

Nicotine arms race: JUUL and the high-nicotine product market

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ABSTRACT

Objective Until recently, purveyors of vaping products marketed e-liquids in the 1%–3% range of nicotine concentration with those at 3% described as ‘super high’ intended for two packs/day smokers. The goal of this study is to evaluate the degree to which JUUL, with its 5% nicotine and 75% US market share, has spurred other e-liquid vendors to raise the nicotine levels of their products.

Methods Online search to identify brands offering e-liquid in exceptionally high nicotine concentration ($\geq 5\%$) and to catalogue the appearance of devices which emulate JUUL.

Results JUUL compatible pods (14) and JUUL knock off devices (39) were identified which offer equal or higher nicotine than JUUL. More than 70 e-liquid brands sell high-nicotine products ($\geq 5\%$) in bulk (≥ 30 mL) equivalent to >40 cigarette packs. All of these products come in multiple youth appealing sweet and fruity flavours. It was noted that nicotine percentage is inconsistently reported (eg, JUUL is 5% by weight vs 5.9% by volume).

Conclusions JUUL has triggered a widespread rush among aerosol purveyors to market e-liquid in unprecedentedly high nicotine concentrations. The rapidly rising popularity of high-nicotine e-liquids threatens to addict a generation of youth. When sold in large quantity bottles (eg, 30 mL) they represent a childhood poisoning risk. Labelling of nicotine concentration in e-liquids needs to be standardised to avoid consumer confusion. The addictiveness and toxicity of these products makes it imperative that regulators act swiftly to enact protective measures.

INTRODUCTION

Representing a new generation of e-cigarettes, JUUL was introduced in June 2015 with a novel chemistry (nicotine salts) enabling higher concentrations in a limited aerosol plume.

As addiction is central to their business model, the tobacco industry has long sought to enhance the bioavailability of nicotine in their cigarette products.¹ Nicotine comes in different pH-dependent forms. The more alkaline variant, possibly boosted during manufacture of traditional cigarettes, is unprotonated and exists as a free base. Raising pH has been shown to enhance the absorption of aerosolised nicotine by the respiratory system.² While free base nicotine is rapidly absorbed in the lungs, it is relatively bitter and has greater harshness sometimes described by smokers as ‘throat hit’. In its protonated form, nicotine exists at a lower pH as a salt with a weak acid.

Among numerous possible acids, benzoic has become most popular as a nicotine salt e-liquid. JUUL’s original patent stated: ‘*It has been unexpectedly discovered herein that certain nicotine salt formulations provide satisfaction in an individual superior to that of free base nicotine, and more comparable to the satisfaction in an individual smoking a traditional cigarette. The satisfaction effect is consistent with an efficient transfer of nicotine to the lungs of an individual and a rapid rise of nicotine absorption in the plasma.*’³ Nicotine salts are not only less harsh, but they are also less bitter, making e-liquids more palatable despite higher nicotine levels. Shortly before the product was introduced to the marketplace, JUUL design engineer Steve Christensen explained the nicotine chemical innovation: ‘*You won’t find raw nicotine in nature. It’s mixed in with organic acids and other substances. It’s this cocktail that makes nicotine palatable. We figured out how to incorporate some of these organic acids into the juice . . . so we were able to get a very cigarette-like experience.*’⁴

The tobacco in a traditional combustible cigarette has a nicotine concentration of approximately 1.5%–2% (1.5–2 mg/mL).⁵ The definition of ‘high’ and ‘super high’ nicotine in e-liquid has evolved over recent years. Before 2015, most e-liquids were in the 1%–2% nicotine range and 3% was usually the highest offering described by e-liquid purveyors as intended for two packs a day smokers.^{6–8} JUUL introduced 5% nicotine salt solution consisting of 59 mg/mL in 0.7 mL pods. Each pod delivers around 200 puffs and the company claims it releases a similar amount of nicotine to a pack of 20 cigarettes. Study of nicotine absorption biomarkers show JUUL and other high-nicotine pod devices deliver nicotine at substantially higher levels than earlier e-cigarette devices.⁹ The high rate of adoption of JUUL by American youth has been described as an epidemic by public health leaders including US Food and Drug Administration (FDA) Commissioner Scott Gottlieb.^{10–12} An online survey of JUUL users between the ages of 15 and 24 show that 63% were unaware that the product contained nicotine.¹³

In focusing on JUUL, many critics in the public health community have missed a key issue of major concern. Following JUUL’s lead, many purveyors of nicotine salt-based e-liquids offer nicotine concentrations at the 5%, 6% and even 7% level. The goal of this paper is to describe the proliferation of high-concentration salt-based nicotine products, spurred by the financial success of JUUL, and to analyse the potential consequences of the rapidly emerging shift in the aerosol market.



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METHODS

A systematic online search was undertaken, between August and September 2018, to identify devices which emulate JUUL in their design (JUUL-a-likes) and offer high nicotine ($\geq 5\%$) salt e-liquid. Google search terms included: nicotine salts, high nicotine, nicotine e-liquid, nicotine e-juice, nicotine pod and JUUL compatible pods. A large number of online US vape stores and brand websites were reviewed. A JUUL-a-like was defined as a small pod-based system of similar size to JUUL. Because newly introduced vaping products vigorously strive to get a foothold in the marketplace by promoting their wares online, we believe that the spectrum of products identified comprehensively reflects the market during the study period.

A second category of interest was JUUL compatible pods offered by competitors seeking to carve out a share of the robust demand for JUUL consumables. Also compiled were vendors offering high-nicotine e-liquid in bulk quantity, typically in 30 mL bottles. Data for each brand of pod and bulk e-liquid were compiled for nicotine concentration, volume and flavour offerings. The master data base is available as a supplemental digital file (online supplementary file 1).

In describing e-liquid flavours, two descriptive categories were used. Tobacco flavours included e-liquids named tobacco, original, cigar, Cubano, Carolina bold, golden leaf and classic tobacco. Not included in the tobacco category were sweetened or mint flavoured tobacco descriptors such as candied tobacco, sweet tobacco, ice tobacco, creamy tobacco, tobacco chill, etc. The category of youth-oriented flavours included three groups: (1) desserts such as gummies, cookie, custard, pie, cake, peanut butter, butterscotch, sorbet, taffy, sugar, marshmallow, caramel, mint, Danish, donut, creamsicle, mocha and so on; (2) fruity flavours such as mango, strawberry, raspberry, melon, apple, watermelon, kiwi, peach, grape, pineapple, banana, lime, cherry, blueberry, grapefruit, passion fruit, lemon, tangerine, guava and so on; and (3) conceptual flavour names included whimsical descriptions such as unicorn, God's gift, illuminati, very cool, mtn doo, cryptic blast, antidote, pinkie, dragon and so on.

RESULTS

JUUL pods and pods marketed as JUUL compatible

We identified 14 brands marketing 15 JUUL compatible pods, some with higher nicotine concentrations than JUUL (up to 6.5%) (table 1). Most devices were introduced by established e-cigarette companies or startups with a few offerings by major tobacco companies. Most of these pod systems have a capacity between 0.7 mL and 2 mL of e-liquid. Pods fall into two categories: those prefilled with nicotine and flavour and those which can be filled with e-liquid by the consumer. Twelve of these offer closed pods prefilled with e-liquids and three were refillable. Ten of the 12 undersell JUUL's pod price of \$4 by as much as \$1.50. Most also offer higher capacity pods than JUUL (1 mL vs 0.7 mL). Among the 12 prefilled pods, all offered sweet and fruity flavours but only half carried an unsweetened tobacco variety. JUUL's most popular flavour is mango.¹⁴ Seeking to emulate JUUL's success, all but one vendor of JUUL compatible pods offer mango flavour.

Small, pod-based vaping devices which emulate JUUL

Thirty-nine small, elongated, pod-based devices were identified: 19 non-refillable, 17 refillable and 3 disposables (table 2, online-supplementary table 2). Some resembled JUUL (JUUL-a-likes) while others had a distinctive design. None of these were present on the market prior to the introduction of JUUL. All of their

Table 1 Nicotine concentration and flavour types among JUUL pods and pods marketed as JUUL compatible (September 2018)

	Highest nicotine (%)	Tobacco flavours	Youth-oriented flavours	Pod price	Pod volume (mL)
JUUL pods	5.9	2	6	\$4.00	0.7
JUUL-compatible pods (prefilled, not refillable)					
4X	6.5	0	6	\$3.75	1
Eon Smoke	6	1	9	\$3.75	1
Edge	6	0	5	\$4.25	0.7
Fuma	5.5	1	3	\$4.00	1
Viv	5	0	6	\$3.75	1
ZIIP	5	1	5	\$2.75	1
Airbender	5	0	10	\$3.50	1
3X	5	0	4	\$3.00	1
Loon	5	1	8	\$2.60	0.7
Magic Mist	5	1	1	\$2.50	–
VQ	5	0	4	\$3.50	1
Zalt	5	1	7	\$3.25	1.1
JUUL-compatible pods (fillable)					
J Pod	–	–	–	\$3.25	1
Blankz!	–	–	–	\$3.25	1
4X fillable	–	–	–	\$3.00	0.7

pods exceed JUUL's 0.7 mL capacity, with most between 1 mL and 2 mL. All but three of the prefilled varieties carry unsweetened tobacco flavours, but all offer a variety of sweet and fruity flavours. The refillable pod systems allow consumers to choose among the innumerable e-liquid brands (online supplementary file 2). The three disposable JUUL-a-like devices were relatively inexpensive and offer nicotine strengths equivalent or higher than JUUL.

High-volume, high-nicotine e-liquid products

We identified 71 American e-liquid brands that were found to sell high-nicotine salt e-liquids ($\geq 5\%$) products in bulk (≥ 30 mL) (table 3, figure 1). These were characteristically packaged in brightly coloured plastic bottles and came in a wide variety of sweet and fruity flavours (online supplementary table 1).

Measurement of nicotine concentration

JUUL, unlike most e-liquid brands, measures its nicotine content by weight rather than by volume (eg, JUUL is 5% by weight vs 5.9% by volume). JUUL's method takes into account the higher specific gravities of propylene glycol and glycerin, thus reducing the calculated percent nicotine when compared with many other e-liquid providers. Most e-liquids labelled as 5% nicotine contain 50 mg/mL. This inconsistency in labelling of nicotine concentration is likely to cause confusion among consumers.

DISCUSSION

Since its introduction in June 2015, JUUL has disrupted the e-cigarette market in several important ways. Among other attributes, JUUL is easily concealable and has a novel nicotine formulation. Our study documents that JUUL's success in the e-cigarette marketplace has spurred a variety of new pod-based products with exceptionally high nicotine. Despite the cleverness of its design features, a historian 20 years from now may

Table 2 Nicotine concentration and flavour types of small pod devices which emulate JUUL ('JUUL-a-likes') (September 2018)

Pod devices	Highest nicotine	Tobacco flavours	Youth-oriented flavours	Pod price	Pod volume (mL)
Stig	6%	1	3	\$6.66	1.2
Space Jam The Byrd	6%	1	3	\$5.00	0.85
Bo	5.5%	1	7	\$6.66	1.5
Sol	5%	1	3	\$5.00	2
Phix	5%	1	7	\$5.00	1.5
XFIRE	5%	1	3	\$4.00	0.75
Kwit stick	5%	0	4	\$5.00	1
Stix	5%	2	3	\$4.50	1.7
Zoor	5%	0	4	\$7.24	2
Myle	5%	1	4	\$4.50	0.9
Vaptio C-Flat	5%	0	6	\$4.00	1
Jak Epic	5%	1	3	\$2.50	0.75
Hangsen IQ	5%	1	2	\$3.66	0.90
Baton Vapour	5%	1	4	\$6.00	1
NicoPod	5%	1	3	\$5.00	1.1
Kilo	4.5%	1	9	\$5.00	1.5
Pod Devices of Major Tobacco Company					
Vuse Alto (RJ Reynolds)	5%	2	2	\$6.75	1.8
MyBlu Intense (Imperial)	4%	3	13	\$5.00	1.5
MarkTen Elite (Altria)	1.8%	1	4	\$4.49	1
Disposable JUUL-a-Likes					
Eon Smoke	7%	1	6	\$20	1.3
Teemo	6%	1	4	\$11.50	1.3
Fogg	5%	2	3	\$18	–

conclude that JUUL's most consequential impact was that it introduced markedly higher nicotine concentrations to the e-cigarette market.

As of September 2018, there were at least 39 JUUL knock off devices on the market. The vast majority of these emulate, and sometimes exceed, JUUL's exceptionally high nicotine levels. Like JUUL, they are also inconspicuous, small enough to easily fit in a pocket or purse, and their purpose as a nicotine delivery system may not be obvious to many casual observers, including parents and teachers.¹⁵ The proliferation of newly introduced JUUL-a-like devices in 2018 would seem to contravene the requirement spelled out in the FDA deeming regulation which requires premarket approval of all newly introduced vaping devices proposed for entry to the market after August 2016.^{16 17} In October, 2018 the FDA announced notice of possible enforcement actions against these recently launched devices.¹⁸

JUUL has been active in opposing the new entries to the market its success inspired. In August 2018, JUUL filed trademark filing against 30 alleged 'counterfeiters' in the US District Court of Eastern Virginia.¹⁹ In both October and November 2018, JUUL filed complaints to the US International Trade Commission seeking to block the importation of nearly 40 devices which it described as a: 'cascade of copy-cats entering the market'.^{20 21} The company's alleges that the motivation of the newly introduced devices was to exploit JUUL's success: 'Seeing an opportunity to capture some of JLI's (JUUL Labs, Inc.) success with minimal investment, Respondents blatantly emulated the distinctive design of the JUUL system.' The complaint goes on to allege:

Table 3 Large volume (≥ 30 mL), high-nicotine ($\geq 5\%$) salt e-liquid brands sold in bottles in multiple sweet and fruity flavours (September 2018)

13th Floor Elevators	iQuit Salt	Slush salts
Air Factory	Juice Head	Solace
Airbender Saltz	Juice Roll UPZ	SUA vapours
Alternative Salts	Khali Vapors	Sugoi Vapor
Aqua salts	Lix Nic Salts	Superb Salt Nic
Back2Back Salts	Lung Hit Salts	SVLT
Beard Salts	Might Salts	The Finest Salt Nic
BLVc unicorn	Mighty Vapors	Time Bomb Salts
Boho Vape	Milk Pop	Vapetasia
Bomb Bombz	Minute Man Vape	Vapetasia Salts
Brella Salts	Nic Salt	VGOD salt nic
Candy King on Salt	Nkd 100	Xen Smart Vape
Clancys	Nujuice	Yami salts
Cloud Nurdz Salts	Okami salt	Yogi Salts
Dinner Lady salt	Pod Juice	Zoor
Foodfighter Salts	Pop Clouds the salt	
Fresh Pressed Salts	Premier Nic Salts	
Frisco Vapor	Prophet Premium	
Fruit freeze salts	Propoganda Salts	
Glas Basix	Ripe Vines	
Gorilla Warfare Salt	Ruthless Nic Salt	
Halo Evo	Salt Factory	
Halo Tribeca	Saltbae	
Humble salts	Salty Krew	
I Love Salts	Salty Man	
Infamous salt collection	Salty Podz	
INFZN Salts	Saucy Salts	
iONIC Nic Salts	Shijin	

'Respondents market these JLI look-alike devices—often at a fraction of the price of the JUUL system—without the same attention to quality control that JLI employs.'²⁰ JUUL is not intended as a means of weaning off of nicotine addiction, but rather has a business model based on ongoing sales of consumables (JUUL pods). In 2015, Ari Atkins, a JUUL engineer, commented: 'We don't think a lot about addiction here because we're not trying to design a cessation product at all.'²² This helps to explain the vigour of JUUL's action against counterfeit and copycat pods which enable users to purchase discounted JUUL devices and then refill them with non-JUUL products.

While first-generation cig-a-like devices did not deliver comparable nicotine levels to a cigarette, advanced personal vaporisers, with their larger aerosol volumes, may achieve similar absorption curves to combustible cigarettes.^{23–25} The average traditional cigarette contains 8–9 mg of nicotine and delivers approximately 1–1.5 mg of nicotine to the bloodstream.⁵ The amount absorbed varies according to how the cigarette is smoked. JUUL states that its pods are equivalent in nicotine delivery to a pack of 20 traditional cigarettes which contains some 160–180 mg of nicotine of which some 20–30 mg are absorbed by the smoker. The absorption of nicotine in JUUL can be compared with cigarettes using the company's data. A JUUL pod contains only a quarter of the nicotine of a cigarette pack (0.7 mL x 59 mg/mL=41.3 mg per pod) implying that its pulmonary absorption of nicotine is some four times that of a combustible cigarette. The difference may be accounted for by nicotine lost in combustible products by side stream smoke, the fraction of nicotine lost into the air from



Figure 1 Examples of large volume (30 mL), highly concentrated (5%, 5.5%, 5.9%), salt nicotine e-liquids on the market in youth-oriented flavours.

the smouldering tip, as well as nicotine remaining in the butt. In addition, unlike the aerosolised nicotine from e-cigarettes, a portion of the nicotine in tobacco smoke is bound to particulate matter and only the fraction which adheres to the alveoli may be absorbed.²⁶ The threshold for addiction of a young person has been estimated at 5 mg/day, or about 4–5 traditional cigarettes.⁵ A youth would reach the addictive threshold by inhaling the aerosol generated by merely $\frac{1}{4}$ of a JUUL pod per day.

This study identified over 70 brands offering highly concentrated nicotine e-liquids ($\geq 5\%$) in quantities 43 times greater (30 mL) than in JUUL (0.7 mL). Actual levels of nicotine in refill bottles may diverge, either higher or lower, from what is listed on the label.²⁷

Most bottles were brightly coloured and depicted sweet or fruity flavours (eg, mango, gummy bear). Bulk nicotine may be used either in refilling low volume pods which deliver modest aerosol plumes or in high powered open tank advanced personal vaporisers which expel much larger clouds of aerosol. Some bulk nicotine vendors include a caution against the latter. Although traditionally it has been said that 60 mg of nicotine is sufficient to kill an adult, more contemporary analysis shows that the lethal dose is closer to 500 mg (7 mg/kg).²⁸ The lethal amount for a 70 kg adult (490 mg) is clearly many times that of a 10 kg 2-year-old (70 mg). A JUUL pod contains 41 mg of nicotine (59 mg/mL \times 0.7 mL). This is vastly less than a similarly concentrated 30 mL bottle of nicotine salt e-liquid (1770 mg) which is theoretically potent enough to kill 25 toddlers.

While a toddler is unlikely to ingest the e-liquid in a closed pod, small bottles with colourful labels showing sweet or fruity flavours are likely very tempting to children. Deaths have been reported in children following ingestion of earlier generation, much lower nicotine e-liquids.²⁹ Calls to poison control centres due to childhood nicotine exposure have proliferated since the introduction of e-cigarettes.³⁰ As nicotine will absorb through intact skin, even contact of a concentrated e-liquid with a child's skin could lead to toxicity.

Another theoretical danger of flavoured bulk nicotine in high concentration is excessive dosing using a high powered tank system. Because of the large volume of aerosol produced, even low levels of nicotine in the e-liquid have been shown to achieve cigarette-like levels of nicotine absorption.²⁴ JUUL has demonstrated that its low power, low volume, 59 mg/mL nicotine achieved levels similar to a cigarette.³ Using a similarly concentrated nicotine in a high power, large volume device, which delivers many times the volume of aerosol as JUUL, can theoretically result in deleteriously high levels of nicotine exposure.

High concentration nicotine aerosol may also exacerbate secondhand effects. Czogala and co-workers tested 3 brands of early generations of e-cigarettes with nicotine concentrations of 11, 18 and 19 mg/mL which showed potential exposures on approximately 10% that of combustible cigarettes.³¹ While JUUL and its emulators are 3–6 times more concentrated than those tested in this study, their exhaled volume is small. However, when concentrated

nicotine e-liquids are used in high powered tank devices, the giant plume of exhaled aerosol could well lead to involuntary exposure to nicotine greater than that emanated by traditional cigarettes.

The proliferation of highly concentrated nicotine e-liquid has lowered the price of addiction. Pricing is a crucial factor in youth adoption as adolescents are notably price sensitive due to their limited discretionary income. The price of a pack of cigarettes is between \$6 and \$8 in most states and higher in some populous states such as New York (\$14). A JUUL pod, which delivers nicotine similar to a pack of cigarettes, has a retail price of \$4 and JUUL compatible pods are as low as \$2.50. Bulk e-liquid in 30 mL (5% nicotine) bottles average \$16–\$17. For example, Pod Juice sells “Loops” (picturing fruit loops cereal) with 5.5% salt nicotine in 30 mL bottles for \$13.99.³² Used in a refillable pod device of 0.7 mL (as with JUUL), this is the nicotine equivalent of 40 packs of cigarettes or about 35¢ per cigarette pack’s worth of nicotine.

JUUL has portrayed their company as wholly focused on rescuing adult smokers. ‘*What started as a design challenge has become a mission to impact the lives of adult smokers*’ (JUUL Tweet July 12, 2017). The company’s 2018 mission statement specifies its goal is to: ‘*Improve the lives of the world’s one billion adult smokers*’ (initial appearance on JUUL Twitter feed on April 2, 2018).³³ It is important to acknowledge that pod-based high-nicotine e-cigarettes may well be more effective means of transitioning nicotine addicted smokers from combustible products, a change likely beneficial to their health. Whether $\geq 5\%$ nicotine devices are more effective in transitioning cigarette smokers than other cessation aids has yet to be established by independent research. The body of data regarding lower nicotine devices suggests low grade evidence that e-cigarettes assist with smoking cessation better than placebo.³⁴ Others reviewing data for e-cigarettes on the market in 2015 have concluded that e-cigarettes are associated with significantly less quitting among smokers.³⁵ Compared with high powered tank systems, whose high temperature coils produce potential carcinogens such as formaldehyde, JUUL uses a low power aerosolisation system which may generate fewer deleterious chemicals.^{24 36}

In June 2018, JUUL made the bold, and likely unsupported pronouncement on its website that: ‘*The company’s research shows more than one million smokers have already switched to JUUL, and we are working to enable millions more to switch in the coming years through technological innovations.*’³⁷ In October 2015, JUUL co-founder James Monsees has said; ‘*We need to be the most educated company, the most diligent, the most well-researched company in vaporization more broadly—not just for the tobacco industry.*’³⁸ The company has not released data on underage use of JUUL.

Policy Implications

Discussions among the public health community concerning high concentration nicotine aerosol products focus on the need to develop effective reduced risk tobacco products for adult smokers while simultaneously protecting adolescents from using them as a gateway to nicotine addiction. It is a challenge to formulate an optimal regulatory formula which would simultaneously protect youth from nicotine addiction while encouraging the transition of smokers to safer nicotine delivery systems or, even better, to break their addiction altogether.

Various measures could be considered to achieve both protection of adolescents while maintaining high nicotine for heavy smokers. In 2009, the US Congress banned characterising flavours from traditional cigarettes except for tobacco and menthol.³⁹ In 2015, the Center for Disease control reported that 7 or 10 students who use tobacco use a flavoured product.⁴⁰ Many public health

experts advocate regulation banning youth appealing flavours from all nicotine containing e-liquids and allowing only unsweetened tobacco flavour to accompany nicotine. Opponents, primarily from the vaping industry, point to industry sponsored studies which suggest that flavours are important to adult transition from smoke to aerosol.^{41 42}

Another regulatory option would be to cap the amount of nicotine permissible in e-cigarettes. JUUL, as it is sold in the USA (59 mg/mL nicotine), would not be permitted in Europe or the UK which have adopted limits of 20 mg/mL nicotine.⁴³ If the USA adopted this standard, it would almost certainly reduce the tendency of e-cigarettes to act as a gateway to youth nicotine addiction. However, it may also reduce their efficacy in cigarette smoking cessation. As high-nicotine versions may well prove more efficacious in transitioning cigarette smokers to aerosol, one option would be to allow sale of high-nicotine e-liquids only by doctor’s prescription.

Another measure to reduce youth nicotine exposure would be to require purveyors of high-nicotine e-liquids to carry zero nicotine versions of their flavours along with the high-nicotine versions. A sizeable price differential, with the zero nicotine version priced less, would enhance appeal to youth who have limited discretionary income. The goals of non-nicotine versions would be subverted if the products were not made equally available in all vending channels (eg, online, retail outlets) and if they did not carry the same age restrictions as the nicotine version. Disadvantages of this approach includes the fact that chronic inhalation of aerosols containing propylene glycol and glycerin together with flavourant chemicals may have adverse health effects.⁴⁴ In addition, such an approach would have the potential to encourage youth to initiate smoking behaviour and then potentially transition to nicotine containing products. In addition, zero nicotine products in sweet flavours may encourage wider youth use and thus contribute to the renormalisation of smoking behaviour. However, countering this argument is the reality that JUUL has made vaping pervasive among American youth and that renormalisation among the school age demographic has already occurred.

A limitation of this study is that our online searches, while comprehensive, captured only products promoted online and likely only a fraction of these. Many local vape shops prepare their own high-nicotine formulations, a segment of the market which would have escaped our detection. In addition, the high-nicotine marketplace is expanding at impressive speed and by the time this paper is published many other new products will have entered this nascent market.

There is a clear need to regulate the sale of higher concentration nicotine solutions in larger volumes. Colourful bottles depicting sweet dessert labels with 5, 10, 20 or even 30 mL of highly concentrated nicotine carry an excessive risk of lethal child poisoning. Child-resistant packaging resistant packaging for e-liquids is being enacted by an increasing number of American states, but with inconsistent standards and weak enforcement.⁴⁵ While small quantities (eg, ≤ 1 mL) of concentrated nicotine solutions may be of lower risk when sold in hermetically closed pods, regulators should consider whether or not larger volumes of flavoured high-nicotine liquids should remain allowed on the marketplace unfettered by regulation.

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Competing interests None declared.

What this paper adds

- ▶ Until recently, most e-cigarette liquids carried 1%–2% nicotine with a few at 3% labelled as ‘super high’ intended for the ‘two packs a day smoker.’
- ▶ In 2015, JUUL introduced a 5% (59 mg/mL) pod vaping device with a novel nicotine chemistry (nicotine salts) which improved palatability enabling higher concentrations without undue bitterness.
- ▶ Following JUUL’s phenomenal success in the marketplace, numerous knock-off devices were introduced which emulated, or even exceeded, JUUL’s very high nicotine level.
- ▶ All purveyors of high-nicotine e-liquids offer them in sweet and fruity flavours.
- ▶ Bulk high-nicotine e-liquids, typically sold in 30 mL bottles, represent a poisoning risk for children.
- ▶ Nicotine percentage is inconsistently portrayed on labels.

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