HHS Public Access

Author manuscript

Int J Drug Policy. Author manuscript; available in PMC 2016 June 01.

Published in final edited form as:

Int J Drug Policy. 2015 June ; 26(6): 583–588. doi:10.1016/j.drugpo.2015.01.020.

Nicotine levels in electronic cigarette refill solutions: A comparative analysis of products from the US, Korea, and Poland

Maciej L. Goniewicz[a], **Ribhav Gupta**[a], **Yong Hee Lee**[a], **Skyler Reinhardt**[a], **Sungroul Kim**[b], **Bokyeong Kim**[b], **Leon Kosmider**[c,d], and **Andrzej Sobczak**[d]

[a]Department of Health Behavior, Roswell Park Cancer Institute, Buffalo, New York [b]Department of Environmental Health Sciences, Soonchunhyang University, Asan, South Korea [c]Medical University of Silesia, Sosnowiec, Poland [d]Institute of Occupational and Environmental Health, Sosnowiec, Poland

Abstract

Background—Electronic cigarettes vaporize nicotine dissolved in glycerine and/or propylene glycol (e–liquid). Due to a lack of regulations, e-liquids may contain inaccurately labelled nicotine levels. Our aim was to test nicotine levels in samples of e-liquids from three countries.

Methods—We measured nicotine concentration in 32, 29 and 30 e-liquids purchased between 2013 and 2014 from locations in the United States (US), South Korea, and Poland, respectively.

Results—Nicotine concentration in the US products varied from 0 to 36.6 mg/mL. Traces of nicotine were found in three US products labelled as '*nicotine free*'. Two-thirds of South Korean products did not contain detectable amounts of nicotine, whereas nicotine concentration in other products varied from 6.4±0.7 to 150.3±7.9 (labelled as '*pure nicotine')* mg/mL. In products from Poland, nicotine concentration varied from 0 to 24.7±0.1 mg/mL. Overall, we found significant discrepancies (>20%) in the labelled nicotine concentrations in 19% of analysed e-liquids.

Conclusion—Most of the analysed samples had no significant discrepancies in labelled nicotine concentrations and contained low nicotine levels. However some products labelled as '*nicotine-free*' had detectable levels of the substance, suggesting insufficient manufacturing quality control. We identified a single product labelled as '*pure nicotine*' which contained significantly higher

Corresponding author: Maciej L. Goniewicz, PharmD, PhD, Assistant Professor of Oncology, Department of Health Behavior, Division of Cancer Prevention and Population Science, Roswell Park Cancer Institute, Elm and Carlton Streets, Buffalo, NY 14263, USA. Tel: +1-716-845-8541; Fax: +1-716-845-1265; maciej.goniewicz@roswellpark.org.

Conflict of Interest Statement

MLG reports a grant from Pfizer (2011 Global Research Award for Nicotine Dependence), a manufacturer of smoking cessation drugs, outside the submitted work; AS reports personal fees from eSmoking Institute, Poznan, Poland, and nonfinancial support from Chic Group LTD, a manufacturer of electronic cigarettes in Poland, outside the submitted work. The other authors have nothing to disclose.

concentration of the drug, increasing the risk of accidental poisoning. The study reveals the need for quality standards of these new nicotine containing products.

Keywords

e-cigarettes; electronic cigarettes; nicotine; refill solutions

Introduction

Electronic cigarettes (e-cigarettes, ECs) are emerging nicotine delivery devices which operate in an intricate manner. An atomizer within the device allows the nicotine liquid solution (e-liquid) held in a cartridge or reservoir (tank) to be vaporized. The e-liquid consists of a base, typically made from propylene glycol, glycerine, or a mixture of these two substances. When user puffs on the EC, the heating coil inside the device is manually or automatically activated. The e-liquid, when heated, creates the visible vapour which can be inhaled by the user of the device. In addition to producing a smoke-like effect, the base also serves as a solvent for nicotine.

Due to the wide appeal of ECs, they have begun to evolve into a wide range of products to suit the array of customers. The different models of ECs are commonly classified into three main categories based on their functionality and characteristics. The first generation of ECs was built to resemble tobacco cigarettes and thus these products are commonly referred to as ‘cig-a-likes’. They usually contain low-voltage batteries and replaceable e-liquid cartridges, although some devices are disposable. The second generation of ECs has stronger batteries and a larger reservoir for the nicotine solution (tank systems). The latest generations of the product named ‘mods’ or ‘personal vaporizers’ have even stronger batteries, more effective vaporization system, and are often customized. The second and newest generations of the product typically are refillable with e-liquids.

There are relatively few research reports regarding nicotine delivery from ECs; most of the research is based upon first generation devices. Initially, these products were shown to deliver relatively low doses of nicotine compared to tobacco cigarettes, but current devices, which use concentrated nicotine solutions, may deliver nicotine to blood at levels comparable to those derived from tobacco cigarettes (Bullen et al., 2010; Vansickel Cobb, Weaver, & Eissenberg, 2010; Vansickel & Eissenberg, 2013; Hajek et al., 2014). When the efficiency of newer electronic cigarettes is compared to older models, it was reported that there is a 49% increase in nicotine delivery to the bloodstream of the user (Farsalinos et al., 2014). However, it still remains unclear whether various types and models of ECs effectively deliver nicotine to the lungs or the oral mucosa.

ECs emerged onto the international market as an alternative to the traditional tobacco cigarettes. ECs were initially introduced in China in approximately 2003, and quickly gained popularity, spreading across the globe. By the end of first decade of the twenty-first century, the devices had entered the US, European, and Asian markets. The immediate success of ECs serves as a challenge to the current regulatory structure designed for traditional cigarettes, inherently posing some concerns. The new situation may lead to a re-evaluation of the regulation of all products that contain nicotine, including tobacco (Benowitz &

Goniewicz, 2014; Goniewicz, Hajek, & McRobbie, 2014; Etter, 2014). Another concern is the lack of mandatory manufacturing standards for ECs on regional and national levels. There are many EC and e-liquid manufacturers, largely in China, Europe and the US, but these products are not manufactured along typical standards imposed on drug delivery devices, and there is a variation in quality control (Benowitz & Goniewicz, 2014; Grana, Benowitz, & Glantz, 2014). Therefore, there is no guarantee that the nicotine is of a pure grade, that cartridges are filled according to their label, and that the e-liquids are free of impurities or toxic elements. Other causes of concern may include non-desirable interactions with the packaging material (for example adsorption of nicotine on surfaces inside the bottle, release of chemicals from packaging material into the nicotine solution, or chemical reactions between product ingredients and container material), inadequate handling and storage (Benowitz & Goniewicz, 2014).

Regulations of ECs vary widely across countries, ranging from complete prohibition to unregulated marketing. Manufacturers and distributors of e-liquids are not adequately controlled by the agencies that otherwise control medications and tobacco products, because of the varying policies of each country. This new market has largely developed outside an appropriate regulatory framework, allowing for some manufacturers and vendors to develop, lacking adequate knowledge about product safety (Barboza, 2014). This is particularly concerning when most of these companies do not disclose information regarding their products and manufacturing processes.

In the US, the devices were first popularized by celebrity sponsors and the active advertisement campaign around 2007–2008. The devices were quickly taken under the Food and Drugs Administration's (FDA) jurisdiction as medical devices. However, in 2011 due to the *Sottera Inc. vs. FDA* case (http://www.gpo.gov/fdsys/pkg/USCOURTS-caDC-10-05032), it was ruled that the FDA could not regulate ECs as medical devices unless the devices themselves were marketed for therapeutic purposes. The FDA is poised to deem ECs as a tobacco product, based on the fact that these products contain nicotine derived from tobacco. In doing so, the FDA would be granted the authority to require EC manufacturer registration and disclosure, to regulate product characteristics, and to regulate the industry's marketing. The current regulation of tobacco products by the FDA requires the consideration of both scientific evidence on the risk and benefits posed by the devices to the individual smokers as well as to the population as a whole. Recently, some US-based companies formed the American E-liquid Manufacturing Standards Association (AEMSA), which has developed the guidelines for nicotine labelling in EC products. According to these guidelines nicotine concentration in e-liquids should be within ±10% of the labelled value (American E-liquid Manufacturing Standards Association, 2014).

ECs made their way to South Korea in 2008 and have since been heavily marketed as an alternative to the conventional tobacco cigarette. The authority to regulate the products is split between the Korean Food and Drug Administration (KFDA) and the Ministry of Finance (MoF). The KFDA has the authority to regulate all products sold without nicotine while the MoF regulates all products containing nicotine. Currently, the legislation in South Korea does not restrict the sale or use of the devices; however the Korean government has heavily taxed the sale of the products. Moreover, the open sales of the products, is coupled

with the adolescent-focused advertising. A survey among Korean adolescents conducted in 2011 found that 9.4% have ever used ECs and 4.7% were current EC users with a vast majority of users being tobacco smokers (Lee, Grana, & Glantz; 2014).

In Poland, the consumption of ECs is rising rapidly. It has been estimated that one out of ten Polish have already tried ECs, which in total amounts to about 1.2 million users (Goniewicz et al., 2014a; Prokurat, 2014). Marketing data shows that around 5% percent of ECs bought by Poles comes from local factories, whereas the rest is imported (90% from China) (Prokurat, 2014). Since 2010 there has been a dynamic growth of the ECs distribution network with kiosks and stands appearing across the country. Current Polish laws do not yet regulate the ways in which ECs can be sold and used, thus studies have shown an increasing popularity of the devices amongst the Polish youth (Goniewicz & Zielinska-Danch, 2012; Goniewicz et al., 2014b). Even though Polish laws do not regulate this sector, recently, the European Parliament voted to regulate ECs and refill solutions under the Tobacco Product Directive unless they are produced as medicinal devices (European Parliament and the Council; 2014). Beginning in mid-2016, advertising for ECs will be banned in the 28 nations of the European Union, including Poland, which currently serves as the status quo for conventional tobacco products. Containers must be childproof. Lastly, the concentration of nicotine will be limited to 20 mg/ml (European Parliament and the Council; 2014).

The purpose of this international study was to measure nicotine concentration in a sample of popular nicotine refill solutions from three countries: US, South Korea, and Poland. We estimated the accuracy of labelled nicotine concentrations of analysed e-liquids by comparing detected amounts with amounts declared on product packaging.

Materials and Methods

Products

This study examined popular brands of e-liquids available in the US, South Korean, and Polish markets. Since the Internet remains an important distribution channel for these products, we browsed web search engines, price comparison websites, online marketplaces, and Internet discussion forums for EC users and identified popular brands of e-liquids specific to each country. The products were purchased between July 2013 and August 2014, either online or from regional venues. We purchased a total of 91 commercial products: 32 from the United States, 29 from South Korea and 30 from Poland.

The products from each country were sent to the Tobacco Product Laboratory in Roswell Park Cancer Institute, Buffalo, USA for testing. After arrival to the laboratory, each product was catalogued and assigned a unique sample number. All samples were stored in their original containers in a refrigerator at 4°C prior to analysis, in order to minimize the risk of nicotine degradation. Laboratory technicians were blinded to the labelled nicotine levels and to the product names, until the determined levels were obtained.

Calibration and control solutions were prepared in a variety of nicotine concentrations ranging from 0 to 250 mg/mL. The base of each calibration and control e-liquid solution was composed of glycerine (49%), propylene glycol (49%) and water (2%). The various nicotine

solutions were prepped by spiking the base with varying amounts of pure nicotine (99%, Alfa Aesar, UK), followed by vigorous vortexing. The calibration solutions and control samples were stored in amber vials at 4°C prior to analysis.

Sample preparation

Samples were prepared as described previously (Goniewicz, Kuma, Gawron, Knysak, & Kosmider, 2013). Briefly, samples of 100 µl of each product were collected from each original container using the reverse pipetting technique. The samples were diluted with 10 ml methanol, and an internal standard (100 µl quinoline solution 50 mg/ml in methanol) was added. The samples were then vigorously shaken for 10 min and subsequently analysed as described below. Each sample was prepared in triplicates in order to validate the results, and the calibration/control solutions were prepared in multiplicity as well.

Analytical chemistry

Nicotine concentrations were measured using gas chromatography with a nitrogen-phosphorous detector (GC-NPD, Agilent, USA). The modified the standard NIOSH 2551 method for determination of nicotine in air (National Institute for Occupational Safety and Health, 1998). A HP-5, 30 m × 0.32 mm × 0.25 µm (Agilent, USA) capillary column with flow rate of helium of 2.4 ml/min was used. Temperature of the injector and detector was 300°C, and the column temperature increased from 60 to 200°C (20°C/min) and was held constant for 5 minutes. The injection volume was 1 µl, and quinoline served as the internal standard. The retention times for quinolone and nicotine were 4.74 and 5.45 minutes, respectively.

The method was validated as per the International Conference on Harmonization guideline Q2 (International Conference on Harmonization, 2005). A calibration curve was generated to cover the range of nicotine concentration from 0 to 250 mg/ml. To ensure accurate results for the samples each calibration curves had linear coefficients of.99 ($R^2 \geq 0.99$) or above. The average nicotine recovery was 102% and the lower quantitation limit was 0.05 mg/ml.

Statistical analysis

An average level of nicotine in each solution, their standard deviation, and the relative differences in the labelled amounts of nicotine per product as compared to the detected levels were analysed. Measured amounts of nicotine in original cartridges were compared with values declared on their packages using one-sample *t* tests. For all tests the Statistica 9.0 software (Statsoft, USA) was used.

Results

The comparison of labelled and determined nicotine concentrations in all e-liquids analysed in the study is presented in Table 1. Nicotine concentration in 32 samples from the **United States** varied from below limits of quantitation (BLQ; US-28) to 36.6±1.0 (US-21) mg/mL. The differences between labelled and detected nicotine concentrations varied from −92.4% (US-12) to +103.7% (US-30). Nine out of 32 (28%) US products tested in the study showed differences between labelled and detected nicotine concentrations larger than ±20%.

Furthermore, we found traces levels of nicotine in three products labelled as '*nicotine-free*' (US-05, US-06, and US-26).

In the **South Korean** samples, two thirds (n=19) of tested products did not contain detectable amounts of nicotine. In samples which contained nicotine, the concentration varied from 6.4±0.7 (SK-24) to 150.3±7.9 (SK-29) mg/mL. The highest nicotine concentration of 150.3±7.9 mg/mL was found in a sample SK-29 labelled as '*Pure Nicotine'*. It was also the highest concentration of nicotine found in the study. Furthermore, the differences between labelled and detected nicotine concentrations varied from −37.4% (SK-29) to −2.8% (SK-03). Five out of 29 (28%) Korean products tested in the study showed differences between labelled and detected nicotine concentrations larger than −20%. We did not find any traces of nicotine in all 19 products labelled as '*nicotine-free*'.

In the 30 samples from **Poland**, nicotine concentration varied from 0 (PL-02, PL-03, PL-04, PL-08, and PL-22) to 24.7 (PL-14) mg/mL. The differences between labelled and detected nicotine concentrations varied from −38.3% (PL-17) to +9.4% (PL-27). Only three products from Poland (10%) tested in the study showed differences between labelled and detected nicotine concentrations larger than −20%. None of the product labelled as '*nicotine-free*' contained detectable amounts of nicotine (PL-03, PL-04, PL-08, and PL-22).

Discussion

The present study looked at the nicotine levels in samples of EC refill solutions from three countries: US, South Korea, and Poland. We found a high diversity in nicotine concentrations of products within each country. In addition, there were some differences in nicotine concentrations across the three countries. For example, a significant proportion (66%) of South Korean products was labelled as '*nicotine-free*' and did not contain detectable amounts nicotine. In South Korea, these types of nicotine-free products could be mixed with reagent-grade nicotine by clerks at the consumer's request and sold in a separate bottle. Such practices raise concerns regarding the product's quality and consumer safety, as they lack any sort of standards and controls. Future studies need to look whether such production of e-liquids in stores as this may result in higher variability in nicotine content as well as the major risk of spilling the e-liquids in the store.

Our study revealed that the nicotine concentration in a majority of tested products was accurately labelled. The significant discrepancies (>20%) in the labelled nicotine concentrations were found in 19% of analysed e-liquids. Recently, Etter, Zäther, and Svensson (2013) analysed 20 e-liquids of the most popular brands from China, US, France, UK and Belgium, and found that nicotine content in the bottles corresponded closely to the labels on the bottles. In the present study, the majority of the products which were labelled inaccurately were purchased in the United States. This finding is consistent with the results reported by Davis, Dang, Kim, and Talbot (2014) which showed inaccuracies in the labelling of nicotine concentration in e-liquids purchased within the US. The results from the present study also confirm previously reports of accurately labeled products from Poland (Goniewicz, Kuma, Gawron, Knysak, & Kosmider, 2013). The findings discussed above suggest that quality of the products may differ across the countries where the product is

manufactured or repackaged. The inaccurate labelling of the products may be misleading to consumers. For example, users of products containing lower concentrations than labeled may overestimate their nicotine exposure. The effects may place ECs at risk of serving as a less effective substitute for tobacco cigarettes.

An interesting finding is that trace amounts of nicotine were found in some US products labelled as '*nicotine-free*', whereas no nicotine was detected in any of the '*nicotine-free*' products from South Korea and Poland. Also, a significant proportion of US products showed large discrepancies between labelled and detected nicotine concentration (>20%). This may suggest inadequate production standards for e-liquids in the United States. Although there are some voluntary industry standards for e-liquid production in US as set out by AEMSA (American E-liquid Manufacturing Standards Association, 2014), there is still a need for product quality improvement and federal regulation to ensure that all products are accurate in their labelling and production.

We identified a single product labelled as '*Pure nicotine*' (SK-29) in the sample set from South Korea. Chemical analysis revealed that this sample did not actually contain undiluted nicotine. The labelled nicotine concentration was 210 mg/mL, although the detected concentration in the product was 150.3±7.9 mg/mL, indicating a significant difference in the declared and determined nicotine content. If this highly concentrated product is not diluted before the EC is refilled with it, its inhalation can cause adverse effects associated with nicotine overdosing, including nausea and headaches. Access to highly concentrated e-liquids may also increase the risk of accidental poisoning after ingestion of this type of product. There have been some attempts to regulate the maximum nicotine concentration in EC products. For example, the limit of 20 mg/mL is set in the EU Directive (European Parliament and the Council; 2014).

Although this study investigated a large number of commercial products from three different countries, it has some limitations. We selected the products based on their popularity on-line in each country. Due to a lack of comprehensive marketing data we were not able to verify whether the selected products are also popular when they are sold by other distribution channels, such as retail shops or kiosks. The other important limitation of the study is that we measured the nicotine concentration in a single bottle of each tested product. Future studies should look at the consistency of nicotine concentration across batches of the same brand brands. Finally, we were not able to verify where the tested products were actually manufactured. Although China remains the major supplier of ECs and refill solutions, many ECs producers have begun to move manufacturing to the US or Europe (Barboza, 2014). There is a risk that some products tested in our study may have been made in the same facility and imported to the US, Korea, or Poland.

Findings from our study support a need for regulation of nicotine refill solutions for use in ECs. Such regulation should enforce the accurate labelling and packaging of the products. Manufacturing standards are also needed for these new products to assure product quality and the safety of consumers. Furthermore, regulation is needed to minimize the risk of accidental poisoning by these products. In addition, to ensure an effective degree of product quality and safety, a regulatory approach should be made to prevent the access to the

products by minors and prevent infants from consuming the e-liquid by enforcing child-proofed packaging.

Acknowledgments

Funding

This study was supported by NIH grant 1R01DA037446-01.

The authors thank Noel Leigh for editorial help.

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HIGHLIGHTS

- Nicotine concentrations were measured in 91 e-liquids from US, South Korea, and Poland.
- We found significant discrepancies in the labelled nicotine concentrations in 19% of products.
- Traces of nicotine were found in three US products labelled as '*nicotine free*'.
- A single product labelled as '*pure nicotine*' contained high concentration of the drug.
- The study revealed the need for quality standards of the e-liquid products.

Table 1

Comparison of labelled and determined nicotine concentrations in 91 commercial e-cigarette refill solutions from United States (n=32), South Korea (n=29), and Poland (n=30).

Sample Code	E-liquid Brand Name	E-liquid Type/Flavour	Labelled Nicotine Concentration (mg/mL)	Determined Nicotine Concentration (mg/mL) Mean±SD (n=3)	Relative Difference (%)
United States					
US-01	Crystal Canyon	Calypso	24	33.1±0.8	+37.9*
US-02	Crystal Canyon	Ecto Cooler	6	5.8±0.2	−3.1
US-03	EC Blend	Dragon's Tear	36	28.5±0.6	−20.9*
US-04	EC Blend	Dragon's Tear	12	10.4±0.9	−13.2
US-05	EC Blend	Dragon's Breath	0	0.9±0.1	n/a*
US-06	EC Blend	Dragon's Crown	0	0.9±0.1	n/a*
US-07	eCig Boss	Grapefruit	18	14.7±0.4	−18.4*
US-08	eCig Boss	Cuban Supreme	12	11.2±0.8	−7.0
US-09	Planet	Blackberry	11	10.9±0.8	−0.8
US-10	Planet	Jasmine	8	5.6±0.6	−30.4*
US-11	Good ejuice	Bubble Gum	32	24.5±0.9	−23.3*
US-12	Guilty Pleasures	Sweet Orange	16	1.2±0.1	−92.4*
US-13	High Caliber	Black Cherry Pina Colada	24	18.0±0.3	−25.1*
US-14	Mister	Chai Tea	18	16.9±0.5	−6.1*
US-15	Mister	Apple Ice	12	12.8±0.7	+6.6
US-16	Mister	Saturn	12	10.9±0.8	−9.1
US-17	MyVaporStore	Mocha Lite	24	22.7±0.5	−5.6*
US-18	PinkSpotVapors	Wild Blueberry	18	14.9±0.3	−17.0*
US-19	PinkSpotVapors	Pink Spot	6	4.7±0.4	−20.9*
US-20	PinkSpotVapors	Gummy Bear	6	6.6±0.8	+9.2
US-21	Pure Smoker	Back Country Tobacco	32	36.6±1.0	+14.4*
US-22	Pure Smoker	Berrodica	24	27.3±0.7	+13.6*
US-23	Top Vapor	Root Beer	36	36.4±0.8	+1.0

Sample Code	E-liquid Brand Name	E-liquid Type/Flavour	Labelled Nicotine Concentration (mg/mL)	Determined Nicotine Concentration (mg/mL) Mean±SD (n=3)	Relative Difference (%)
US-24	Top Vapor	Tobacco	11	12.9±0.3	+17.1*
US-25	Totally Wicked	Peppermint	30	28.8±0.6	−3.9*
US-26	Totally Wicked	Sex On The Beach	0	0.8±0.2	n/a*
US-27	Tsunami	Fruit Punch	18	16.5±0.4	−8.4*
US-28	Tsunami	Hawaiian tropical	0	BLQ	n/a
US-29	Uno Vapor	Cinnamon	12	11.5±0.5	−4.3
US-30	Uno Vapor	Cherry	6	12.2±0.7	+103.7*
US-31	Virgin Vapor	Caramel Kona Milkshake	24	24.4±0.7	+1.6
US-32	Virgin Vapor	Maple French Toast	5	4.9±0.8	−1.8
South Korea					
SK-01	America's Smoke Juice	Ultralite	0	ND	n/a
SK-02	America's Smoke Juice	Savory	0	ND	n/a
SK-03	Halo	Torque56	18	17.5±1.3	−2.8
SK-04	Halo	Tribeca	18	17.3±1.1	−3.9
SK-05	DIY Flavor Shack	Paradise	16	15.5±0.7	−3.1
SK-06	DIY Flavor Shack	Café Latte	16	12.1±0.3	−24.4*
SK-07	DIY Flavor Shack	Pomegranate	16	12.1±2.0	−24.4*
SK-08	Maximum	Washington Duke	0	ND	n/a
SK-09	Maximum	American Blend	0	ND	n/a
SK-10	Maximum	Himalaya Frost	0	ND	n/a
SK-11	Maximum	Citronade	0	ND	n/a
SK-12	D&S	Mild Cigar	0	ND	n/a
SK-13	D&S	Texas Cigar	0	ND	n/a
SK-14	D&S	Ice Tundra Berry	0	ND	n/a
SK-15	D&S	Blueberry Mojito	0	ND	n/a
SK-16	D&S	Sweet Melon	0	ND	n/a
SK-17	Korea Biomedical	Mild	0	ND	n/a
SK-18	Korea Biomedical	Cig	0	ND	n/a
SK-19	Hello	Cigar	0	ND	n/a
SK-20	Real	Herb Brown	0	ND	n/a

Sample Code	E-liquid Brand Name	E-liquid Type/Flavour	Labelled Nicotine Concentration (mg/mL)	Determined Nicotine Concentration (mg/mL) Mean±SD (n=3)	Relative Difference (%)
SK-21	Ritchy	Citrus Mix	18	14.1±2.9	−21.7
SK-22	Ritchy	American Blend	18	14.8±3.9	−17.8
SK-23	Ritchy	Cuban Cigar	18	16.9±0.6	−6.1*
SK-24	Cignit	Cigar	11	6.4±0.7	−30.6*
SK-25	Martha	Cigar	0	ND	n/a
SK-26	Martha	Ice Blue	0	ND	n/a
SK-27	Martha	Apple Mint	0	ND	n/a
SK-28	Martha	Heaven	0	ND	n/a
SK-29	Pure Nicotine	n/a	210	150.3±7.9	−37.4*
Poland					
PL-01	Health E-cigarette	Chocolate	18	16.4±0.5	−8.9*
PL-02	G&S Idealny	Cuban Tobacco	0	ND	n/a
PL-03	Expert III	Tobacco Cappuccino	0	ND	n/a
PL-04	Expert III	Spicy Biscuit	0	ND	n/a
PL-05	Expert III	Tobacco Gold	22	17.5±0.1	−20.5*
PL-06	Expert III	Tobacco Black Cherry	22	19.4±0.1	−11.8*
PL-07	Expert III	Tobacco Vanilla	9	7.3±0.1	−18.9*
PL-08	Dean Liquid	Apple	0	ND	n/a
PL-09	M&P Newmedica	Cannabis	11	11.3±0.7	2.7
PL-10	M&P Newmedica	Black Currant	8	8.1±0.2	1.3
PL-11	Prince Sensation	Artic Mint	11	10.5±0.1	−4.5*
PL-12	Evaper	Lavender	12	11.3±0.4	−5.8*
PL-13	Evaper	Mojito	18	19.6±0.2	8.9*
PL-14	Evaper	Classic Pipe	24	24.7±0.1	2.9*
PL-15	Evaper	Maple	8	8.2±0.2	2.5
PL-16	Hangsen Original	Green Tea	18	18.6±0.3	3.3*
PL-17	IN-E.Smoke	MB	18	11.1±0.1	−38.3*
PL-18	IN-E.Smoke	Banana	n/a	3.7±0.1	n/a

Sample Code	E-liquid Brand Name	E-liquid Type/Flavour	Labelled Nicotine Concentration (mg/mL)	Determined Nicotine Concentration (mg/mL) Mean±SD (n=3)	Relative Difference (%)
PL-19	Good Vaper	Red Rose	18	19.3±0.2	7.2*
PL-20	Good Vaper	Exotic	18	18.5±0.1	2.8*
PL-21	BM E-dym	Virginia	12	12.5±0.1	4.2*
PL-22	Dean Liquid	Strawberry	0	ND	n/a
PL-23	Diversity	USA Mix	18	18.4±0.3	2.2
PL-24	P1	Blackberry	18	18.3±0.3	1.7
PL-25	P1	Blackberry	6	5.8±0.1	−3.3*
PL-26	Mild Best	Tobacco	18	18.5±0.2	2.8*
PL-27	Cottien	Cocktail Party	16	17.5±0.3	9.4*
PL-28	Aromative	Pure Tobacco	15	16.2±0.2	8.0*
PL-29	Provog	Menthol	24	24.2±0.9	0.8
PL-30	Liquid concentrated	Double Energy	11	8.8±0.1	−20.0*

Note: SD – standard deviation; n/a – not applicable; ND – not detected; BLQ – below limit of quantitation;

* indicates statistical significant difference between labelled and detected nicotine concentration ($p<0.05$; *t*-test)