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Title: **Erosive potential of commonly available vapes, a cause for concern?**

Type of paper: Research article

Abstract

Objectives Relatively little is known about the erosive potential of vape products, an important consideration for dental health. This study analysed flavoured vapes with potentially low pH, including fruit and drink flavours.

Methods pH of forty-five purposefully selected vapes were measured undiluted in triplicate. Serial dilution was conducted on the most erosive product to investigate if/when the erosive potential pH of 5.5 was reached. One of the most erosive samples was tested, undiluted and diluted, after 4 months of opening. Content analysis of the vape labels determined ingredients, place of manufacture, product usage instructions and health warnings.

Results 84% of undiluted vape samples had a pH below 5.5. Erosive potential was not predicted by the flavour, with orange and cola samples higher than anticipated (pH 3.56-6.23 and 5.04-5.63 respectively). Products that were predicted to be non-acidic such as vanilla showed considerable variation ranging from pH 4.69-5.63. Freshly opened or stored samples did not reach a non-erosive potential pH of 5.5 or above, even when diluted to represent concentrations used when vaped.

Labels were not detailed enough to ascertain which ingredients were contributing to acidity or buffering capacity or to allow consumers to identify the least harmful products in terms of oral health

Conclusions.

Present labelling of commercially available vapes do not allow consumers to ascertain the erosive potential and possible dental damage that may be inflicted by their use. More effective labelling and/or health warnings are required to educate consumers and dental health professionals of these products.

Key Words. E-cigarettes, vapes, vaping solution, pH, dental erosion, dental health

Introduction

Tobacco products and patterns of tobacco use are changing. E-cigarettes are a delivery system that heat an e-liquid, usually consisting of propylene glycol or vegetable glycerine and flavouring agents with or without nicotine generating an aerosol called vape, in addition vapes are the term used to describe the e-liquids by users[1]. Whilst smokeless tobacco vapes have been heralded by some as a means of reducing smoking related harm[2] vapes are still associated with immediate and long-term adverse health effects including cancer and adverse impacts on the cardiovascular system, lungs and pulmonary function[1]. The heating process causes pulmonary inflammation, reduction of the hosts defence system, neutrophil inflammation, mucus hypersecretion, and protease-mediated lung tissue damage, which are linked to the development of chronic obstructive pulmonary disease and generates carcinogens, oxidizing agents, including free-radicals and other toxins as an aerosol of ultrafine particles similar to cigarettes[3]. In addition, the flavours in e-cigarette vape liquids can be harmful in themselves. Toxic compounds such as diacetyl, which has been linked to severe respiratory disease, have been found in 75% of flavoured e-cigarettes[4].

The World Health Organisation[5] and the US Food and Drug Administration[6] have warned against the widespread use of e-cigarettes as a nicotine replacement product. Both bodies have recognised that e-cigarettes may be less harmful than tobacco smoking, given the lack of tar in e-cigarettes, but they emphasise that e-cigarettes are almost certainly more dangerous than medicinal nicotine replacement products.

Relatively little is known about the erosive potential of vape products, which is an important consideration for oral, particularly dental health. An enormous number of vape liquids are available on the market, one UK company alone advertises over 1900 flavours[7], others report over 10, 000 commercially available flavours[8]. Vape flavours such as strawberry cake, blueberry donut, manic mango and pear drops indicate they may have a low pH, depending on the ingredients used in the manufacturing process. Products with a pH of 5.5 or below are regarded as having erosive potential, permitting dental erosion or the dissolution of dental hard tissues: enamel, dentin and cementum caused by non-bacterial acids. These acids lead to further softening of the tooth surface and therefore increase the risk of dental decay[9].

The aim of this study was to analyse a selection of flavoured vapes available via a major UK online retailer to investigate any possible erosive effects. Vapes with flavours potentially having a low pH were selected, including fruit and drink flavours[10,11].

Methods:

Forty- five different e-cigarette fluids (vapes), available online in the UK were purposefully selected, based on their flavour being likely to be acidic and show erosive potential, that is a pH below the critical value of 5.5[9]. This allowed examination of factors that may affect the erosive potential of vapes including type of flavour and ingredients. Two nicotine flavoured products were used for comparison as it has been established that nicotine vapes are alkaline[12] to determine if the erosive potential of the vape liquid was reduced by the presence of the alkaloid.

Samples were kept at room temperature (15-20^{o}C) prior to initial pH measurement, in triplicate, using a standardised procedure[13] and a Testo 205 instrument (AG, Germany) a pH meter with temperature measurement probe. A two-point calibration of the pH meter to two decimal places was undertaken at the start of each session using standard pH buffers (4.00 and 7.00) encompassing the expected pH value of the vapes.

Vape fluids were diluted to represent the concentration at which they are vaped. This is an approved protocol[13] which maintains consistency during analysis, given that the many modes of converting vapes into an aerosol vary considerably posing challenges when examining potential health effects[1].

Firstly, the forty-five vapes were measured, undiluted, in triplicate with means and standard deviations reported. Secondly a serial dilution was conducted on the most erosive product using successive dilutions of 5 and 10ml of de-ionised distilled water, in order to investigate if/when the erosive potential pH of 5.5 was passed. Finally, following the initial pH analysis of freshly opened samples outlined above, one of the most erosive samples, was tested, undiluted and diluted, to determine any effect on the erosive potential, after 4 months of open storage. The temperature of all samples was 23-25^{o}C during the pH measurement, an important consideration, as temperature affects pH[14] and the protocol indicated all products should be between 22^{o}C-25^{o}C for pH determination[13].

Cross tabulations and Chi square analysis were conducted using IBM SPSS Statistics for Windows, Version 27.0. Armonk, NY: IBM Corp on recoded results. Recoding was logical due to the large range of pH values and of flavours. Flavours were categorised into 4 types (fruit n= 33, acidic beverage n= 4, confectionary/dessert n=2 and other e.g vanilla, coffee n=4). Country of manufacture into two categories, China (n=29) and rest of world (n=16) and pH into 2 categories erosive and non-erosive.

Content analysis of the vape labels were undertaken to determine ingredients, place of manufacture and possible effects on pH as well as product usage instructions and health warnings, by inputting data into an excel spreadsheet.

Results:

Products were obtained from nine different manufacturers, 3 Chinese providing 29 samples, 1 German providing 11 flavours, 4 different UK manufacturers providing 1 sample each and 1 product from a manufacturer in the Netherlands.

The majority of the undiluted samples n= 38/45 (84%) had a pH below 5.5, indicating erosive potential was not predicted by the flavour. The 4 orange-samples ranged from 3.56-6.23 and both cola-samples were higher than anticipated (pH=5.04-5.63), given the pH of cola drink is less than pH 3[15]. In addition, products that were predicted to be non-acidic such as vanilla showed considerable variation ranging from pH 4.69-5.63. The inclusion of nicotine ensured non-erosive potential with pH levels (7.5-7.9), of the two samples tested: Cherry Bomb and Blueberry Bomb (Figure 1).

The freshly opened Red Bullz vape fluid had a pH of 3.26 and required dilution with 35ml of de-ionised distilled water (water) to reach a non-erosive potential of 5.54.

There was no significant association with flavour and pH level analysed via chi-square= 5.71, 3 df, p = 0.127 despite a strong trend, the majority of fruit flavours being acidic, with a pH below 5.5 (n= 30/33), compared with half of the samples of each of the remaining flavour categories (acidic beverage, confectionary/dessert and other).

Whilst Chinese samples were more likely to fall below the dental erosion critical point of 5.5, there was no significant association between place of manufacture and pH, Fishers exact probability test = 3.694, df=1 p=0.077.

After opening and storage of samples for a period of 4 months, at ambient temperature (18-20^{o}C) the Maiden's prayer vape sample undiluted was 3.60 and therefore indicated a very large buffering capacity, although this was not measured in the study. After dilution with 300ml of water the pH (4.33) was still potentially erosive. Based on this result a dilution of over 1 litre would be required to reach a safe, non-erosive pH for this product.

Ingredients lists were not detailed enough to ascertain which ingredients were contributing to acidity or buffering capacity. All products contained glycol, stated as propylone or propolyne glycol by the Chinese manufacturers and reported by the UK and EU manufacturers as propylene glycol. All except one manufacturer listed vegetable glycerin, which was replaced by glycerol in one of the Chinese manufacturer's samples. The German manufacturer was the only one to list distilled water as an ingredient or use EU additive numbers in addition to ingredient names. Flavouring agents were inconsistently listed as 'natural flavours', 'natural and artificial', 'flavours' 'flavourings' or specific flavours e.g 'Heizenburg' or 'berry flavouring' that still lacked compositional detail (Table 1).

Various health warnings were listed on all outer packaging/individual labels or where packages were too small on the manufacture's websites, these warnings have been summarised in Table 2. All products indicated they were not suitable for use by under 18's.

With regard to allergies all of the Chinese samples mentioned propylene glycol and the German sample glycerol. Allergies were not mentioned by any of the UK or Netherlands manufacturer. Two Chinese and the German samples advised against use by pregnant/lactating women. Only the German sample mentioned avoidance of use by those with other health conditions such as diabetes, cardiovascular disease and those treated with antidepressants or asthma medication. All labels, except for the German sample stated they were harmful if swallowed and gave simple advice to follow if this occurred. In addition, all manufacturers except for the German product mentioned that if the user felt unwell during or after use, they should contact a doctor. Only the German and one of the Chinese samples indicated that vapes should not be used by those who do not smoke (Table 2).

Discussion

This scoping survey was based on a small, purposefully sampled selection of products whose names indicated they may have erosive potential, however, flavour showed no clear relationship with pH (Figure 1). Young consumers, including those who have never smoked are reported as being particularly attracted to fruit and sweet flavoured vapes [16, 17, 18]. However, even potentially erosive products such as cola flavour fell close to the non-erosive potential of pH 5.5, whilst the non-erosive flavours such as vanilla showed considerable variation, ranging from an erosive potential pH of 4.69, to a non-erosive potential of pH 5.63. This is potentially misleading for consumers who are not health literate, with regards to label reading or that are vaping as they believe vaping is less harmful to themselves and others. Research in the UK indicates young consumers (11-16-year olds) perceive fruit (cherry) and candy floss flavours as less harmful than nicotine or coffee flavoured vapes[16]. In 2016 a USA survey of over 15,000 12-30+ year olds in Texas reported > 95% of first used and usual e-cigarettes were flavoured, with fruit and candy flavours predominating [4].

The majority of the undiluted samples in this study (84%) had a pH below 5.5, indicating erosive potential (Figure 1). Dilution of the most erosive sample (Red Bullz), freshly opened (pH 3.18), required 35ml water with 2ml vape fluid to produce a non-erosive vape. Vapes are consistently diluted to a concentration of 2ml per 20ml of distilled water to represent the concentration of vapes as used[13, 19]. Furthermore, storage on opening for four months at ambient temperature, of one of the most erosive samples (Maiden's prayer, pH 3.60) did not alter the pH to such an extent that a non-erosive potential would be possible, with a dilution of over 1 litre required to reach a safe, non-erosive potential pH. This indicates in the samples tested that erosive potential is maintained after opening and consumers will not be able to dilute to a non-erosive level, as is the case with diluted fruit drinks[10]. The vapes used in the present study all indicated they could be used for a period of 12 months after opening.

Most vape bases, including all those examined in the present study consist of combinations of propylene glycol and glycerin with or without water, typical volume ratios of 20% propylene glycol to 80% glycerin are reported[20], but could not be verified for the vapes in the present study due to the lack of detail in the labelling. Propylene glycol is a colourless liquid that possesses a faintly sweet taste. When heated into an aerosol, its breakdown products include acetic acid, lactic acid, and propionaldehyde, all of which can demineralise

enamel[20]. These vapes are also hygroscopic, and can bind water in saliva, which can result in xerostomia[20]. Glycerin is a colourless, odourless, and sweet-tasting liquid, 60% as sweet as sucrose but is not metabolised by cariogenic bacteria. However, in combination with some fruit flavourings, including pineapple, apple and plum glycerin results in a 4-fold increase in microbial adhesion and two times increase in biofilm formation. The viscous aerosols produced by heated e-liquids allow *Streptococcus mutans* to stick to enamel, resulting in demineralisation and can lead to rampant caries[8, 20]. Many e-liquids share similar physical and chemical properties to sugary and gelatinous foods that have been proven to be major risks for dental caries and a recent population-based cross-sectional study revealed that daily use of e-cigarettes is independently associated with poor oral health[21].

Whilst inclusion of nicotine ensured non-erosive potential with pH levels above 7.0 it would be irresponsible to give the health message of switching to a nicotine vape in order to reduce the possible risk of demineralisation, given the high risk of oral and whole body health complications associated with nicotine use[22].

The authors feel the differences in pH of similarly named products must be due to the composition of the ingredients in individual products. However, ingredients lists were inconsistent and lacked the detail necessary to ascertain which ingredients were contributing to acidity or buffering capacity (Table 1). There was insufficient detail provided as to the presence of natural or artificial flavouring compounds to investigate if naturally or artificially flavoured products had a greater or lesser erosive potential. In addition, a direct link between low pH vapes and the possible dental erosion needs to be further investigated. Although the topic has not been studied extensively, it seems reasonable to conclude that vaping may have a negative influence on gingival, periodontal, and implant health. The individual effect would be determined by the concentration of nicotine in the vaping product, the heat output of the vaping device, the frequency of vaping, and the host response of the patient[20], in addition the present study indicates the flavouring ingredients are also an important consideration. The present study also indicates that consumers would be unable to select less harmful products by the information provided by the companies on the label or via their websites.

Various health warnings were listed on all outer packaging/individual labels or where packages were too small on the manufacture's websites (Table 2). All

products indicated they were not suitable for use by under 18's as legislated by the majority of governments including China, Australia, USA, European Union and Great Britain[23]. Both the nicotine containing vape samples examined in the present study were appropriately labelled with a health warning and concentration of nicotine. However other information with regards to who should avoid use in terms of health conditions (e.g. pregnancy, diabetes, cardiovascular disease and those treated with antidepressants or asthma medication) or non-smokers were inconsistent, possibly due to differing legislation enforcement throughout the world[23]. Post use most of the products indicated medical advice should be sought if the person felt unwell during or after consumption (Table 2).

Conclusion:

The present labelling standards of commercially available vapes do not allow consumers to ascertain the potential erosive potential and possible dental damage that may be inflicted by their use. Users are therefore unable to determine which of these generally erosive products are safer for use, furthermore dental professionals will not be able to advise their patients with respect to relative safety. This supports present WHO advice that e-cigarettes should not be used, particularly by non-smokers.

It is suggested by the authors that all vapes should carry specific oral-health warnings re: possible cariogenic and possibly erosive risk. Short term (4 month) storage does not reduce erosive potential of one of the more erosive products, neither does normal dilution rates associated with vaping.

Health warnings on vapes should be standardised and enforced in a similar manner to traditional tobacco products, irrespective of nicotine content.

More research is required to establish if at normal vape dilutions any of the flavoured vapes reach a pH above the erosive potential. More information concerning frequency and duration of vaping and effects of health warnings on consumers use to enable more effective advice to be given by dental professionals with regards to vaping.

Conflicts of interest the authors have no conflict of interest.

Data availability Data is available from the lead author.

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Figure 1 Mean and standard deviation pH of 45 purposefully selected e-cigarette vapes, undiluted and freshly opened. Red line indicates cut off point of erosive potential pH (5.5).

Table 1 Ingredients listing as it appeared product packaging/website (including spelling errors).

Table 2 Health/use warnings on product labels/packaging/websites.