Because I had made an attempt to quit smoking already and I wanted an aid to help me keep off tobacco	27%	35%
To save money compared with smoking tobacco	24%	22%
Because I felt I was addicted to smoking tobacco and could not stop using it even though I wanted to	16%	17%
Because I want to continue to smoke tobacco and I needed something to help deal with situations where I cannot smoke (e.g. workplaces, bars or restaurants)	15%	8%
To avoid putting those around me at risk due to second-hand tobacco smoke	12%	13%
Other	1%	3%

A smaller number of surveys specifically assessed reasons for trial and gave the option of selecting curiosity, which was frequently endorsed as an important reason for experimentation in US adults from the general population as well as in a sample of opioid-dependent smokers [58-60].

In youth, reasons for use has rarely been surveyed; one survey on reasons for experimentation among 1,175 students (middle school, high school and college) who had ever tried EC reported that the top three reasons for e-cigarette experimentation were curiosity (54.4%), the availability of appealing flavours (43.8%) and friends' influence (31.6%). Compared with never smokers, however, ever cigarette smokers (OR=37.5, 95% CI: 5.0 to 283.3) and current cigarette smokers (OR=102.2, 95% CI: 13.8 to 755.9) were many times more likely to say they tried EC to stop smoking [61].

A national survey in New Zealand of 3,127 year 10 students (mostly aged 14 to 15) also showed that the most frequently given reason for first trying EC was curiosity, irrespective of smoking status (64.5% overall) [62].

Reasons *not* to use EC are rarely assessed. The ASH Smokers' survey 2014 asked current and ex-smokers about advantages and disadvantages of EC. Among those who had never used EC, the three most important disadvantages were "*They might be too expensive*" (46%), "*They might not be safe enough as a product*" (39%) and "*They might not satisfy my desire to smoke enough*" (31%).

Reasons why trial does not become use

The rates of ever having tried an EC in the ASH GB Smokefree adult survey are more than three times those of current use; in the ASH GB Smokefree youth survey, about five times as many respondents had tried an EC as were currently using an EC, indicating that **most of those who try EC do not progress to current use**. A small number of surveys assessed why respondents who had tried an EC did not continue use.

In a national sample of 3,878 US adults who reported ever trying EC, two-thirds did not continue to use them and this was linked to the main reason for trying them. Trial turned into continued use for only a minority (19%) of those who did not know their main reason for trying them or whose main reasons were curiosity, friends or family members or advertising. Continued use was more common for those whose main reasons for trial included help to quit smoking or reduce harm. Those who did not continue use were asked for their reasons for stopping. The reason most often given was that they were just experimenting (49%) [58].

In the survey by Kong et al., reported previously, it appears that 98.5% of experimenting students did not continue use. Reasons for discontinuation were assessed but unfortunately the most commonly chosen response was 'other' (23.6%, open-ended responses included "I don't like it", "I just tried once") followed by "uncool" (16.3%) and health risks (12.1%) [61].

Some surveys can be used to assess why smokers may not continue to use EC. The ASH Smokers' survey in 2014 indicates that disappointment with the help EC provide in reducing smoking urges may be an important reason. Among smokers who had tried EC but did not continue using them, 44% said that a disadvantage of the products was that "*They might not satisfy my desire to smoke enough*". No other reason got a higher rate of agreement in this group. A high proportion of smokers who were currently using EC also stated this reason (37%), but the proportion was significantly ($p<0.05$) lower in ex-smokers who had used (32%) or were currently using EC (7%), suggesting that satisfaction with the device/s may be a correlate of stopping smoking.

Of concern is that data suggest that some smokers may not continue to use EC instead of smoking because of a misguided belief that EC would be harmful to their health. In the ASH Smokers' survey 2014, the second most frequently endorsed disadvantage was "*They might not be safe enough as a product*" (35%) among smokers who had tried an EC but were not using one anymore. Similarly, in a survey of US respondents, among 227 respondents who had tried EC in the past, were no longer using them but were still smoking cigarettes [44], the most frequently endorsed reason was that EC didn't feel enough like smoking cigarettes, followed by dislike of the taste and that they were bad for health. It would appear therefore that these respondents stopped EC use in favour of continuing to smoke more deadly cigarettes.

Summary of findings

A number of surveys in different populations provide evidence that reducing the harm from smoking (such as through cutting down on their cigarette consumption or helping with withdrawal during temporary abstinence) and the desire to quit smoking cigarettes are the most important reasons for using EC. Curiosity appears to play a major role in experimentation. Most trial of EC does not lead to regular use and while there is less evidence on why trial does not become regular use, it appears that trial due to curiosity is less likely to lead to regular use than trial for reasons such as stopping smoking or reducing harm. Dissatisfaction with products and safety concerns may deter continued EC use.

Policy implications

- Smokers frequently state that they are using EC to give up smoking. They should therefore be provided with advice and support to encourage them to quit smoking completely.

- Other reasons for use include reducing the harm from smoking and such efforts should be supported but with a long-term goal of stopping smoking completely.

8. Harm perceptions

Perceptions of the harmfulness of EC are frequently assessed in surveys, most commonly relative to conventional tobacco cigarettes. However, a recent Eurobarometer survey [63] asked smokers in absolute terms whether EC were harmful to the health of those using them. Overall in Europe, 40.6% perceived EC as not harmful (UK: 48.6%), 28.5% as harmful (UK: 14.6%) and 30.9% did not know if they were or were not harmful (UK: 36.8%).

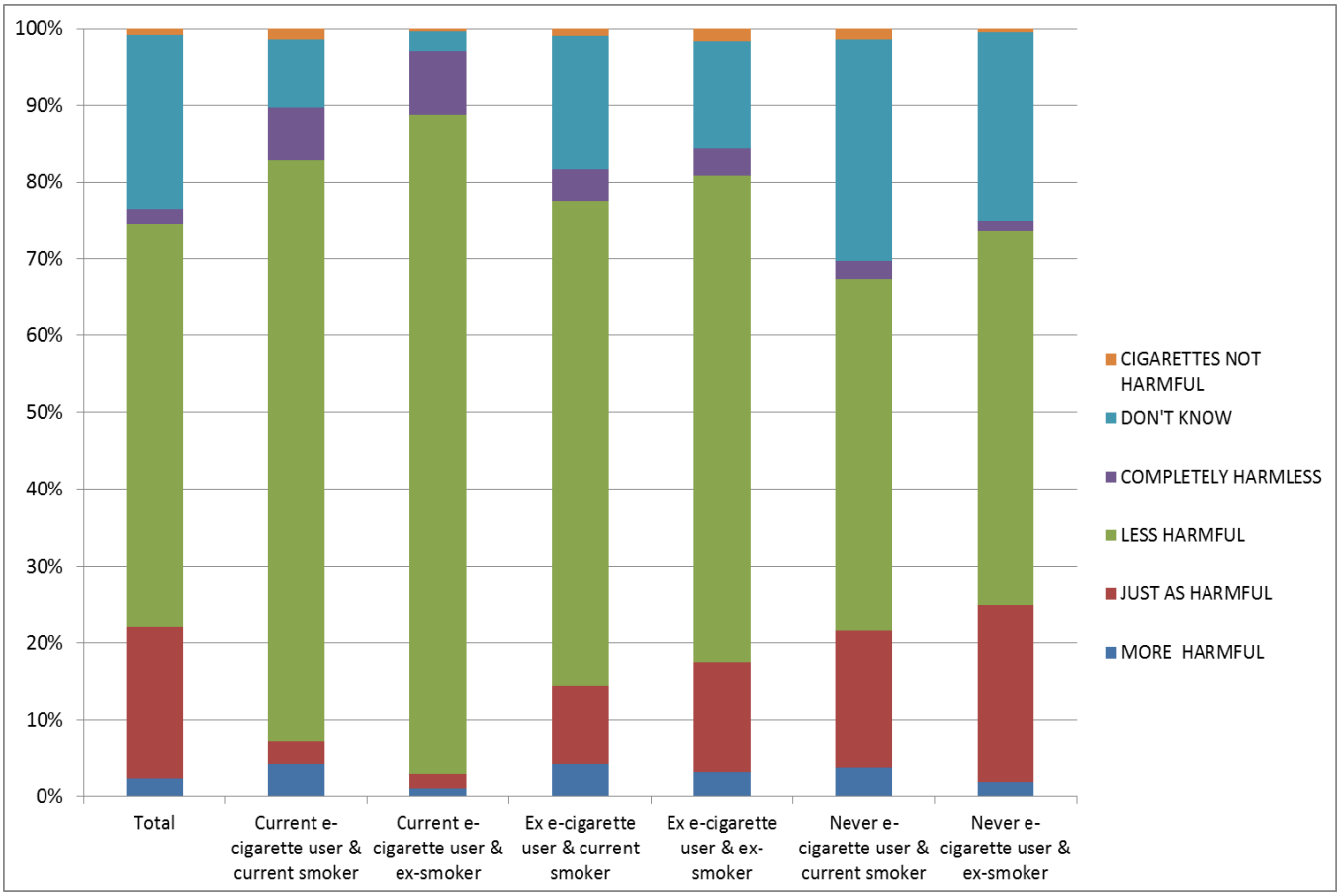
Harm perception relative to cigarettes

In GB, the ASH surveys and the Internet Cohort survey have included questions on the perceived relative harm of EC. These surveys consistently show that compared with conventional tobacco products, EC were perceived as less harmful by a small majority of respondents, **but with a sizeable minority inaccurately judging them to be more harmful, about as harmful or being unsure about their relative risks**. For example, in the 2015 ASH Smokefree GB adult survey, 2% thought that EC were more harmful than cigarettes, 20% equally harmful, 52% less harmful, 2% completely harmless and 23% did not know.

Harm perception differed by smoking status ($\chi 2=104.05$, $p<0.001$) and by EC use status ($\chi^2=453.4$, $p<0.001$) (Figure 15). Overall, smokers were more likely to judge EC to be less harmful compared with cigarettes (63.7%, including 'completely harmless') than ex-smokers (55.6%), whereas never-smokers were least likely to judge EC as less harmful (51.2%, all $p<0.05$). A higher proportion of current EC users (87.4%) thought that they were less harmful compared with cigarettes than those who had tried but were not using (68.8%) or never-users (50.4%), among whom the proportion was lowest (all differences $p<0.05$). Perceptions among youth were similar to adults. For example, in the 2015 ASH Smokefree GB youth survey, 2% thought that EC were more harmful than cigarettes, 21% equally harmful, 67% less harmful and 10% did not know.

In the STS, the proportion believing EC to be less harmful appears to be even lower. Only 44.1% of current smokers in England between November 2014 and March 2015 believed that EC were less harmful than cigarettes [15].

Figure 15: Perceptions of relative harmfulness of e-cigarettes in comparison with tobacco cigarettes by e-cigarette use and smoking status. ASH Smokefree GB adult surveys (weighted)



Trends in harm perceptions relative to cigarettes over time

Since 2013, perceptions of the relative harmfulness of EC have become less accurate. Significantly larger proportions perceived EC to be at least as harmful as cigarettes in 2014 than in 2013 both in the Internet Cohort GB surveys (Figure 16) and in the ASH youth surveys (Figure 17 [64]). In the Internet Cohort GB survey, there was no significant change from 2012 to 2013, but from 2013 to 2014 the proportion thinking that EC were less harmful decreased in favour of equally or more harmful ($p<0.001$). For youth, between 2013 and 2014, the decrease in the proportion endorsing 'less harmful' and the increase in the proportion endorsing 'equally harmful' were significant ($p<0.01$). There were no significant changes in the proportion endorsing 'more harmful' or 'don't know'.

In the ASH adult surveys, data on harm perception are available for 2013 to 2015 (Figure 17). In line with the other GB surveys, this survey found a steep increase in the proportion perceiving EC to be equally harmful as cigarettes ($p<0.001$).

Figure 16: Perceptions of relative harmfulness of e-cigarettes in comparison with tobacco cigarettes. Internet Cohort GB surveys (N=1,209 respondents with data at all three time points)

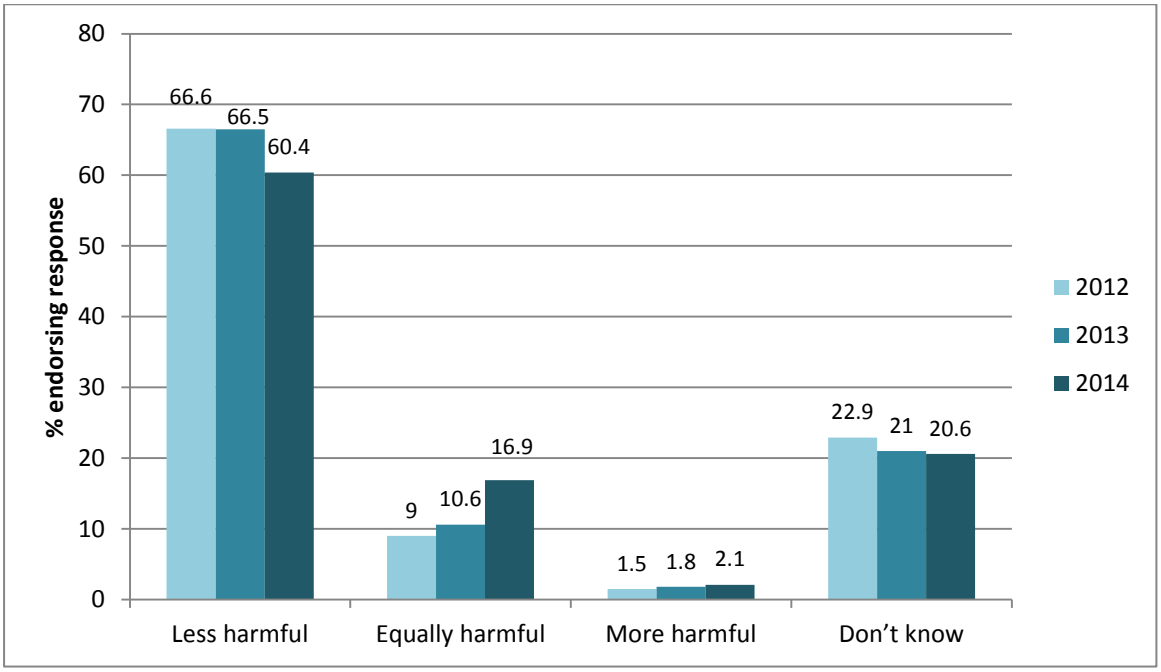
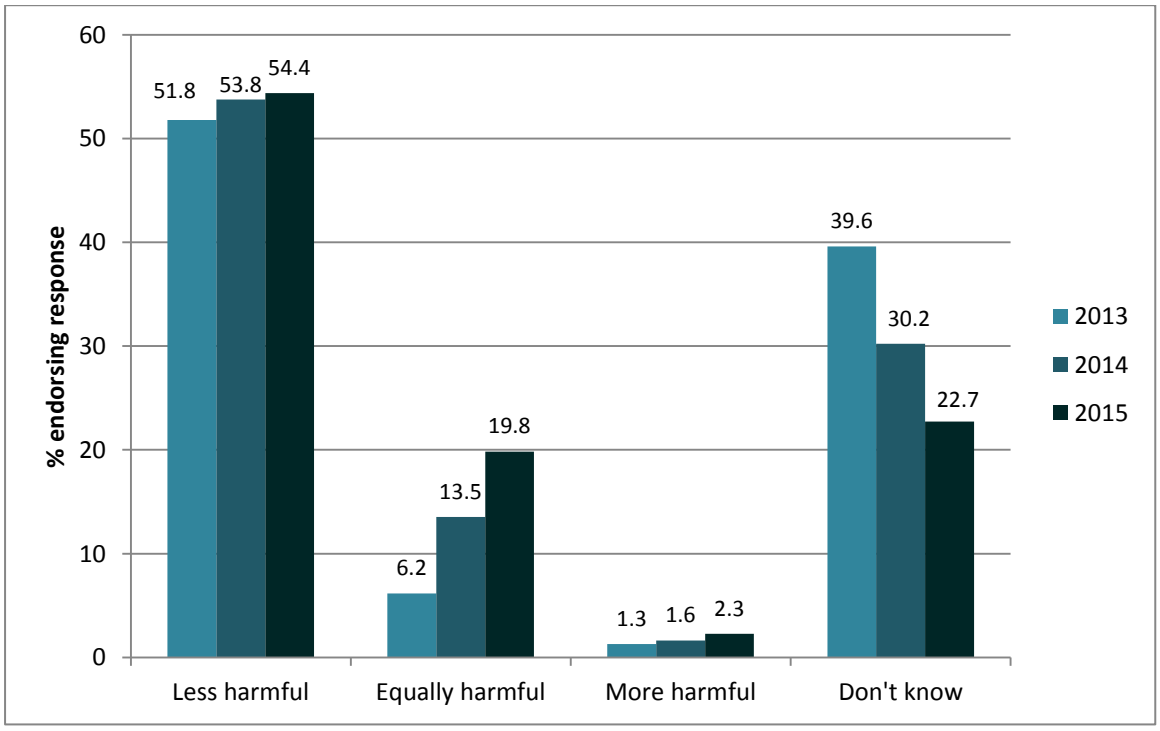
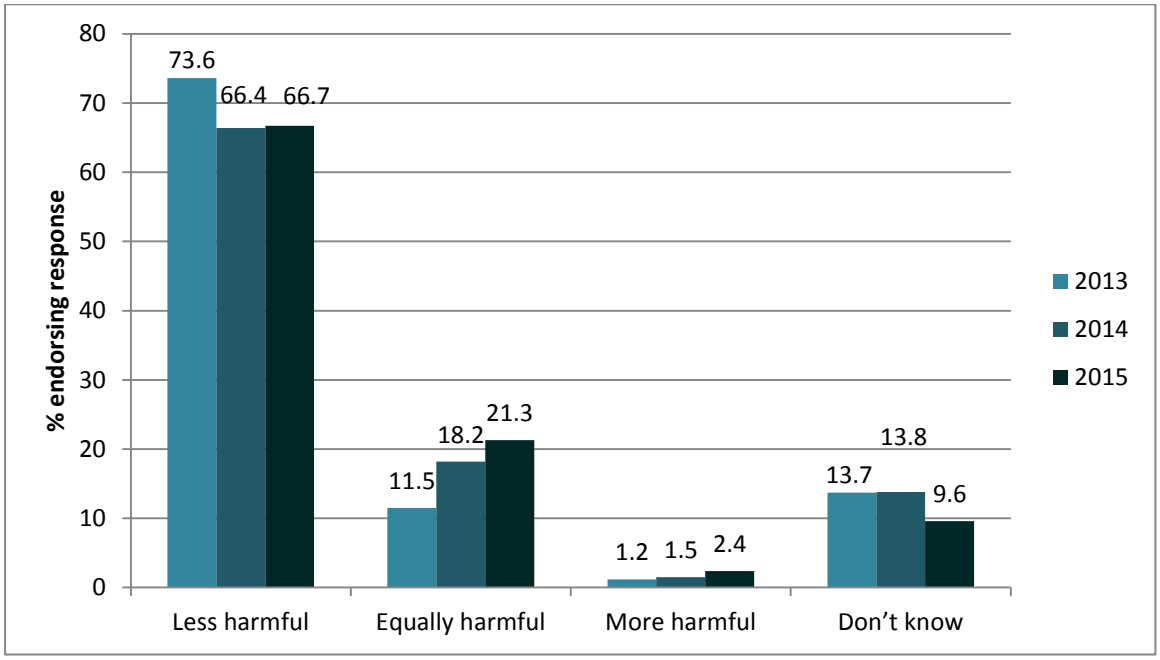


Figure 17: Perceptions of relative harmfulness of e-cigarettes in comparison with tobacco cigarettes. ASH Smokefree GB adult surveys (weighted)



Notes: "Less harmful" includes those saying "Electronic cigarettes are completely harmless". "Not applicable – I do not think regular cigarettes are harmful" not shown (2013: 1.2%, 2014: 0.9%, 2015: 0.8%)

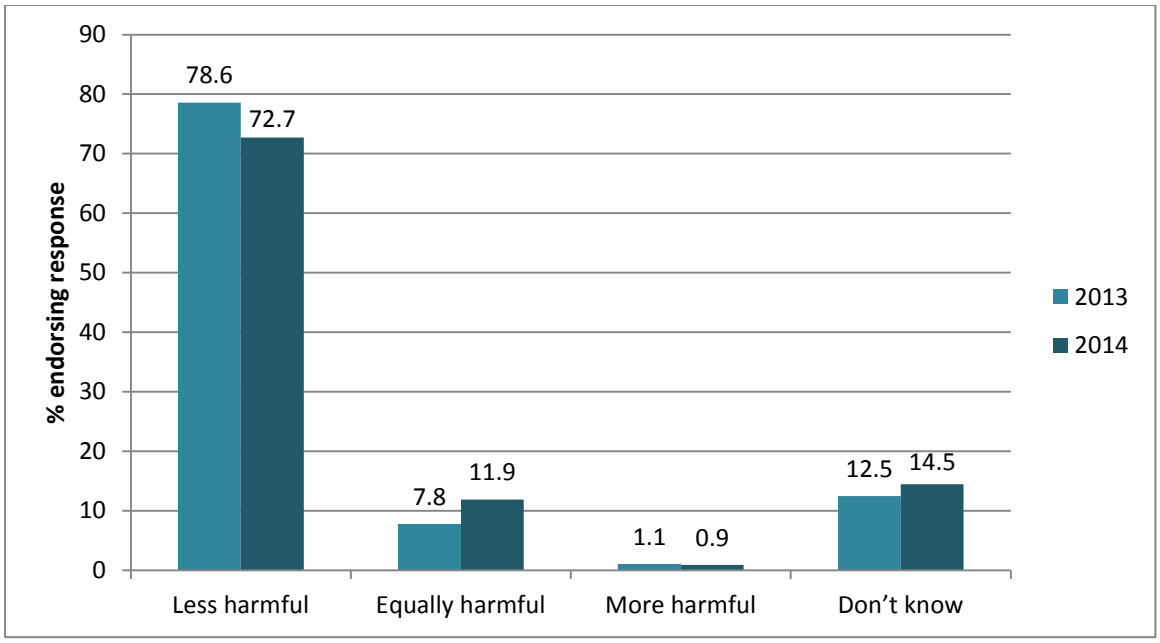
Figure 18: Perceptions of relative harmfulness of e-cigarettes in comparison with tobacco cigarettes. ASH Smokefree GB youth surveys (2013 and 2014) taken from Eastwood et al., in press[64].



Surveys from the US also suggest that from 2010 to 2013, the proportion of current smokers aware of EC who believed that EC were less harmful than smoking cigarettes declined considerably [65]. Youth in the US appear to have a less realistic perception of the relative harm of EC compared with cigarettes than UK youth. In the 2012 National Youth Tobacco Survey, of those who were aware of EC, around one-third perceived them to be less harmful than cigarettes and around half were unsure [66, 67].

The ASH Smokefree GB youth survey in 2013 and 2014 further included a question on the harm of EC to persons around a user. Again, the proportion who thought them less harmful than traditional cigarettes decreased from 2013 to 2014 ($p<0.05$), and the proportion who thought they caused similar levels of harm increased ($p<0.01$) (Figure 19).

Figure 19: Perceptions of relative harmfulness of e-cigarettes to people around the user. ASH Smokefree GB youth surveys



Harm perception relative to nicotine replacement therapy (NRT)

The ASH Smokers' survey in 2014 asked respondents about their perception of EC compared with NRT (Table 20). The largest group of respondents thought EC were about as safe. Notably, a higher proportion thought that EC were safer than NRT than believed that NRT was safer than EC. This was particularly pronounced in current EC users.

Table 5: Relative harm perception by e-cigarette use status ASH Smokers' survey 2014

	E-cigarette use status			
	Never	**Current**	**Ex**	**Total**
	39.10%	**21.30%**	**39.70%**	
	(n=470)	**(n=256)**	**(n=477)**	**(n=1203)**
Compared to NRT				
Safer	14 (66)	28.1 (72)	22 (105)	**20.2 (243)**
About as safe	28.1 (132)	44.1 (113)	35.6 (170)	**34.5 (415)**
Less safe	16.2 (76)	6.3 (16)	13 (62)	**12.8 (154)**
Don't know	41.7 (196)	21.5 (55)	29.4 (140)	**32.5 (391)**

One US survey of 1,400 current and former smokers also assessed expected outcomes of using EC compared with NRT [68]. EC were perceived to be less risky, cost less, cause fewer negative physical feelings, taste better, provide more satisfaction, and be better at reducing craving, negative affect, and stress.

Summary of findings

Although the majority of adults and youth still correctly perceive EC to be less harmful than tobacco cigarettes, there has been an overall shift towards the inaccurate perception of EC being at least as harmful as cigarettes over the last year, for both groups. Intriguingly, there is also some evidence that people believe EC to be less harmful than medicinal nicotine replacement therapy (NRT).

Policy implications

- Clear and accurate information on relative harm of nicotine, EC and tobacco cigarettes is needed urgently (see also Chapter 10).
- Research is needed to explore how health perceptions of EC are developed, in relation to tobacco cigarettes and NRT, and how they can be influenced.

9. E-cigarettes, nicotine content and delivery

Background

We have undertaken a review of available evidence concerning nicotine released by EC. The review is divided into four parts, covering nicotine that EC use (vaping) releases into ambient air, nicotine content of e-liquid, nicotine content in e-vapour, and nicotine delivery to EC users (vapers). The main concern with nicotine in EC relates to the question of whether EC use exposes users or bystanders to the risk of nicotine poisoning. For this reason, we start with a short introductory review of this topic.

Toxicity of nicotine

Nicotine in the form of tobacco and more recently NRT has been available to thousands of millions of people and large numbers of them, including small children, have ingested considerable doses of nicotine. Fatal nicotine poisoning, however, is extremely rare. This fact strongly contradicts the often-repeated claim that an ingestion of 30-60mg of nicotine is fatal. The source of this claim proved difficult to locate – textbooks just cite older textbooks. Eventually, the assertion was found to be based on dubious self-experiments conducted in the 1890s [69].

We are aware of one unconfirmed newspaper report of a fatal poisoning of a two-year old child [70] and of three published case studies of small children who drank e-liquid. A two-year old was admitted to hospital with vomiting, ataxia, and lethargy, and was discharged after 24 hours of observation [71]. In the second report, an 18-month old girl drank 24mg nicotine in e-liquid, vomited and was irritable, and recovered fully within an hour or so [72]. The third article presented a case of a 30-month old child suspected to have ingested e-liquid. The quantity of e-liquid was uncertain and the child was asymptomatic with all clinical observations reported to be normal [73].

With the increase in EC use, there has been an increase in calls to poison centres following accidental exposures but these remain lower than calls following such exposure from tobacco and none resulted in any serious harm [74] (see next chapter for UK data). Serious nicotine poisoning seems normally prevented by the fact that relatively low doses of nicotine cause nausea and vomiting, which stops users from further intake.

Apart from accidental poisoning, nicotine has also been used in suicide attempts. Suicide attempts with large amounts of pesticides containing nicotine sulphate often succeed [75] but completed suicides using e-liquids are extremely rare. Where adults

drank up to 1,500mg of nicotine in e-liquid, the result was vomiting and recovery within a few hours [76]. One fatal outcome was recorded with 3,950mg of nicotine found in gastric content. The victim seems to have drunk three vials of e-liquid totalling over 10,000mg of nicotine[76]. An intravenous injection of unknown quantity of e-liquid also resulted in death [77].

E-liquid normally comes in 10ml bottles containing up to 360mg of nicotine (see below). This poses no risk to vapers if used as intended. The liquid however should be in 'childproof' packaging to prevent small children, who may find the flavouring appealing, from drinking it. This seems to have been widely accepted by the EC industry. All e-liquids we have seen so far in the UK and globally were sold in child-resistant packaging.

Review methods

We searched the US National Library of Medicine (Pubmed) using the following search terms: ((cotinine OR nicotine) AND (blood OR plasma OR urine OR saliva OR liquid OR aerosol OR pharmacokinetic$)) AND (electronic cigarette$ OR e-cig$ OR ENDS). This search returned 161 records. The abstracts of all records were screened.

Papers were included if they were peer-reviewed and presented data regarding nicotine in e-liquid, aerosol, or body fluids (blood, saliva or urine). Studies that reported data on blood, salivary, or urine cotinine were also included.

A total of 112 records were excluded as they did not contain any relevant information, leaving 49 records. The full papers of these records were retrieved and reviewed.

From the full text review, 25 studies provided data regarding nicotine content of ambient air, e-liquid and vapour, and 16 provided data on nicotine delivery to users. The remaining eight papers did not contain any relevant information. Three further relevant papers were published during the writing of this report and were also included.

Nicotine in ambient air, e-liquid and e-vapour

We identified five studies of nicotine in ambient air, 14 studies of nicotine in e-liquid and nine studies of nicotine vapour. The results are summarised below. We tabulate the results where appropriate and provide a narrative summary where there are only a few studies available. Each section is concluded with a brief summary.

Passive vaping: Nicotine from e-cigarette use in ambient air

Four studies examined nicotine exposure from passive vaping. Long et al., 2014 measured nicotine content of EC exhalations. EC exhalations contained eight times less

nicotine than cigarette exhalations [78]. Estimating environmental nicotine exposure, however, has to take into account the fact that side-stream smoke (ie the smoke from the lighted end of the cigarette, which is produced regardless of whether the smoker is puffing or not) accounts for some 85% of passive smoking and there is no side-stream EC vapour. A study measuring nicotine residue on surfaces in houses of smokers and vapers reported only negligible levels from vaping, 169 times lower than from smoking [79].

Colard et al., 2015 describe a model for estimating environmental workplace exposure [80]. The model predicts much lower nicotine exposure from vaping than from smoking, at levels negligible in health terms.

Goniewicz and Lee 2014 found that nicotine from EC vapour gets deposited on surfaces, but at very low levels [81]. This poses no concerns regarding exposure to bystanders. At the highest concentration recorded (550 µg/m^2), an infant would need to lick over 30 square metres of exposed surface to obtain 1mg of nicotine.

Ballbe et al., 2014 provide the most informative data collected to date as this study measured the actual levels of airborne nicotine in homes of ex-smokers who live either with smokers (N=25) or with vapers (N=5) and also in 24 control homes [82]. The study also measured salivary and urinary cotinine in partners of smokers and vapers. As expected, there was little nicotine in non-smokers' homes. The air in the homes of vapers contained six times less nicotine than the air in the homes of smokers. There was less of a difference between cotinine levels of partners of vapers and smokers (1.4 to 2 fold difference), most likely due to some 'ex-smokers' still occasionally smoking, but even with this possible contamination, the nicotine levels absorbed via passive vaping were negligible. Partners of vapers had mean cotinine concentrations of 0.19 ng/ml in saliva and 1.75 ng/ml in urine, which is about 1,000 times less than the concentrations seen in smokers and similar to levels generated by eating a tomato [83].

Summary

EC release negligible levels of nicotine into ambient air with no identified health risks to bystanders.

Nicotine in e-liquids

Fourteen studies tested more than 400 different e-liquids, mainly to check the accuracy of product labelling. Their results are summarised in Table 6, updated from an earlier review by Cheng et al., 2014 [84].

Table 6: Nicotine in refill solutions, cartridges and aerosols of e-cigarette products
(Adjusted from Cheng et al. 2014)

Study	Matrix	Units	Nicotine level	Maximum deviation from label*
Westenberger [85]	Cartridge	mg/cartridge	0.00 to 6.76	N.A.
	Aerosol	µg/100mLpuff	0.35 to 43.2	N.A.
	Refill solution	µg/mL	N.D. to 25.6	N.A.
	Cartridge	mg/cartridge	0.00 to 6.76	N.A.
Cobb *et al* [86]	Cartridge	mg/cartridge	3.23±0.5 to 4.07±0.54	–80 to –77%†
	Aerosol	µg/35 mL puff	0.3 for puffs 11 to 50 to 1 for puffs 1 to 10	N.A.
Trehy *et al* [87]	Refill solutions	mg/mL	0 to 25.6	–100 to 100%†
	Cartridge	mg/cartridge	0 to 21.8	–100 to 100%†
	Aerosol	µg/100 mL puff	0 to 43.2	N.A.
Cheah *et al* [88]	Cartridge	mg/cartridge	0.00 to 15.3	–89 to 105%†
Pellegrino *et al* [89]	Cartridge	% W/W	<0.001 to 0.25	N.A.
	Aerosol	mg/m^3	<0.01 to 6.21	N.A.
McAuley *et al* [90]	Indoor air	ng/L	538 to 8770	N.A.
Goniewicz *et al* [91]	Refill solution	mg	0±0.0 to 25±1.1	–75 to 28%
	Cartridge	mg	0±0.0 to 19±0.5	–89 to 25%
	Aerosol	mg/150 puffs	0.3±0.2 to 8.7±1.0	N.A.
Etter *et al* [92]	Refill solution	mg/mL	N.D. to 29.0	–15 to 21%†
Kirschner *et al* [93]	Refill solution	mg/mL	14.8±0.2 to 87.2±2.7	–50 to 40%†
Cameron *et al* [94]	Refill solution	mg/mL	8.5±0.16 to 22.2±0.62	–66 to 42%†
Goniewicz *et al* [95]	Liquids	mg/mL	N.D. to 36.6 (150.3 'pure nicotine')	-92 to 104%
Geiss *et al* [96]	Liquids	mg/mL	N.D. to 20.8	-0 to 16%
Kavvalakis *et al* [97]	Liquids	%w/v	1.01 to 1.62	-17 to +6%
Farsalinos *et al* [98]	Liquids	mg/ml	Labelled 12-18	-21 to +22%

*Deviation from label = (measured value – labelled value) * 100/labelled value.

†Calculation performed by this analysis based on reported data in each study.

N.A. = not available; N.D. = none detected.

A range of analytical methods was used, which may have contributed some variation. There is no established standard and different studies use different approaches. Cheah et al., used gas chromatography coupled with flame ionization detector [88]; Etter et al., gas chromatography coupled with mass spectrometry and ultra high-performance liquid chromatography coupled with diode array detector [92]; McAuley et al., gas chromatography coupled with nitrogen-phosphorus detector [90]; Goniewicz et al., gas chromatography coupled with thermionic specific detector [95]; Trehy et al., high-performance liquid chromatography coupled with diode array detector [87]; Westenberger high-performance liquid chromatography coupled with ultraviolet/ visible spectroscopic detector [85]; Kubica et al., liquid chromatography coupled with tandem mass spectrometry [99]; and Kirschner et al., liquid chromatography coupled with time-of-flight mass spectrometry [93].

The data generated so far provide answers to three questions:

Do e-liquids pose a poisoning hazard?

The vast majority of vapers use ‘ready-made’ liquids in 10ml bottles, but some aficionados, primarily in the US, buy high concentration nicotine solutions in larger quantities for DIY dilution. An e-liquid was identified labelled as containing 210mg/ml which in fact contained only 150mg/ml [95] but even this may pose risk if ingested in larger volume. DIY liquids are rarely used in Europe, but for spurious reasons, Europe is poised to prohibit sales of products with nicotine concentrations above 20mg/ml. When this happens, the popularity of DIY e-liquids among dependent vapers, who now cannot access the products they need but can mix them themselves at home at low cost, may increase.

‘Ready-made’ e-liquids come in strengths of up to 36mg/ml nicotine, with the highest concentration recorded of 36.6mg/ml. This poses no risk of nicotine poisoning if used as intended. An overenthusiastic vaper, like someone who is over-smoking, receives a reliable warning via nausea. If the 10ml bottle of e-liquid was drunk, it would cause nausea and vomiting but would be unlikely to inflict serious harm. To protect young children from accidental exposure though, e-liquids should be in ‘childproof’ packaging.

How accurate is product labelling?

The real content exceeded markedly the labelled concentration only in samples where the declared content was very low (6mg/ml) and the real concentrations ranged up to 12mg/ml (ie still low levels). The most striking examples of inaccurate labelling concerned much lower nicotine levels than those declared in e-liquids confiscated in Singapore where EC are banned, for example, a liquid labelled as containing 24mg of nicotine contained only 3mg [88]. This however was most likely due to samples being several years old. Market competition seems to have led to improved standards as

poorly labelled products are now less common and overall the labelling accuracy has improved. For instance in the latest study which sampled 263 liquids from 13 manufacturers, the correlation between the declared and measured concentrations was r=0.94 with the samples ranging from -17% to +6% of the declared value [85]. In another study testing the five most popular EC brands, the consistency of nicotine content across different batches of nicotine cartridges of the same products was found to be within the accuracy required from medicinal nebulisers [100]. Given the generally adequate labelling accuracy and the fact that the actual nicotine intake by vapers is dictated by a host of other factors discussed below, the accuracy of labelling of common e-liquids poses no major concerns.

Is there is a risk from e-liquids inaccurately labelled as containing 0 nicotine?

All samples labelled as containing 0 nicotine were nicotine free in the newer studies, but three early studies found nicotine in some samples of '0 nicotine' e-liquids. One sample reported in 2011 was clearly mislabelled [87] but in all other cases, only trace contamination was detected (below 1mg/ml). This would have no central effect on users.

Summary

Poorly labelled e-liquid and e-cartridges mostly contained less nicotine than declared and so posed no risk to users. The accuracy of product labelling currently raises no major concerns.

Nicotine in e-vapour

A number of studies evaluated nicotine in EC vapour generated by puffing machines. A recent experiment [101] has shown that parameters of puffing topography, especially puff duration and puff frequency, have a major influence on nicotine delivery. This poses a serious problem in interpreting the existing studies. The key parameters used by puffing machines differ widely across studies, and may not correspond well or at all with vapers' behaviour generally and especially with the way individual EC products are used. To illustrate the point, Table 7 below, from Cheng et al. 2014 [84], shows the wide range of settings used in different studies. (Table 7 includes some unpublished studies).

Table 7. Settings of EC puffing parameters. From Cheng et al 2014 [84].

Study	Puff volume (mL)	Puff interval (s)	Puff duration (s)	Puffs/session	Smoking machine
Goniewicz *et al [100]*	70	10	1.8	15	Palaczbot*
Pellegrino *et al [89]*	498	8	3	16	Aspiration

Ingebrethsen [102]	55	30	2 to 4	10	Lab-built device
McAuley *et al [90]*	50	30	4	50	SCSM
Trehy *et al [87]*	100	60	2	30	Lab-built device
Williams & Talbot [103]	N.A.	60	2.2	10/11	Lab-built device
Cobb *et al[86]*	35	60	2	≥50	Machine ISO
Trtchounian *et al [104]*	N.A.	60	2.2	10	Lab-built Puff box
Uchiyama *et al [105]*	N.A.	N.A.	N.A.	N.A.	Premium Smoker
Westenberger [85]	100	60	N.A.	N.A.	Lab-built device
Laugesen [106]	38, 58	N.A.	N.A.	N.A.	Syringe

N.A., not available.

For instance, the average puff duration in experienced vapers is 2.8 seconds [101], but some studies used puffs lasting for up to 4 seconds. This can overheat the e-liquid and provide unrealistically high readings (see Chapter 11).

Although it would be feasible to establish some empirical standards, eg of puff duration and frequency, by observing vapers, any general standard would have to average values across different products. As different products, and especially products from different ‘generations’, are used differently, such a blanket regimen would still provide inaccurate and potentially misleading information.

A recent study discovered another serious problem with trying to make sense of nicotine content in e-vapour. Across five common e-liquids with middle ranges of strength, the actual nicotine concentration in the e-liquid had almost no relationship with the nicotine content in vapour when the devices were puffed on by a machine at a standard rate [100]. The e-liquid of course had to contain a certain minimal level of nicotine as with little or no nicotine in e-liquid, there would be little or no nicotine in vapour. This finding concerning machine testing also does not mean that nicotine levels in e-liquids are irrelevant for EC users. Although EC technology is developing to maximise nicotine delivery, a vaper seeking high blood nicotine levels is likely to struggle to achieve them with a weak e-liquid. The reason for the low correlation between nicotine in e-liquid and in e-vapour is that the battery output, type of wicks, ventilation holes and other mechanical characteristics of each individual EC product determine how much vapour and nicotine is released – before the individual puffing style and preferences generate yet another key determinant of nicotine delivery to users.

These findings have an important implication. Above the necessary minimum level of nicotine, nicotine concentrations in e-liquid and even the concentrations in vapour, if measured by standard puffing schedules, are of limited relevance. For light smokers, 18mg/ml ‘mild’ e-liquid may be sufficient, but they may also prefer a stronger liquid and take shorter and less frequent puffs. A heavy smoker who would be expected to prefer a 28mg/ml ‘strong’ liquid may in fact chose a ‘moderate’ strength if they favour long and frequent puffs.

In real-life use, vapers have no way of knowing in advance what liquid strength and product characteristics they will prefer. As with other consumer products of this type, such as cigarettes, coffee and soft drinks, vapers have to try several EC models and different e-liquids before settling on a preferred product that matches their preferences.

For practical purposes, general labelling of the strength of e-liquid, along the lines used for indicating coffee strength, may provide sufficient information for consumers. The current vapers’ preferences suggest as a rough rule of thumb that ‘mild’ equates to 16–20mg/ml, ‘medium’ to 21–26mg/ml and ‘strong’ to 27–36mg/ml.

Translating these findings into regulatory recommendations, it would seem that regulation to enforce standard nicotine delivery may not be needed because nicotine delivery is influenced by a host of factors, including user puffing preferences, and because consumer preferences differ. EC products will hopefully continue to evolve guided by differential market success, with the result that more smokers find EC helpful and switch to them.

Summary

Across the middle range of nicotine levels, nicotine delivery to vapour is determined primarily by mechanical and electrical characteristics of EC products and by the duration and frequency of puffs. General labelling of the strength of e-liquids, along the lines used for indicating coffee strength (eg mild, medium and strong), is likely to provide sufficient information for consumers.

Nicotine delivery to e-cigarette users

To assess nicotine intake from EC, a number of studies took blood samples from smokers during and after vaping. Table 8 summarises data from 17 studies that investigated nicotine delivery from EC in humans. The narrative description of the studies and additional details concerning their findings are presented in Appendix C.

The two key questions in this field are:

a) How much nicotine EC deliver compared to cigarettes, and
b) How fast EC deliver nicotine compared to cigarettes.

As in every new field, methodological problems limit the usefulness of some of the data collected so far. Two problems in particular are prominent.

1) Almost all studies used prescribed puffing regimes, sometimes derived from observations of smokers rather than vapers. We described above the evidence that puffing schedules have a major influence on nicotine delivery to vapour. Puffing schedules that do not correspond with vapers' behaviour are thus unlikely to provide realistic nicotine delivery data. Only three studies allowed vapers to puff ad-lib on first use.

2) Regarding the question of the speed of nicotine delivery, all existing studies started blood sampling only after five minutes of vaping. Cigarettes provide peak nicotine plasma levels very quickly (eg peak arterial nicotine concentrations of around 20ng/ml nicotine are reached within 20 seconds of starting to puff on an cigarette [107]). Data collected so far do not allow an appraisal of whether EC are approaching cigarettes in this key parameter.

Despite these limitations, the studies above have generated several strands of useful information on how much nicotine vapers obtain over time and how this compares with nicotine intake from cigarettes.

Cotinine is a metabolite of nicotine with a long half-life which shows nicotine exposure over time. Cotinine data are thus not influenced by the laboratory puffing schedules. Some studies suggest that experienced vapers can, over time, reach nicotine levels comparable to those obtained from smoking [108-110], although others have found plasma or salivary cotinine levels that are still lower than those observed in daily smokers [111-113].

Cigalike EC deliver lower levels of nicotine than cigarettes [114-116], especially to novice users [117-119]. Vapers obtain slightly more nicotine from them with practice, but nicotine delivery is comparatively low and slow [115]. Experienced users can obtain a rise in blood nicotine concentration of between 8 and 16ng/ml [120, 121]. Tank systems deliver nicotine more efficiently than cigalikes and somewhat faster [120, 122, 123].

Overall, the data indicate that within five minutes of use of a cigalike EC, blood nicotine levels can rise by approximately 5ng/ml. For comparison, after chewing a piece of 2mg nicotine chewing gum, peak plasma concentrations of 3–5ng/ml are observed within approximately 30 minutes [124, 125]. For experienced users of tank systems the increase in blood nicotine concentration within five minutes of use can be 3–4 times higher.

Speed of nicotine delivery seems important for smokers' satisfaction. Cigarettes deliver nicotine very fast via the lungs. It is likely that to out-compete cigarettes, EC will need to provide nicotine via the lungs as well. Although some EC products may already provide a degree of lung absorption, most nicotine is probably delivered via a much slower route through buccal mucosa and upper airways, in a way that is closer to the delivery from nicotine replacement medications than to the delivery from cigarettes.

This tallies with two other observations. Vapers feel they are less dependent on EC than they were on cigarettes [126]; and non-smokers experimenting with EC do not find them attractive and almost none progress to daily vaping [127]. This contrasts with the fact that about half of adolescents who experiment with cigarettes progress to daily smoking [128].

In addition to mechanical characteristics of EC and user puffing behaviour discussed in previous sections, the composition of the chemicals used to produce the vapour, typically vegetable glycerol and/or propylene glycol (PG), may also influence nicotine delivery. E-liquid with a mix of vegetable glycerol/PG was associated with better nicotine delivery than a vegetable glycerol-only e-liquid with the same concentration of nicotine [129]. The presumed effect is that PG vaporises at a faster rate than vegetable glycerol when heated in the EC and so is able to carry more nicotine to the user.

If EC continue to improve in the speed of nicotine delivery, they are likely to appeal to more smokers, making the switch from smoking to vaping easier. It may be important in this context to note that if the smoking-associated risk is removed, nicotine use by itself, outside pregnancy, carries little health risk and in fact conveys some benefits.

Table 8: Studies examining nicotine intake in vapers

Study	Participants	EC Device	Methods	Results
Vansickel et al 2012 [119]	20 smokers naïve to EC	Vapor King (cigalike), 18mg/ml nicotine	Overnight abstinence, baseline blood sample, after 5 mins 10 puffs, 30 sec inter-puff interval, 5 mins after last puff blood sample. Repeated 5x, 30 mins in between	At end of last puffing bout plasma nicotine increased from 2.2 ng/ml at baseline to 7.4 ng/ml.
Vansickel & Eissenberg 2012 [121]	8 vapers using EC for average of 12 months	Own EC 1 used 9 mg/ml 6 used 18 mg/ml 1 used 24 mg/ml	Overnight abstinence, Baseline blood, after 5 mins 10 EC puffs at 30 sec intervals, 5 and 15 mins after first puff blood sample, 60 min ad-lib vaping	Increase in plasma nicotine from 2.0 ng/ml to 10.3 ng/ml in 5 mins. Cmax = 16.3 ng/ml at end of ad lib period
Yan & D'Ruiz 2014 [129]	23 smokers	4 types of Blu (cigalike) EC (1.6% to 2.4%) Marlboro cigarette	Randomised 6 sessions 7-days get used to EC, 36 h abstinence. EC = 50x5 sec puffs, 30 sec	During controlled puffing Cmax (ng/ml): EC 10.3 to 18.9; cig 15.8

Study	Participants	EC Device	Methods	Results
		(cig)	intervals. Cig ad lib puff duration at 30 sec intervals. Then ad lib use for 60 mins. Blood: 10 mins pre, 5, 10, 15, 20, 25, 30, 45, 60, 75, 90 mins post start of controlled puffing.	Tmax: 30mins for EC and 5 mins for cig During ad lib use -Cmax (ng/ml): EC 13.7 to 22.42; cig 29.3
Vansickel et al 2010 [118]	32 smokers)	Own brand cig NJOY EC (18mg) Crown 7 EC (16mg) Sham (unlit cig) EC were cigalike	Randomised crossover, overnight abstinence. Baseline blood, EC – 10 puffs at 30 sec intervals, blood at 5, 15, 30, 45, 60 mins	Only cig produced significant rise in nicotine (18.8 ng/ml at 5 mins)
Van Staden et al 2013 [113]	13 smokers	Twisp eGo (18mg/ml nicotine)	Provided with EC and asked to use this and stop smoking for two weeks	Cotinine ng/ml Baseline: 287, at 2 weeks 97 (p=0.0011)
Spindle et al 2015 [120]	13 vapers > 3 months, e-liquid ≥12mg/ml	Own EC (all tank systems) 1 x 12 mg/ml 3 x 18 mg/ml 9 x 24 mg/ml	Overnight abstinence, two sessions. Baseline blood, EC – 10 puffs at 30 sec interval. Blood at 5 and 15 min.	Plasma nicotine at Baseline: 2.4 ng/ml 5 mins: 19.2 ng/ml 10 mins: 10.2 ng/ml
Bullen et al 2010 [117]	8 smokers	Ruyan V8 (cigalike) 16mg/ml (puff for 5 mins) Inhalator 10mg (puff for 20 mins) Own brand cig (puff for 5 mins)	Randomised crossover, overnight abstinence. Baseline blood, product use, blood at 5, 10, 15, 30, and 60 mins.	Cmax (ng/nl): EC=1.3; Inh=2.1; Cig=13.4 Tmax (mins): EC=19.6; Inh=32.0; Cig=14.3
Flouris et al 2013 [130]	15 smokers	Giant (cigalike) 11mg/ml	Smoked 2 cigs, puffed EC to match smoking. Cotinine immediately and 1 h after puffing	No difference between products
Capon-netto et al 2013 [40]	Sample size not stated	Categoria (cigalike) 7.2mg for 12 weeks 7.2mg/5.4mg for 12 weeks	RCT – 12 weeks of EC use	Salivary cotinine 6 weeks: 42 ng/ml; 12 weeks: 91 ng/ml 6 weeks: 68 ng/ml; 12 weeks: 70 ng/ml
Etter & Bullen 2011 [110]	30 vapers Mean EC use 94 days	Own brand EC Mean nicotine content 18mg/ml	Ad libitum use	Salivary cotinine 322 ng/ml
Dawkins & Corcoran 2014 [114]	14 vapers, 7 dual users,	Skycig (cigalike) 18mg/ml	10 puffs in 5 mins, then 1 hour ad lib	After 10 mins: 0.74 – 6.77 ng/ml After ad lib: 4.35-25.6 ng/ml

Study	Participants	EC Device	Methods	Results
	Used EC for 4.7 months			
Nides et al 2014 [116]	29 smokers, 55% used EC in past	NJOY®King Bold (cigalike) 26mg	EC ad lib 1 week, 12 h abstinence. 2x10 puffs (30 sec inter-puff interval) 60 mins apart Blood before and 5, 10, 15, 30 minutes after	N=16 had no baseline plasma nicotine Rise 5 min after first puffs: 3.5 ng/ml; after second puffs: 5.1 ng/ml
Norton et al 2014 [112]	16 smokers	Smoke 51 TRIO (cigalike) 11 mg/ml	Day 1: own brand, saliva sample Given EC and stopped smoking. Saliva at day 5. Analysis of 16 who abstained from smoking for 72 hours	Significant decrease in saliva cotinine between baseline (338.0 ng/ml) and day 5 (178.4 ng/ml), p<0.001
Hecht et al 2014 [111]	28 vapers (median 9 months), 96% daily users	Average nicotine 12.5 +/- 7.0 mg/ml All tank system EC	Measured toxicants, carcinogens, nicotine and cotinine in urine	Nicotine: 869 ng/ml Cotinine: 1880 Smokers normally Nicotine: 1380 ng/ml, cotinine: 3930 ng/ml
Hajek et al 2014 [115]	40 smokers,	Greensmoke (cigalike) EC (2.4% nicotine)	Overnight abstinence Baseline blood, first EC use ad-lib 5 mins, blood at 5, 10, 15, 20, 30 and 60 mins. Repeated after 4-weeks of ad lib use	***Baseline:*** Cmax: 4.6, Tmax: 5, AUC: 96 ***4-weeks:*** Cmax: 5.7, Tmax: 5, AUC: 142
Farsalinos et al 2014 [122]	N=23 vapers (19 months use)	A: V2 (cigalike) B: Tank system EVIC at 9 watts, EVOD Same 18mg/ml liquid	Abstained for 8 hrs Blood baseline and after 10 puffs over 5 mins, 1 h ad lib, blood every 15 mins	A:5 mins: 4.9 ng/ml 1h: 15.8 ng/ml B: 5 mins: 6.6 ng/ml 1h: 23.5 ng/ml
Oncken et al 2015 [123]	N=20 smokers given EC for 2 weeks	Menthol or non-menthol tank system with 18mg/ml liquid	Blood baseline, 5 min ad lib vaping, blood at 5,10,15,20,30 min	At 5 min nicotine increased by 4-5 ng/ml

Summary of findings

The accuracy of labelling of nicotine content currently raises no major concerns. Poorly labelled e-liquid and e-cartridges mostly contained less nicotine than declared. EC used as intended poses no risk of nicotine poisoning to users. However, e-liquids should be in ‘childproof’ packaging.

Duration and frequency of puffs and mechanical characteristics of EC play a major role in determining nicotine content in vapour. Across the middle range of nicotine levels, in machine tests using a standard puffing schedule, nicotine content of e-liquid is related to nicotine content in vapour only weakly. EC use releases negligible levels of nicotine into ambient air with no identified health risks to bystanders. Use of a cigalike EC can increase blood nicotine levels by around 5ng/ml within five minutes of use. This is comparable to delivery from oral NRT. Experienced EC users using the tank EC can achieve much higher blood nicotine levels over a longer duration, similar to those associated with smoking. The speed of nicotine absorption is generally slower than from cigarettes but faster than from NRT.

Policy implications

- General labelling of the strength of e-liquids, along the lines used for example indicating coffee strength, provides sufficient guidance to consumers.

- Regulatory interventions should ensure optimal product safety but make sure EC are not regulated more strictly than cigarettes and can continue to evolve and improve their competitiveness against cigarettes.

10. Safety of e-cigarettes in the light of new evidence

Introduction

PHE commissioned a review of EC in 2014, which covered EC safety [131]. The review found that the hazard associated with use of EC products currently on the market "is likely to be extremely low, and certainly much lower than smoking" and "the health risks of passive exposure to electronic cigarette vapour are likely to be extremely low".

These conclusions tally with a review by an international team of experts, which estimated the risks of vaping at less than 5% of the risks of smoking [10] and a comprehensive review of relevant literature by another international team which concluded that "EC aerosol can contain some of the toxicants present in tobacco smoke, but at levels which are much lower. Long-term health effects of EC use are unknown but compared with cigarettes, EC are likely to be much less, if at all, harmful to users or bystanders" [132].

Over the past few months, however, several reports have suggested that EC may pose more risks than previously thought [133-137].

We were asked to review these studies to see if in the light of this new evidence, the conclusions of the PHE 2014 review need to be adjusted. We present below the details of these studies together with any additional data that may assist with their interpretation.

Aldehydes in vapour from e-cigarettes

Two recent reports raised a possibility that under certain conditions, EC may release high levels of aldehydes. Aldehydes, including formaldehyde, acrolein and acetaldehyde, are released in tobacco smoke and contribute to its toxicity. Aldehydes are also released with thermal degradation of propylene glycol and glycerol in e-liquids. Previous studies detected the presence of aldehydes, especially formaldehyde, in the vapour from some EC, but at levels much lower than in cigarette smoke [138]. Across brands, EC released 1/50th of the level of formaldehyde released by cigarettes. The highest level detected was six times lower than the level in cigarette smoke [138].

In November 2014, following a press release from Japan [136], major media around the world reported variations of a headline: "E-cigarettes contain 10 times the carcinogens of regular tobacco". This was based on a Japanese researcher reporting at a press conference that during tests on a number of EC brands, one product was identified

which released 10 times more formaldehyde than cigarettes. The press release states that the formaldehyde was released when the e-liquid was over-heated. The study has not been published yet and so no further details are available, but the two experiments described below provide the explanation for this finding.

In January 2015, a similar report was published as a research letter to the *New England Journal of Medicine* (NEJM) [133]. In this study, negligible levels of formaldehyde were released at lower EC settings, but when a third generation EC (EC with variable power settings) was set to the maximum power and the apparatus was set to take puffs lasting 3–4 seconds, this generated levels of formaldehyde that, if inhaled in this way throughout the day, would exceed formaldehyde levels in cigarette smoke between five and 15 times.

The EC was puffed by the puffing machine at a higher power and longer puff duration than vapers normally use. It is therefore possible that the e-liquid was overheated to the extent that it was releasing novel thermal degradation chemicals. Such overheating can happen during vaping when the e-liquid level is low or the power too high for a given EC coil or puff duration. Vapers call this phenomenon ‘dry puff’ and it is instantly detected due to a distinctive harsh and acrid taste (it is detected by vapers, but not by puffing machines) [139]. This poses no danger to either experienced or novice vapers, because dry puffs are aversive and are avoided rather than inhaled.

A study has just been published testing the hypothesis that the NEJM report used dry puffs [140]. An equivalent EC product was set to the same or normal settings and used by seven vapers. The vapers found it usable at normal settings, but all received dry puffs and could not use the device at the settings used in the NEJM report [133]. The product was then machine tested. At the dry puff setting, formaldehyde was released at levels reported in the NEJM letter and the Japanese press release. At normal settings, there was no or negligible formaldehyde release.

We are aware of two studies that examined aldehyde levels in vapers. In a cross-sectional study, vapers had much lower levels of acrolein and crotonaldehyde in urine than smokers [111]. The other study, funded by the Medicines and Healthcare products Regulatory Agency (MHRA), examined changes in acrolein levels in smokers who switched to exclusive EC use and in those who continued to smoke while also using EC. As both EC and cigarettes release acrolein, there was a concern that ‘dual users’ may increase their acrolein intake compared to smoking only. The results showed a substantial decrease in acrolein intake in smokers who switched to EC, but it also found a significant decrease in acrolein intake in dual users (ie people that were both smoking and vaping). This was because they reduced their smoke intake as indexed by exhaled CO levels. Normal vaping generated negligible aldehyde levels [141].

Although e-liquid can be heated to a temperature which leads to a release of aldehydes, the resulting aerosol is aversive to vapers and so poses no health risk.

Summary

There is no indication that EC users are exposed to dangerous levels of aldehydes.

Effects of e-cigarette vapour on mice lungs

A paper published in February 2015 [135] generated worldwide media coverage with claims that it linked EC to lung inflammation, lung infection, and even lung cancer.

Groups of mice were put in a small container exposing them to vapour from six EC ('Menthol Bold' 1.8% nicotine) puffed on a rotating wheel at six puffs per minute for 1.5 hours, twice daily, over two weeks. The control mice were not exposed to this treatment.

Animals were infected with either streptococcus pneumonia via intranasal instillation and killed 24 hours later, or with tissue culture influenza virus and monitored for weight loss, mortality, and lung and airways inflammation. Compared to the control group, the experimental animals had an increase in pro-inflammatory cytokines, diminished lung glutathione levels, higher viral titre, and were more likely to lose weight and die. The study identified free radicals in EC vapour as the potential culprit.

There are several problems with the study and with the way its results have been interpreted.

EC vapour is inhaled as a replacement for tobacco smoke, but the study attempted no comparison of the effects on the lungs from smoke and vapour exposures. This makes a meaningful interpretation of the results difficult. A comparison was made, however, of the levels of free radicals. Even at the very high vapour density generated by the study procedure, the level of free radicals identified in vapour was "several orders of magnitude lower than in cigarette smoke".

In addition to this, the mice in the experimental group were exposed to a much higher level of stress than the control group, and stress affects bacterial and viral response. Long and repeated containment in the small and crowded smoke chamber emitting an overpowering smell is a stressor in itself, but the animals also suffered repeated nicotine poisoning. The mice showed an average cotinine concentration of 267ng/ml. Cotinine is the primary metabolite of nicotine and in humans the amount of nicotine needed to give similar cotinine levels are tolerated by heavy smokers, but highly aversive to non-smokers, who would be expected to feel sick and vomit at this level of exposure. Mice are much more sensitive to nicotine than humans (LD50 in mice is 3mg/kg, in humans

6.5–13mg/kg [69]). Accelerated weight loss, reduced immunity and early death in the experimental group were much more likely the result of protracted stress and nicotine poisoning than the result of exposure to free radicals (which were in any case 1,000 times lower than from cigarettes).

A similar study from 2015 [134] reported oxidant reactivity (which is linked to free radicals) of e-liquid and cytokine release in exposed lung tissue and in mice exposed to EC vapour. Again, no comparison with exposure to smoke was reported.

Human studies do not corroborate any of the findings reported here. A case study of lipoid pneumonia, which could have been caused by EC flavouring, received worldwide attention in 2012 [142] but despite extensive interest in the phenomenon, no further cases were published. Adverse effects of vaping are primarily local irritation and dry mouth [132]. A study that monitored asthma patients who switched from smoking to vaping found significant improvements in symptoms and in respiratory function [143]. The recent Cochrane Review found no significant adverse effects associated with EC use for up to 1.5 years [39].

Summary

The mice model has little relevance for estimating human risk and it does not raise any new safety concerns.

Particles in e-cigarette vapour

For completeness we are including information on another recent report which was interpreted as showing that EC may be dangerous to bystanders. At an EC Summit conference in London in November 2014, Harrison and McFiggans reported on particles present in EC vapour. Their presentation was reported in the British Medical Journal under the title “E-cigarette vapour could damage health of non-smokers” [137]. McFiggans and Harrison requested a retraction of the piece because their findings did not concern any health risks. It is the content of the particles rather than their presence or size which has health implications [144].

Impact of media reports that e-cigarettes are dangerous

Together with previous health scares, the articles reviewed here may be having a significant impact on public perception of EC safety. In the US, 82% of responders believed that vaping is safer than smoking in 2010, but the figure has shrunk to 51% in 2014 [65]. A perception that EC pose as much risk as smoking is the most likely explanation of the recent decline in adoption of EC by smokers [145].

Summary of findings

Two recent worldwide media headlines asserted that EC use is dangerous. These were based on misinterpreted research findings. A high level of formaldehyde was found when e-liquid was over-heated to levels unpalatable to EC users, but there is no indication that EC users are exposed to dangerous levels of aldehydes; stressed mice poisoned with very high levels of nicotine twice daily for two weeks were more likely to lose weight and die when exposed to bacteria and viruses, but this has no relevance for human EC users. The ongoing negative media campaigns are a plausible explanation for the change in the perception of EC safety (see Chapter 8).

None of the studies reviewed above alter the conclusion of Professor Britton's 2014 review for PHE. While vaping may not be 100% safe, most of the chemicals causing smoking-related disease are absent and the chemicals that are present pose limited danger. It had previously been estimated that EC are around 95% safer than smoking [10, 146]. This appears to remain a reasonable estimate.

Policy implications

- There is a need to publicise the current best estimate that using EC is around 95% safer than smoking.

- Encouraging smokers who cannot or do not want to stop smoking to switch to EC could be adopted as one of the key strategies to reduce smoking related disease and death.

11. Other health and safety concerns

There have been a number of newspaper reports about the hazards of EC use including e-liquid ingestion/poisonings, fires, battery explosions etc [147-149]. In this chapter we review available national data on these issues to endeavour to quantify the risk.

Poison reports

Data on e-liquid exposures in the UK are available from the National Poisons Information Service (NPIS)[150]. The NPIS provides information about poisoning to NHS staff and publishes data based on enquiries made by phone, using their online database TOXBASE, and by consultant referrals. The NPIS report for 2013/14 [150] details 204 enquiries related to the liquid content of EC and their refills, most of which reported accidental exposure, however 21 enquiries were related to intentional overdoses using e-liquids. Most incidences concerned ingestion of the liquid in EC or their refills (n=182) although small numbers of inhalation (n=17), eye contact (n=13) and skin contact (n=12) enquiries were also reported. The NPIS further reported that the number of enquiries about e-liquids has increased since 2007 (Figure 20) broadly reflecting the increasing popularity of EC.

A large proportion of exposures to e-liquids were in children under five years old (Figure 21), a finding that is replicated in a US study on calls to poison centres [151]. However, the concentration of events concerning children is not unique to e-liquids. Children under five years old appear to be more vulnerable than adults to accidental poisoning in general (Figure 22).

Figure 20: Number of telephone enquiries to National Poisons Information Service (NPIS) about e-cigarettes over time

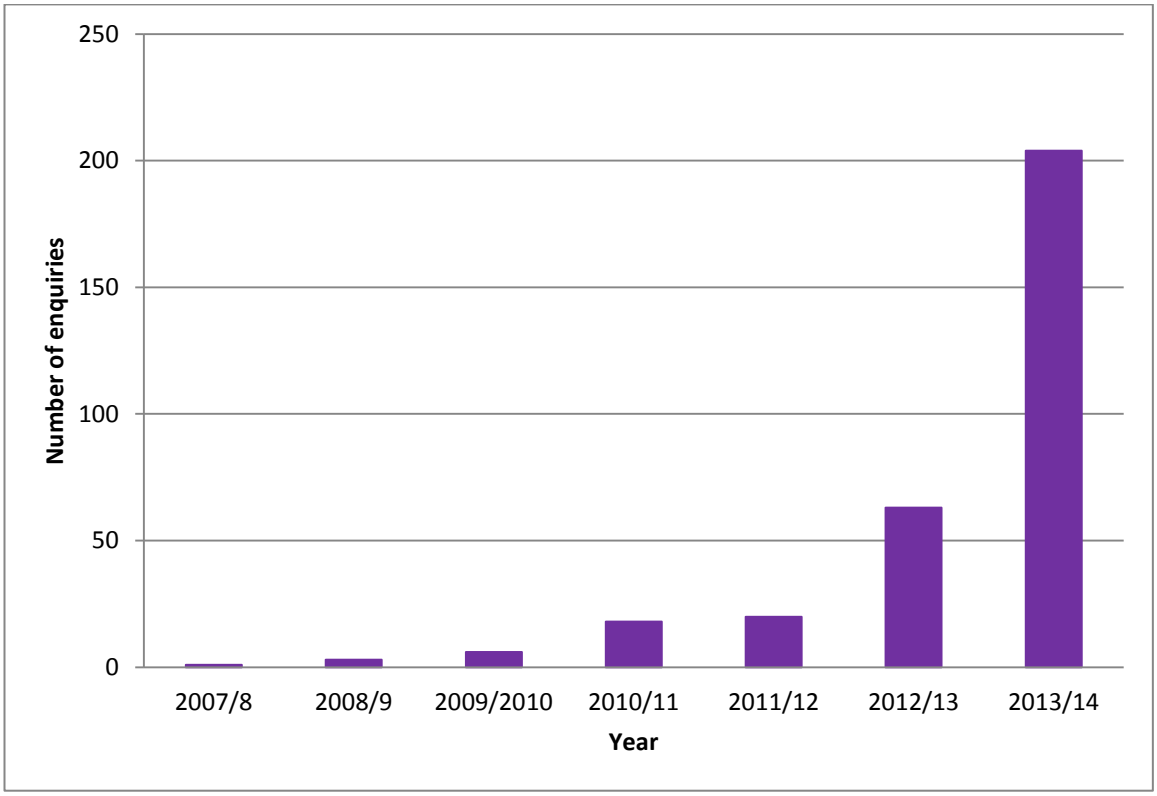


Figure 21: Number of enquiries about e-cigarettes to NPIS by age

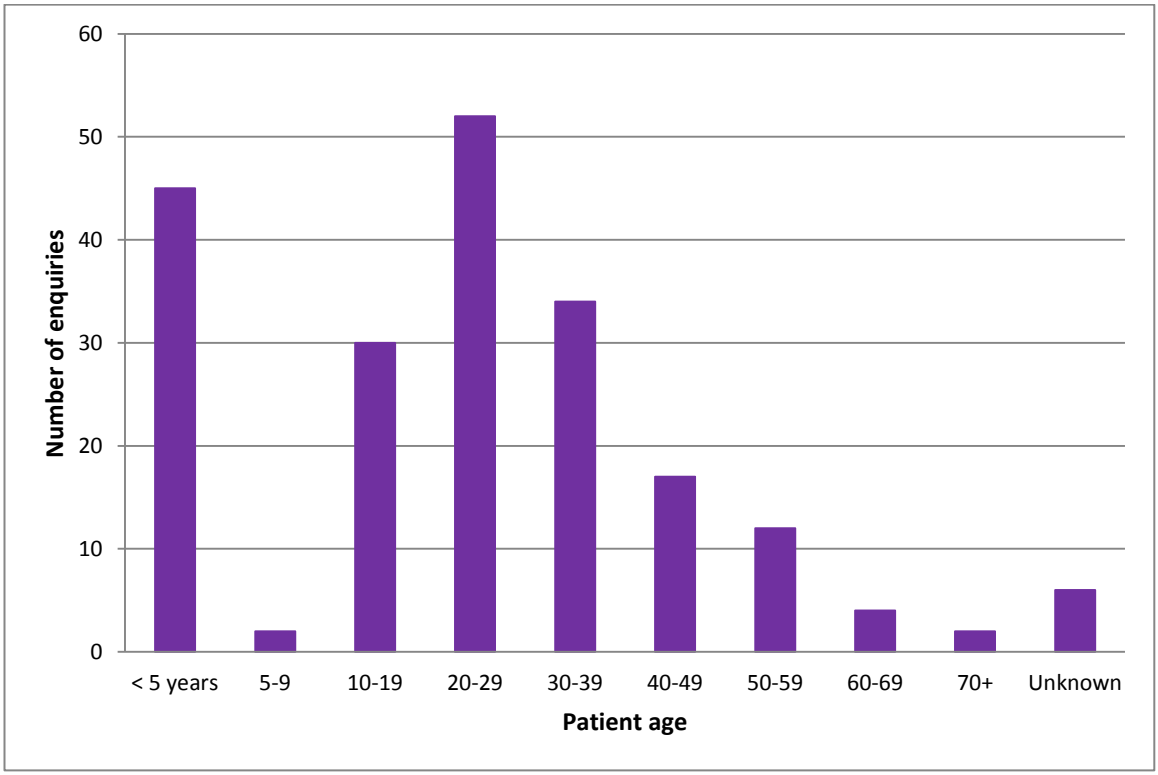
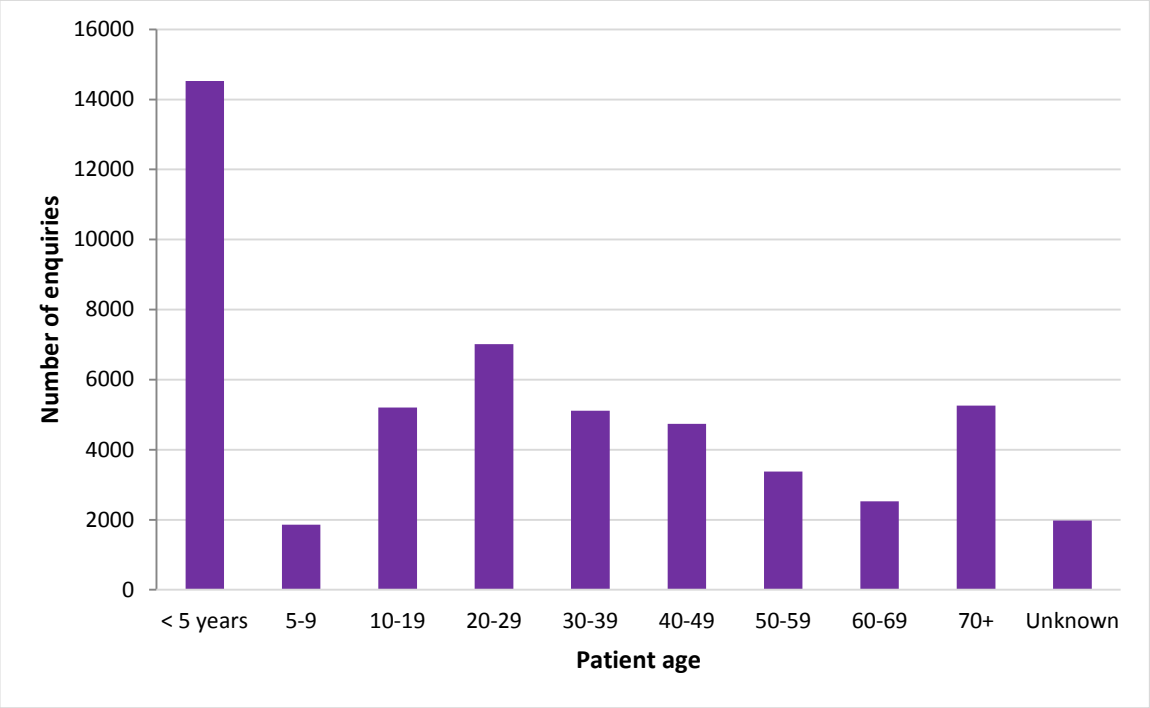


Figure 22: Age of poisoned patients overall reported in telephone enquiries to NPIS 2013/4



Exposures to poisonous liquid among children are of concern; however they should be taken in context. The same report from the NPIS recorded 208 exposures to liquid in reed diffusers, 1,168 exposures to pesticides and more than 600 to paracetamol. E-liquids seem to contribute towards domestic poisoning incidents but regulations, such as child safety caps, could limit this risk.

The clinical outcomes of exposures to e-liquids, as detailed in the NPIS report, were predominantly either ‘no toxicity’ or ‘mild toxicity’. There were two reported cases of ‘moderate toxicity’ and one ‘severe’ case that required treatment in an intensive care unit. Toxicity symptoms included conjunctivitis, irritation of the oral cavity, anxiety, vomiting, hyperventilation and changes in heart rate.

Fire

A number of news articles report the risk of fire and explosions from EC [147, 149, 152]. These reports suggest that faulty or incompatible chargers are the main causes of EC related fires along with faults relating to lithium batteries [152]. In order to assess the risks of fire we used the two data sources below:

1) In 2014, the BBC made Freedom of Information requests to UK fire services [153] and reported that there were 43 recorded call outs for fires related to EC in 2013 and 62 between 1 January 2014 and 15 November 2014. They added that call outs to EC related fires were rising in frequency. This report was based on responses from 43 out of 46 fire services in the UK [153, 154]

2) The official reporting statistics for the UK [155] do not specifically report EC as a cause of fire. There were 2,360 accidental fires between April 2013 and March 2014 where the source of ignition was “smokers’ materials” causing 80 fatalities and 673 non-fatal casualties. Additionally, there were 3,700 fires from faulty appliances and electrical leads causing 19 fatalities and 820 non-fatal casualties. It is not clear what proportion of these were caused by EC.

Regulations covering chargers and quality standards of production could help reduce the risk of fire and explosion in EC. An unpublished Department for Business, Innovation and Skills (BIS) funded market surveillance exercise in 2013/14 found that six out of 17 EC had no instructions for charging, and that eight out of 17 EC did not have a charging cut-off device and therefore did not meet the requirements of BS EN 62133:2013 'Safety requirements for portable sealed secondary cells and batteries for use in portable devices'[4]. It seems likely that the risk of fire and electrical fault is similar to other domestic electrical products, indicating that EC should be subject to the same guidelines and safety mechanisms.

Summary of findings

There is a risk of fire from the electrical elements of EC and a risk of poisoning from ingestion of e-liquids. These risks appear to be comparable to similar electrical goods and potentially poisonous household substances.

Policy implications

- The risks from fire or poisoning could be controlled through standard regulations for similar types of products, such as childproof containers (contained within the TPD but which are now emerging as an industry standard) and instructions about the importance of using the correct charger.
- Current products should comply with current British Standard operating standards.
- Records of EC incidents could be systematically recorded by fire services.

[4] BIS Funded Market Surveillance Exercise 2013/14. The Electrical Safety of Electronic Cigarettes and the Labelling of E-liquids. Lancashire County Council. Unpublished report.

12. International perspectives

Overview

Internationally, countries have taken a wide variety of approaches to regulating EC [156]. Current approaches range from complete bans on the sale of any EC, to applying existing laws on other products to EC (poison, nicotine, and/or tobacco laws), to allowing EC to be sold under general consumer product regulations. Similarly, within countries, different laws have also been applied at the state/provincial level, along with municipal by-laws, extending into areas including taxes on EC, and bans on use in places where smoking is banned. Furthermore, several nuances in laws exist, making it difficult to make broad statements about the regulations in a given country. This section focuses on presenting (1) studies that have compared the use of EC internationally across countries using representative samples and comparable methods, (2) a brief review of adolescent surveys internationally, and (3) the cases of Australia and Canada, two countries that have very similar tobacco control policies to the UK but very different policies relating to EC.

Use of e-cigarettes among adults internationally

Three studies have compared the use of EC internationally: (1) International Tobacco Control Project (described in the Methodology section), (2) Eurobarometer study and (3) Global Adult Tobacco Survey.

The International Tobacco Control Project compared EC use (use defined as less than monthly or more often) among smokers and ex-smokers across 10 countries [157]. Gravely et al., 2014 found significant variability in use across countries, but data were gathered across different years. Gravely et al., 2014 concluded that the study provided evidence of the rapid progression of EC use globally, and that variability was due partly to the year the survey was conducted, but also market factors, including different regulations on EC. Notably, EC use was highest in Malaysia at 14%, where a ban on EC was in place.

Two studies using secondary data from the 2012 Eurobarometer 385 survey have examined EC use. Vardavas, et al., 2014 [158] examined ever use (tried once or twice) of EC among smokers, ex-smokers and never smokers aged 15 years and over across 27 EU countries. The study found wide variation in ever EC use among smokers and non-smokers, with ever use varying from 20.3% among smokers, 4.4% among ex-smokers, and 1.1% among never smokers. Of those who had tried, 69.9% reported using EC once or twice, and 21.1% and 9% reported ever using or currently using occasionally or regularly (use or used regularly or occasionally). It is important to note that the question asked about ever using or currently using occasionally or regularly,

and thus would overestimate actual current use. Overall, being a smoker was the strongest predictor of ever using an EC, younger age was also predictive. Respondents who were uncertain about the harmfulness of EC were less likely to have tried an EC. Among current smokers, those who had a made a quit attempt in the past year were most likely to have ever used EC, along with heavier smokers. With regards to use as a smoking cessation aid, 7.1% of smokers who had ever made a quit attempt reported having used EC, compared to 65.7% who used no help, 22.5% who used nicotine replacement therapy, and 7.3% who received behavioural counselling. Geographical differences in EC use noted by the authors included higher ever use in Northern and Eastern Europe compared to Western Europe. The study did not go into detail on occasional or regular users of EC because the numbers were too low for any detailed analyses.

A 2012 study using the same Eurobarometer 385 survey data gave further detail on ever having used or currently using EC occasionally or regularly among smokers and non-smokers [63]. The study found that regular/occasional use was highest in Denmark at 4.2% and lowest in Lithuania and Portugal at 0.6%, and 2.5% in the UK [63].

The Global Adult Tobacco Survey [159] published findings on EC use in Indonesia (2011), Malaysia (2011), Qatar (2013) and Greece (2013) among smokers and non-smokers, the first countries with available data. Of those respondents who were aware of EC, they asked, “Do you currently use e-cigarettes on a daily basis, less than daily, or not at all?” and considered those who said they used ‘less than daily’ or ‘daily’ to be current EC users.

Overall, awareness of EC was highest in Greece (88.5%), followed by Qatar (49%), Malaysia (21%), and Indonesia (10.9%). Use of EC among smokers was highest in Malaysia (10.4%), followed by Qatar (7.6%), Indonesia (4.2%) and Greece (3.4%). Use of EC among non-smokers was highest in Greece (1.3%), followed by the other three countries, Malaysia (0.4%), Indonesia (0.4%) and Qatar (0.4%). Similar to findings from the ITC Project, these numbers are likely influenced by timing of the survey, due to the rapid progression of use of EC globally, and other market factors. Together with the findings from Gravely et al., 2014 [157] they show the rapid global progression of EC use across both high income and lower middle income countries.

Use of e-cigarettes among youth internationally

Whilst there are very few international or European studies which use consistent methodology, there is a rapidly growing body of research on the prevalence of EC use in young people at the country level, as well as reviews in this area [eg [160]]. However, much of this literature on EC use among adolescents is incomparable because of inconsistent measurements of use (confusing ever use, trial, current use), and different age ranges involved. In addition, many of the studies have been poorly reported. For

example, much has been made of the increase in EC observed in the US using the cross-sectional Centers for Disease Control & Prevention (CDC) National Youth Tobacco Surveys [161-163].These reports and press coverage have been heavily criticised [164-166]. The most important feature of the NYTS data was the fall in smoking prevalence over the same period (as observed in the UK, France [167] and elsewhere).

The CDC findings indicated that past 30-day use of EC increased among middle and high school students. For example, the 2014 data indicated that among high school students use increased from 4.5% to 13.4% between 2013 and 2014. Among middle school students, current EC use increased from 1.1% in 2013 to 3.9% in 2014. However, cigarette smoking had continued to decline during this period (high school students: 15.8% to 9.2%; middle school students: 4.7 % to 2.5%) such that smoking was at a 22-year low in the US. These findings strongly suggest that EC use is not encouraging uptake of cigarette smoking.

Whilst most of the recent studies examining youth EC use emanated from North America, the common pattern emerging worldwide is of a very high awareness of EC and an increase in trial of these products among young people [168-178]. Nevertheless, estimates of prevalence of current use of EC vary widely with the highest being reported in Poland at around 30% [174] and Hawaii (29% tried, 18% current) [178]. Most other estimates indicate that a very small minority of youth, less than 3%, currently or recently used EC. Whilst EC experimentation is increasing, regular or current use of EC appears to be largely concentrated in those already smoking conventional cigarettes. The most recent Europe-wide data indicated that 1.1% of never-smokers aged 15 and above had ever tried an EC [158]. Yet little research has focused on how EC are being used among young people, with limited qualitative research studies in this area [179, 180]. Other findings relate to the influence of parents who smoke on EC experimentation in youth [eg [170] and associations between EC experimentation and other substance use [eg [170, 181]. Several studies have also found an association between EC use and openness to cigarette smoking [eg [182] or intentions to smoke cigarettes [eg [168].

The cases of Australia and Canada

Australia has applied existing laws on poisons, therapeutic goods, and tobacco products to EC. Very broadly speaking, the current laws in Australia have resulted in a ban on the sale and importation of EC with nicotine (although there is a mechanism for legal import as an unapproved medicine with a doctor’s prescription). There are no national level prevalence data on EC use in Australia available at this time. One study comparing trends in awareness, trial, and use of EC among nationally representative samples of smokers and ex-smokers (use defined as less than monthly or more often) in Australia and the UK in 2010 and 2013 found reported EC use in Australia in 2013 at 6.6% and use in the UK at 18.8% [183]. Although the use of EC was found to be

significantly lower in Australia than in the UK in 2013, the use of EC increased at the same rate in Australia and the UK between 2010 and 2013 [183].

Canada took a similar approach to regulating EC as Australia by prohibiting the sale of EC with nicotine through existing laws. However, a recent House of Commons report stated that the current regulatory approach was not working to restrict access to EC with nicotine [184]. Canada has now put forward recommendations to develop a new legislative framework for EC that would most likely allow the sale of EC with nicotine [184]. There has been only one population-level survey of EC use in Canada. The 2013 Canadian Tobacco, Alcohol and Drugs Survey (CTADS) of Canadians 15 years and older found that 9% had ever tried an EC, with trial being higher among young people aged 15–19 years at 20% [185]. Use in the past 30 days was lower at 2%, with past 30 day use being higher among young people aged 15–19 years at 3%. Of those who tried an EC, 55% stated the EC did not contain nicotine, while 26% reported it did contain nicotine, with 19% reporting uncertainty. Whether the EC they tried contained nicotine is uncertain given (1) the ban on the sale of EC with nicotine, and (2) reports that many EC sold and bought in Canada are labelled as not containing nicotine but actually contain nicotine [184]. Although it is difficult to make comparisons due to different survey methods and questions, the percentage of young people (15–19 years) who have tried EC in Canada (20%) is roughly similar to the percentage who have tried EC in GB in 2014 (reported at 8%, 15%, 18%, and 19%, for ages 15 to 18, respectively).

Summary of findings

Although EC use may be lower in countries with more restrictions, these restrictions have not prevented EC use. Overall, use is highest among current smokers, with low numbers of non-smokers reporting ever use. Current use of EC in other countries is associated with being a smoker or ex-smoker, similar to the findings in the UK. EC use is frequently misreported, with experimentation presented as regular use. Increases in youth EC trial and use are associated with decreases in smoking prevalence in all countries, with the exception of one study from Poland.

Policy implications

- Future research should continue to monitor and evaluate whether different EC policies across countries are related to EC use and to smoking cessation and smoking prevalence.

- Consistent and agreed measures of trial, occasional and regular EC use among youth and adults are urgently needed to aid comparability.

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Declaration of interests

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Dr Hayden McRobbie is a researcher at QMUL and Director of the Dragon Institute for Innovation (New Zealand), which has no links with any tobacco or e-cigarette manufacturers. He contributed to educational sessions sponsored by Pfizer and Johnson & Johnson, manufacturers of stop-smoking medications, and received investigator-led research funding from Pfizer. He was an investigator on a study of e-cigarettes (EC) produced by Ruyan Group, Beijing and Hong Kong. Ruyan sponsored Health New Zealand Ltd. who provided funding to the University of Auckland to conduct the trial, independently of Ruyan. He was also an investigator on an EC trial funded by the Health Research Council of New Zealand that used EC supplied at no charge by PGM international, a retailer of EC.

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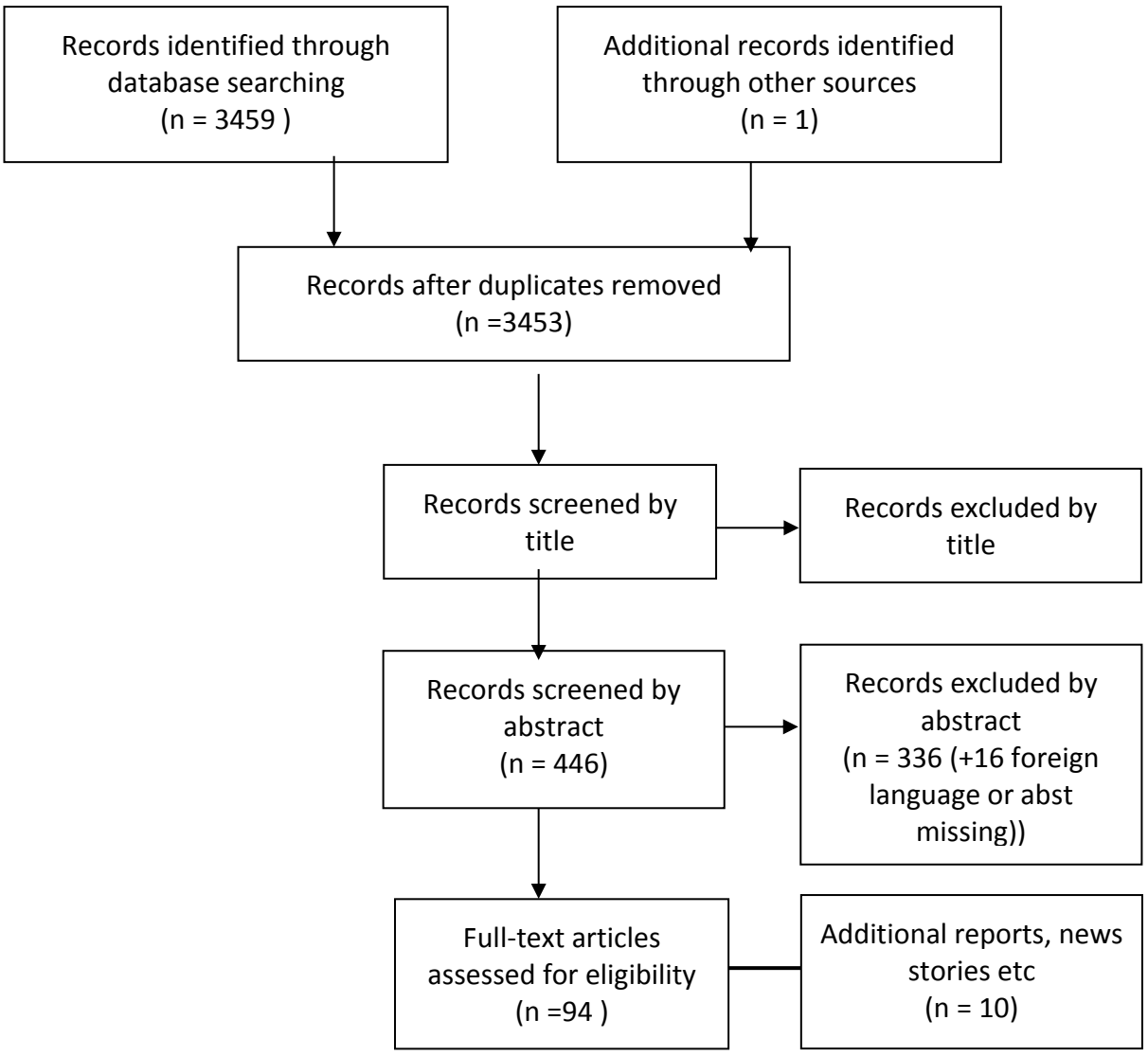
Appendices

APPENDIX A: PRISM Flow Diagram[5]



[5] Please note that we did not carry out a full systematic review for this report but followed systematic review methods. We assessed 94 papers and 9 additional reports included those that were relevant to our objective of describing the **use** of e-cigarettes and how they **impact smoking behaviour,** with a particular focus on the UK.

APPENDIX B: Measures of e-cigarette use

Measures of EC use in studies referenced, in most cases respondents were only asked about EC use if they first answered yes to ever trying an EC/had heard of EC.

Surveys

These questions in all surveys below may have been slightly altered from year to year as the EC market evolved and awareness grew.

Smoking Toolkit Study (STS)

The following four questions are used to assess current use of e-cigarettes: (if already responded they are cutting down)

Q632e37. Which, if any, of the following are you currently using to help you cut down the amount you smoke?
Nicotine gum
Nicotine replacement lozenges\tablets
Nicotine replacement inhaler
Nicotine replacement nasal spray
Nicotine patch
Electronic cigarette
Nicotine mouthspray
Other (specify)

Q632e1. Do you regularly use any of the following in situations when you are not allowed to smoke?
Nicotine gum
Nicotine lozenge
Nicotine patch
Nicotine inhaler\inhalator
Another nicotine product
Electronic cigarette
Nicotine mouthspray
Other (specify)

NEWW53a. Can I check, are you using any of the following either to help you stop smoking, to help you cut down or for any other reason at all?

Nicotine gum
Nicotine lozenge

Nicotine patch
Nicotine inhaler\inhalator
Another nicotine product
Electronic cigarette
Nicotine mouthspray
Other (specify)

QIMW86_1. Can I check, are you using any of the following?
PROBE FULLY: Which others? PROBE UNTIL RESPONDENT SAYS 'NO OTHERS'
PLEASE TYPE IN OTHER ANSWERS CAREFULLY AND USE CAPITAL LETTERS
Nicotine gum
Nicotine lozenge
Nicotine patch
Nicotine inhaler\inhalator
Another nicotine product
Electronic cigarette
Nicotine mouthspray
Other (specify)

ASH Smokefree GB adult survey

Which of the following statements BEST applies to you?

- I have heard of e-cigarettes and have never tried them
- I have heard of e-cigarettes but have never tried them
- I have tried e-cigarettes but do not use them (anymore)
- I have tried e-cigarettes and still use them
- Don't know

The fourth option constitutes 'current use'

ASH Smokefree GB youth survey

An e-cigarette is a tube that looks like a normal cigarette, has a glowing tip and puffs a vaour that looks like smoke but unlike normal cigarettes, they don't burn tobacco.
Have you ever heard of e-cigarettes?

- Yes, I have
- No, I haven't

All those who have heard of e-cigarettes: Which one of the following is closest to describing your experience of e-cigarettes?

- I have never used them
- I have tried them once or twice
- I use them sometimes (more than once a month)

- I use them often (more than once a week)
- Don't want to say

Internet cohort survey

Have you ever heard of electronic cigarettes or e-cigarettes? These are electronic devices that contain nicotine in a vapour and are designed to look like cigarettes, but contain no tobacco.
Yes/No/Don't know

If Yes, Have you ever tried an electronic cigarettes?
Yes/No/Don't know

If Yes, How often if at all, do you currently use an electronic cigarette? (PLEASE SELECT ONE OPTION)

1. Daily
2. Less than daily, but at least once a week
3. Less than weekly, but at least once a month
4. Less than monthly
5. Not at all
6. Don't know

Other studies

Amrock et al., 2015 (US)

Which of the following tobacco products have you ever tried, even just one time?" to which they could select, "electronic cigarettes or e-cigarettes, such as Ruyan or NJOY" alongside other tobacco products. A related question asked if students used e-cigarettes on at least one of the past 30 days.

Biener & Hargraves, 2014 (US)

At baseline, three questions were asked about e-cigarettes: whether the respondent had "ever heard of electronic cigarettes, also known as e-cigarettes"; if so, whether he/she had ever used an e-cigarette even one time, and if so, on how many of the past 30 days the respondent had used an e-cigarette. To assess how intensively and for how long the respondent had used e-cigarettes during the period between interviews, the follow-up interviews included questions to describe e-cigarette usage. Those who were not aware of e-cigarettes at baseline were asked if they had heard of them at follow-up. Those who had not tried e-cigarettes at baseline were asked if they had done so by follow-up. All respondents who reported ever trying them by follow-up were asked

whether they currently used e-cigarettes every day, some days or not at all. If not at all, they were asked if they ever used e-cigarettes “fairly regularly.” If not, whether they had used only once or twice or more often than that. All who had used more than once or twice, were asked a series of questions about their patterns of use: for how long they had used e-cigarettes (less than a month, 1–6 months, more than 6 months); whether they had ever used e-cigarettes daily for at least one week; if so for how long they had used e-cigarettes daily. From these variables, a 3-level measure of intensity of e-cigarette usage was computed: 3 = intensive (used daily for at least 1 month); 2 = intermittent (more than once or twice but not daily for a month or more); 1 = non-use or at most once or twice.

Borderud et al., 2014 (US)

Patients were asked if they had used E-cigarettes within the past 30 days, with the response options being yes or no.

Brose et al, 2015 and Hitchman et al., 2015 (GB)

How often, if at all, do you currently use an electronic cigarette? [Asked of respondents who had ever heard of e-cigarettes and had ever tried one.]

1. Daily
2. Less than daily, but at least once a week
3. Less than weekly, but at least once a month
4. Less than monthly
5. Not at all
6. Don't know

What electronic cigarette equipment do you currently use the most?

1. A disposable electronic cigarette (non-rechargeable)
2. A commercial electronic cigarette kit which is refillable with pre-filled cartridges
3. A commercial electronic cigarette kit which is refillable with liquids
4. A modular system (I use my own combination of separate devices: batteries, atomizers, etc.)
5. Don’t know

Brown et al., 2014 (England)

Which, if any, of the following did you try to help you stop smoking during the most recent serious quit attempt?

1. E-cigarettes
2. NRT bought over-the-counter
3. No aid

Canadian Tobacco, Alcohol and Drugs Survey 2013 (CTADS)

Trial

Have you ever tried an electronic cigarette, also known as an e-cigarette?

1. Yes
2. No
3. Refused
4. Don't know

Last 30 day use

In the past 30 days did you use an electronic cigarette, also known as an e-cigarette?

1. Yes
2. No
3. Refused
4. Don't know

CDC/NYTS and Dutra and Glantz

During the past 30 days, on how many days did you use electronic cigarettes or e-cigarettes such as Blu, 21st Century Smoke, or NJOY?

Gravely et al., 2014 (Republic of Korea, US, UK, Canada, Australia, and Malaysia); Yong et al., 2014 (UK and Australia)

How often, if at all, do you currently use an electronic cigarette? (dichotomised into current use and non-current by combining any use responses vs. not at all)

1. Daily, Less than daily but at least once a week
2. Less than weekly but at least once a month
3. Less than monthly
4. Not at all

Gravely et al., 2014 (Netherlands)

How often do you currently use an electronic cigarette? (dichotomised into current use and non-current by combining any use responses vs. have you stopped altogether)

1. Daily
2. Less than daily, but at least once a week
3. Less than weekly, but at least once a month
4. Less than monthly versus, or
5. Have you stopped altogether?

Gravely et al., 2014 (China)

Are you currently using an electronic cigarette at least weekly? (Yes vs. No)

1. Yes
2. No

Hughes et al., 2014 (Trading Standards NW Study)

"Have you ever bought or tried electronic cigarettes?"

Hummel et al., 2014 (Netherlands)

Respondents who had ever tried e-cigarettes were asked how often they currently used an e-cigarette (daily, at least once a week, at least once a month, less than monthly, or stopped altogether

Lee et al., 2014 (US)

E-cigarette use questions were:

Have you ever used e-cigarettes?

1. yes
2. no

Have you used e-cigarettes in the past 30 days?

1. yes
2. no

Moore et al., 2014 (Welsh study 10-11 year olds)

"Have you heard of e-cigarettes before this survey?"
'Have you ever used an e-cigarette? with response options of 'no', 'yes, once' or' yes, more than once'

Moore et al., 2015 (Welsh study HBSC)

Asked whether they had ever used an e-cigarette with response options of:

- I have never used or tried e-cigarettes
- I have used e-cigarettes on a few occasions (1-5 times);
- I regularly use e-cigarettes (at least once a month)'.

Palipudi et al., 2015 (Global Adult Tobacco Survey)

“Do you currently use e-cigarettes on a
1. Daily basis,
2. Less than daily,
3. Or, not at all?”

Pearson et al., 2014 (US)

Participants were asked which methods they had used to quit in the past 3 months and were presented a list of common quit methods. Participants were considered e-cigarette users if they selected “e-cigarettes” in response to this question or if they entered terms like “vapors,” “vaping,” “vape,” or “ecigs” in the “other quit methods” open-ended response option.

Pepper et al., 2014 (US)

Have you ever used an e-cigarette, even one puff?
Do you now use e-cigarettes every day, some days, or not at all?

Richardson et al., 2014 (US)

Please indicate whether you have ever heard of these products, if you have ever tried them and if you have ever purchased them. Products included ENDS; dissolvables; chew, dip, or snuff (assessed in 1 question); and snus, each presented with brand names to increase validity of responses. Respondents could choose multiple options from the following choices: (1) heard of; (2) tried; (3) purchased; (4) never heard of, tried, or purchased (for those to whom options 1, 2, and 3 were not applicable); (5) refused; and (6) don’t know.

Rutten et al., 2014 (US)

Do you now use e-cigarettes (eg BluCig, NJoy, V2, Red Dragon, etc)? [Picture of three different e-cigarettes included]
1. Every day
2. Some days
3. Not at all

Schmidt et al., 2014 (US)

Have you ever used an electronic cigarette, even just one time in your entire life?
Do you now use electronic cigarettes every day, some days, rarely, or not at all?

Vardavas et al., 2014 (Eurobarometer 27 countries), dichotomised into regularly, occasionally, tried once or twice vs. otherwise; Agaku et al., 2014 (Eurobarometer, 25 countries), dichotomised into regularly or occasionally vs. otherwise;

Have you ever tried any of the following products? (Electronic cigarettes)

1. Yes, you use or used it regularly.
2. Yes, you use or used it occasionally.
3. Yes, you tried it once or twice.
4. No.
5. Don’t Know.

White et al., 2015, New Zealand national youth tobacco use survey in 2012 and 2014

Ever use: Have you ever tried electronic cigarettes?

Appendix C: Narrative summary of studies on nicotine delivery from e-cigarettes

Early studies

Two studies, both published in 2010, examined nicotine delivery from cigalike EC.

Bullen et al., 2010 used a cross-over design to compare nicotine delivery of a 16mg/ml Ruyan V8 EC with a 0mg/ml EC, a nicotine inhalator (10mg) and a conventional cigarette among 8 smokers who abstained from smoking overnight [43]. Participants puffed on their cigarettes and EC ad libitum over 5 minutes, and on the inhalator over 20 minutes. The nicotine containing EC had similar pharmacokinetic parameters to the inhalator (Cmax: 1.3 vs. 2.1 ng/ml; Tmax: 19.6 vs. 32.0 mins), and both were out-performed by a conventional cigarette (Cmax 13.4 ng/ml; Tmax 14.3 mins).

Vansickel et al., 2010 also used a cross-over design and tested nicotine delivery of two EC (NJOY EC (18mg) and Crown 7 EC (16mg) and participants own brand cigarette[118]. Participants abstained overnight and then took 10 puffs on the EC with a 30 sec inter-puff interval. Only the conventional cigarette produced a significant rise in plasma nicotine, from baseline 2.1 ng/ml (SD 0.32) to a peak at 5 minutes 18.8 ng/ml (SD 11.8).

The poor nicotine delivery of these EC was likely to be due to several factors. The EC tested were some of the first to market. The EC used in the Bullen 2010 study were noted to leak and the vaporising component did not always function. Both of these early studies recruited EC naïve smokers, without opportunity to practice using the EC prior to experimentation.

There are other factors that are associated with nicotine delivery, which we have summarised below.

1) More intensive vaping regimens
Vansickel et al., examined nicotine delivery associated with the use of Vapor King (cigalike EC with 18mg/ml nicotine) in 20 smokers naïve to EC [119]. After overnight abstinence, participants used the EC for 5 minutes on a total of six occasions (10 puffs, 30 sec inter-puff interval) 30 minutes apart. A significant increase in plasma nicotine was observed after the fourth bout of puffing, and mean blood nicotine levels had increased from 2.2 ng/ml (SD 0.78) at baseline to 7.4 ng/ml (SD 5.1) at the end of the last bout of puffing.

2) Experience with EC
Vansickel & Eissenberg (2012) report nicotine pharmacokinetics in eight vapers who had been using EC for average of 11.5 (SD 5.2) months [7]. They used their own EC and e-liquid (the majority used an e-liquid with a concentration of 18 mg/ml).

Participants attended the laboratory after overnight abstinence and used their EC under a standardised vaping regimen (10 puffs with a 30 second inter-puff interval) and then a 60 minutes period of *ad lib* vaping. The PK analyses showed a significant increase in plasma nicotine from baseline 2.0 ng/ml to 0.3 ng/ml within five minutes of the first puff. At the end of the ad-lib vaping period the maximum plasma nicotine concentration was 16.3 ng/ml.

Dawkins and Corcoran (2014) examined nicotine delivery associated with the used of the Skycig 18 mg Crown tobacco bold cartridges in 14 vapers, who had been vaping for almost 5 months on average[6]. Using a similar methodology to Vansickel & Eissenberg (2012), the analysis of plasma nicotine from the seven participants that provided a full blood set, showed that levels had increased from 0.74 to 6.77 ng/ml in 10 minutes. However there was individual variation (2.5 ng/ml to 13.4 ng/ml). After an hour of *ad lib* use the maximum nicotine concentration reached was 13.91 ng/ml, again with a wide range of levels observed between individuals (4.35-25.6 ng/ml).

Spindle et al., 2015 studied 13 experienced EC users (> 3 months, with the majority 9/13 using e-liquid strength of 24mg/ml and all using tank systems)[120]. Taking 10 puffs over 5 minutes resulted in an increase in mean blood nicotine levels from 2.4 ng/ml baseline to 19.2 ng/ml at 5 minutes.

Practice in EC use also results in a modest increase in blood nicotine levels. Hajek et al., 2014 tested Greensmoke EC (a cigalike EC with 2.4% nicotine) in 40 smokers, naïve to EC[115]. Participants abstained from any nicotine use overnight and after a baseline blood sample was collected used the EC, *ad lib*, for 5 minutes. This procedure was undertaken twice, on first use and then again after 4 weeks of use. The maximum plasma concentrations increased from 4.6 ng/ml (range 0.9-9.0) to 5.7 ng/ml (range 1.9-11.0), although this increase was not significant. The area under the curve (AUC), however, did show a significant increase, from 96 (range 12-198) to 142 (range 56-234). The time to maximum plasma concentration (5 minutes) did not change.

Nides et al., 2014 provided EC to participants (29 smokers, mean cigarette consumption of 20 cpd, and of 55% of whom had used EC in past) but also allowed them to practice using the EC (NJOY®King Bold, a cigalike EC, with 26mg nicotine) for a week prior to undertaking a PK analysis [116]. Participants (who abstained from all nicotine products for at least 12 hours) then were asked to use EC (10 puffs with a 30 second inter-puff interval) on two occasions 60 minutes apart. Pharmacokinetic (PK) analyses were undertaken in 16 participants who had no detectable plasma nicotine at baseline. The mean rise in blood nicotine was 3.5 ng/ml (range 0.8-8.5 ng/ml) at 5 minutes after the first round of puffing and 5.1 ng/ml (range 1.1 – 7.1 ng/ml) at 10 minutes after the second.

3) Nicotine concentration and chemical composition of e-liquid

Yan & D'Ruiz (2014) examined nicotine delivery from Blu cigalike EC with differing levels of nicotine (2.4% and 1.6%), glycerin/propylene glycol (75% glycerin and 50% glycerin/20% propylene glycol), and flavours (classic tobacco and menthol)[129]. Participants (23 smokers) were randomized to 5 different EC conditions and smoking a regular cigarette in a cross over design. They were given 7 days to familiarize with EC use, and then abstain from all nicotine products for 36 hours prior to test days. On test days participants were asked to take 50 x 5 second puffs on EC at 30 sec intervals (in the cigarette arm they smoked 1 cigarette with usual puff duration at 30 sec intervals). After the controlled puffing testing ppts were allowed 60 minutes of *ad lib* use.

Peak plasma nicotine concentrations were reached sooner for cigarettes (5 minutes) than for EC (30 minutes). During the 30 minutes controlled puffing phase, within EC conditions the highest Cmax was seen with the 2.4% nicotine, 50% glycerin/20% PG (18.09 ng/ml, SD=6.47 ng/ml). The lowest Cmax was observed in the 1.6% nicotine, 75% glycerine (10.34 ng/ml SD=3.70 ng/ml). The Cmax associated with smoking one conventional cigarette was 15.84 ng/ml (SD = 8.64 ng/ml). At the end of the *ad lib* period, the highest Cmax was seen with the conventional cigarette (29.23 ng/ml SD = 10.86 ng/ml), followed by the 2.4% nicotine, 50% glycerin/20% PG EC (22.42 ng/ml; SD = 7.65ng/ml). The glycerine/PG mix resulted in better nicotine delivery than the 75% glycerine solution, which was confirmed in the bench top tests that measured nicotine content in vapour using the Canadian Intense regimen. The high nicotine content in vapour is a likely consequence of the lower boiling point of PG (187.6 degrees Celsius) compared with glycerine (290 degrees Celsius).

4) Type of EC device

Although many vapers start off with using a cigalike EC experienced vapers are more likely to be using tank systems or variable power EC. One of the reasons for this observation is that the tank systems and variable power ECs deliver nicotine more nicotine to the user.

Farsalinos et al., (2014) examined plasma nicotine levels in experienced vapers (n=23) who used a cigalike (V2 with cartomiser) and a new generation (EVIC set at 9 watts with EVOD atomizer) EC with standardized flavour and nicotine concentration (18mg/ml) in a cross-over design[129]. Participants' abstained from EC use for at least 8 hours before completing a bout of 10 puffs over 5 minutes followed by one hour of *ad lib* use. Use of the cigalike EC was associated with an increase in blood nicotine from 2.80 ng/ml at baseline, to 4.87 ng/ml at 5 minutes and 15.75 ng/ml at the end of ad lib use. Significantly greater increases were observed with use of the new generation EC from 2.46 ng/ml to 6.59 ng/ml to 23.47 ng/ml at baseline, 5 minutes and at the end of the *ad lib* period.

Oncken et al., (2015) also examined nicotine delivery in a tank system EC (Joye eGo-C with 18 mg/ml nicotine e-liquid) in 20 smokers who were asked to use an EC for two weeks[123]. Participants were asked to use the EC for 5 minutes ad lib in two laboratory sessions where blood samples were taken for PK analysis. Blood nicotine concentrations increased, significantly, by 4 ng/ml (Cmax 8.2 ng/ml) at the first session and 5.1 ng/ml (Cmax 9.3 ng/ml) at the second session. These levels were reached at five minutes.

Studies that examine cotinine as a measure of nicotine replacement in vapers

We found eight studies that reported on cotinine in urine, blood or saliva as a marker of nicotine exposure in people using EC.

In an RCT of nicotine containing EC versus placebo Caponnetto and colleagues (2013) measured salivary cotinine in participants who had stopped smoking cigarettes, but were still vaping EC (Categoria 7.5mg/ml)[40]. After 12 weeks of use the mean salivary cotinine concentration was 67.8 ng/ml, which is at the lower end of what is typically observed in smokers (eg 66.9-283.7 ng/ml).

In a study that randomised 48 smokers unwilling to quit to one of two tank system EC (18mg/ml nicotine) or to continue to smoke found that at 8 month follow-up mean salivary cotinine did not significantly differ between those who had stopped smoking but were vaping (428.27 ng/ml), achieved a ≥50% reduction in cigarette consumption (356.49 ng/ml) and those who continued to smoke (545.23 ng/ml, SD = 46.32)[41].

Van Staden et al., (2013) examined the change in serum cotinine in 13 smokers who were asked to stop smoking and instead use a Twisp eGo (18mg/ml nicotine) tank system EC for two weeks[113]. There was a significant decrease in cotinine from baseline 287.25 ± 136.05 to two weeks 97.01 ± 80.91 ng/ml suggesting that the EC used did not provide as much nicotine as participants usual cigarettes.

Norton et al., (2014) observed a similar result in 16 abstinent smokers who used a cigalike EC (11 mg/ml) for five days, finding a significant decrease in saliva cotinine between baseline (338.0 ng/ml) and day five (178.4 ng/ml)[112].

Flouris et al., (2013) measured serum cotinine in 15 smokers, who had abstained overnight, after smoking two of their usual cigarettes over 30 minutes and after 30 minutes of vaping a cigalike EC (Giant, 11mg/ml)[130]. EC and cigarettes produced similar effects on serum cotinine levels (60.6 ± 34.3 versus 61.3 ± 36.6 ng/ml). However measurement of cotinine would not give an accurate indicator of exposure in an acute study such as this.

Experienced vapers, using their own devices, however obtain much better nicotine substitution. Etter and Bullen (2011) measured salivary cotinine concentrations in 30 vapers who had been using EC for approximately 3 months on average and no longer smoking[9]. The mean nicotine content of e-liquid was 18mg/ml. Mean salivary cotinine was found to be 322 ng/ml indicating a high level of nicotine replacement via EC.

Similarly Etter (2014) found mean cotinine levels of 374 ng/ml (95% CI: 318-429) in 62 vapers who had not used any other nicotine containing products in the last 5 days [8].

Hecht et al., 2014 measured nicotine and cotinine in urine of 28 EC users (median use of 9 months, using tank system EC with e-liquid containing, on average 12.5 ± 7.0 mg/ml)[111]. Nicotine and cotinine levels in urine were 869 ng/ml (95% CI: 604-1250) and 1880 ng/ml (95% CI: 1420-2480) respectively, although these levels are lower than what are typically observed in smokers (eg nicotine 1380 ng/ml 95% CI: 1190-1600 and cotinine 3930 ng/ml; 95% CI: 3500-4400).

UK: Bristol mobilizes to convert smokers to vaping

This week in the UK, for the National Stop Smoking Day, the municipality of Bristol goes to the street to meet the smokers in the hope of converting them to vaping.

*By **Ghyslain Armand** - March 10, 2016*

Actions in specialty shops

The Municipal Council of Bristol, UK, recommends using the vaporizer as an alternative to tobacco and will meet smokers in the street, this week, with the intention of converting them to this alternative to tobacco.

For the National Stop Smoking Day, municipal teams will visit four electronic cigarette shops located in the city center to offer carbon monoxide test and show how levels in the body differ between smokers and vapers.

Try all available methods

Interviewed by Bristol Post, HI France Councillor, a former smoker, recognizes “how difficult it can be to quit smoking”. He “encourages smokers who are trying to wean to try all methods”. The municipality wants to advise the long-term smokers with this public health message: “Electronic cigarettes are a better option than tobacco. [...] There is no better time than today to stop.”

Marcus Munafo, professor at the University of Bristol, shares the same opinion and regrets that “many people do not realize that the vaporizer is less dangerous than conventional cigarettes”.

In Bristol, where Imperial Brands has its headquarters, the prevalence of smoking is 21.3%. According to the Bristol Post, smokers have the opportunity to triple their chances of withdrawal by using an electronic cigarette while following the recommendations of local support center for smoking cessation.

Several myths associated with the e-cigarette should further be undermined, develops the newspaper. First **misconception** is the **renormalization of the act of smoking**. This is false; the prevalence of smoking is decreasing in England. In addition, the electronic cigarette is **not a gateway to smoking** for children, almost all English vapers are former smokers. In addition, **accidents involving electronic cigarettes** are very rare and are usually caused by negligence.

Ghyslain Armand

Currently living in France I am the chief editor of PGVG Magazine. I've been writing about vaping for the past 4 years. I also lead conferences on this topic for international events such as Vapexpo (Paris).