The impact of electronic cigarettes on the paediatric population

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ABSTRACT

Objective To review the impact of electronic cigarettes (e-cigarettes) on children.

Methods Five electronic databases were searched through 31 December 2013. Studies in English that included data for children younger than 18 years of age were included. In addition, relevant data from articles identified during searches of the e-cigarette literature, relevant state survey data and paediatric voluntary adverse event reports submitted to the US Food and Drug Administration (FDA) were reviewed and included.

Results Use of e-cigarettes by youth is increasing and is not limited to traditional cigarette smokers. Data regarding the reasons for youth e-cigarette initiation and ongoing use are limited. The effects of e-cigarette marketing and the availability of flavoured e-liquids on youth use are unknown. The abuse liability of e-cigarettes in youth is also not known. Unintentional exposures to e-cigarettes and e-liquids have been reported in children. The number of e-cigarette-related reports received by poison centres is increasing. No data are available on secondhand and thirdhand e-cigarette aerosol exposures in children.

Conclusions Data on the impact of e-cigarettes on children are extremely limited. The available data indicate that youth awareness is high and use is increasing rapidly. The extent to which e-cigarette use in youth will result in nicotine dependence and subsequent use of other tobacco products is unknown. e-cigarettes present risks of unintentional nicotine exposure and are potential choking hazards. A greater understanding of the impact of e-cigarettes on children is needed and will be important in the evaluation of the effects of these products on the public health.

BACKGROUND

Electronic cigarettes (e-cigarettes), a popular type of electronic nicotine delivery system, aerosolise and deliver a chemical mixture typically composed of nicotine, propylene glycol and flavourings.[1] The effect of the growing popularity and availability of e-cigarettes[2 3] on children[i] is inadequately characterised. Concerns have been raised that the novel nature and flavouring of these products may appeal to youth[ii 4 5] and that industry marketing is targeting youth.[6] Approaches to e-cigarette legislation across countries are diverse, ranging from unregulated marketing to complete bans.[7] Although some US states and localities have enacted legislation to prevent sales to minors,[8] e-cigarettes can be legally purchased by adolescents in many states and are available to youth via the internet. Additional concerns exist about the potential for youth e-cigarette experimentation to result in use of other tobacco products.[4]

Other identified concerns include accidental exposure to e-cigarette products, especially exposure to the e-liquids that may have high concentrations of nicotine.[5 9] Nicotine in high concentrations is toxic; injury or death may result if a young child ingests e-liquid or is dermally exposed to a significant volume of e-liquid.[10] The health effects of paediatric exposure to secondhand and thirdhand e-cigarette aerosols are also of concern.

An understanding of the impact of e-cigarettes on children is needed to ensure the protection of this vulnerable population and the public health. This review was performed to assess current knowledge and highlight critical research gaps.

METHODS

Literature search and resource review

Systematic literature searches were conducted through 31 December 2013 to identify research related to e-cigarettes and children. Five reference databases (Web of Knowledge, PubMed, SciFinder, Embase and EBSCOhost) were searched using a set of relevant search terms used singly or in combination. Search terms included 'electronic nicotine devices' OR 'electronic nicotine device' OR 'electronic nicotine delivery systems' OR 'electronic nicotine delivery system' OR 'electronic cigarettes' OR 'electronic cigarette' OR 'e-cigarettes' OR 'e-cigarette' OR 'e-cig' OR 'e-cigs' OR 'adolescen' (used to capture 'adolescent', 'adolescents' and 'adolescence') OR 'child' OR 'teen' OR 'youth'.

Articles considered for inclusion were (1) written in English, (2) publicly available, (3) published in a peer-reviewed journal and (4) dealt partly or exclusively with children.

A total of 59 unique articles met the inclusion criteria. Article titles and abstracts were screened for relevance to the impact of e-cigarettes on the paediatric population, yielding 25 articles for full-text review. Of these, 12 published studies were deemed relevant for this analysis. Two additional publications were identified for inclusion based on literature searches that used more general terms relevant to e-cigarettes and a manual search of the reference lists of the studies. The 14 studies included in the analysis were published between 2011 and January 2014. Meaningful study limitations are noted in the analysis. Information from two state surveys was also included.

[i]Children are defined in this paper as the paediatric population aged 0–18 years.
[ii]Youth are defined in this paper not as a specific age in years, but as a developmental stage between childhood and adulthood.

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Adverse event database analysis

The US Food and Drug Administration (FDA) Center for Tobacco Products (CTP) Office of Science has maintained a database of voluntarily reported adverse events (AEs) related to e-cigarettes since the first e-cigarette AE report was received in August 2008. As of 30 September 2013, the database included 74 AEs, 3 of which involved children aged 0–18 years (discussed below).

RESULTS

Literature and resource review

Awareness and use

France

An analysis of e-cigarette use in a representative sample of 188 000 Parisian[iii] students aged 12–19 years was conducted by Dautzenberg *et al*[11] using first quarter 2012 data from a survey on tobacco use. Of the 3409 participants (including 575 non-responders), 277 (8.1%) reported ever use of e-cigarettes (ie, 6.4%, 11.8%, 19% and 9.3% in students aged 12–14, 15–16, 17 and 18–19 years, respectively). Girls aged 12, 13 and 17 years had higher rates of e-cigarette use compared with boys; however, use in boys and girls was the same in respondents aged 14–15 years. Of ever users aged 12–19 years, 47 (18.6%) reported to have never used traditional cigarettes. e-cigarette use was lower in youth smokers who planned to quit now or in 6 months. Ever use was higher in regular smokers, youth who had used shisha or cannabis and youth who had consumed more than three servings of alcohol on more than four occasions.

Hungary and Lithuania

An overview of e-cigarettes published by the German Cancer Research Center included information about e-cigarette use by Hungarian[iv] and Lithuanian[v] youth.[12] The 2012 Global Youth Tobacco Survey identified that 13% of Hungarian youth aged 13–15 years had used e-cigarettes within the last 30 days (16% of boys and 11% of girls), and 93.3% of users were occasional or daily smokers. Higher e-cigarette use was identified among non-daily smokers (60.7%) compared with daily smokers (31.5%). Almost 5% of the non-smokers were users of e-cigarettes. e-cigarette use was reported by 9.1% of Lithuanian youth aged13–15 years (10.3% of boys and 7.7% of girls).

Korea

Three publications provided information about youth e-cigarette awareness and use in South Korea[vi]. [13–15] Cho *et al*[13] conducted an analysis of survey data from the 2008 Health Promotion Fund Project in Korea to evaluate e-cigarette awareness and factors that may affect e-cigarette use among youth in five schools from different geographic regions in Korea. Of the 4341 students who completed the survey, 444 (10.2%) students responded that they were aware of e-cigarettes and 22 (0.5%) students reported ever having used an e-cigarette. Sources of exposure to e-cigarettes included the internet (46.4%), friends (27.9%), television (11.0%) and books (9.3%). Statistically significant higher rates of e-cigarette use were identified in boys, smokers of traditional cigarettes, youth with lower school life satisfaction and youth exposed to traditional cigarette smokers in the home. Statistically significant differences in use between middle and high school students were not identified.

In a 2011 publication by Lee *et al*[14] addressing public health concerns associated with e-cigarettes in South Korea, the authors state that no research studies have evaluated e-cigarette use in South Korea, but the media report that youth account for 20% of e-cigarette sales and that adolescents use e-cigarettes during school and exchange cartridges to sample different flavours. A 2013 study by Lee *et al*[15] analysed 2011 Korean Youth Risk Behaviour Web-based Survey data from students (n=75 643) aged 13–18 years. A total of 9.4% of participants reported ever e-cigarette use and 4.7% reported current e-cigarette use (ie, use in the past 30 days). Of the ever e-cigarette users, 8.0% were ever dual users (ie, e-cigarette and traditional cigarette users) and 1.4% were ever e-cigarette only users. Of the current e-cigarette users, 3.6% were dual users and 1.1% only used e-cigarettes. Compared with never or former traditional cigarette smokers, current traditional cigarette smokers were more likely to use e-cigarettes. Among current smokers, current e-cigarette users smoked more traditional cigarettes than never or former e-cigarette users. Smokers who had tried quitting in the past 12 months were significantly more likely to use e-cigarettes (ie, 40.0% compared with 29.1%). Boys and older students reported higher e-cigarette use (ie, 7.8% of boys compared with 1.8% of girls; 6.2% of 12th graders compared with 2.0% of seventh graders).

Poland

To evaluate awareness, use and perceptions of e-cigarettes in youth and young adults in Poland,[vii] Goniewicz *et al*[16] conducted a survey of more than 20 000 students enrolled at more than 175 nationally representative state high schools and universities between September 2010 and June 2011. Among students aged 15–19 years, 23.5% reported ever use of an e-cigarette and 8.2% reported e-cigarette use within the previous 30 days. Multivariate analyses identified higher rates of e-cigarette ever use in traditional cigarette smokers, boys, youth living in urban areas and youth whose parents smoke traditional cigarettes. e-cigarettes were considered safer than traditional cigarettes by more than 50% of Polish students surveyed. The authors noted that rural areas may have been underrepresented in the survey.

US publications with national data

Two publications provide US national survey data about youth e-cigarette awareness and use. Pepper *et al*[17] analysed data from a November 2011 survey that assessed the awareness and willingness of US boys to try e-cigarettes. The participants (n=228) were 11–19 years old and sons of members of a nationally representative sample of US households. Two participants (1%) had tried e-cigarettes and an additional 67% were aware of e-cigarettes. Awareness was higher in older boys (ie, 72% and 76% in boys aged 14–16 and 17–19 years, respectively) compared with younger boys (ie, 52% in boys aged 11–13 years). Eighteen per cent of respondents were willing to try an e-cigarette. Willingness to try e-cigarettes was lower in non-smokers and not affected by the presence or absence of flavourings.

[iii]The author notes that e-cigarettes appeared recently on the French market and rapidly became a familiar product to young Parisian schoolchildren.[11]

[iv]E-cigarettes are not explicitly regulated in Hungary.[12]

[v]Lithuania does not have specific e-cigarette regulations.[12]

[vi]First introduced in South Korea in 2007, e-cigarettes are available to the public (including adolescents) and have been marketed as safer than traditional cigarettes and as smoking cessation aids.[13 14]

[vii]Per the authors, e-cigarettes have been available on the Polish market since early 2008. Although marketing of e-cigarettes is permitted in Poland within its current regulatory framework, sales to children less than 18 years are prohibited.[16]

The prevalence of ever and current e-cigarette use in US youth was evaluated using data from the 2011 and 2012 National Youth Tobacco Survey (NYTS), a cross-sectional, nationally representative sample of US students in grades 6–12.[18] During 2011–2012, e-cigarette ever and current use[viii] doubled among US middle and high school students. As of 2012, approximately 1.78 million US students reported using an e-cigarette. During 2011–2012, reports of ever and current e-cigarette use in middle school students increased from 1.4% to 2.7% and from 0.6% to 1.1%, respectively, while reports of ever and current e-cigarette use in high school students increased from 4.7% to 10.0% and from 1.5% to 2.8%, respectively. In 2012, 9.3% of ever e-cigarette middle and high school users reported never smoking traditional cigarettes (20.3% of middle and 7.2% of high school ever users).

US publications with state-specific data

Data from the 2013 Florida Youth Tobacco Survey, a survey administered to more than 12 000 middle and high school students in more than 170 Florida[ix] public schools, were analysed to identify ever and current e-cigarette use.[19] Ever use was reported by 4.3% and 12.1% of middle and high school students, respectively. The prevalence of ever use since 2011 increased by 43.3% and 101.7% among middle and high school students, respectively. Current use was reported by 1.8% of middle and 5.4% of high school students. Since 2011, the prevalence of current use increased by 20.0% among middle school students and by 74.2% among high school students. Boys had higher rates of e-cigarette use than girls.

The Utah Prevention Needs Assessment, a survey of more than 50 000 students in grades 6, 8, 10 and 12 identified that the percentage of Utah[x] students (grades 8, 10 and 12) reporting current e-cigarette use increased from 1.9% in 2011 to 5.9% in 2013.[20] Students (grades 8, 10 and 12) were more likely to report current e-cigarette use than current use of any other tobacco or nicotine-containing product and 31.7% of students reporting e-cigarette ever use were never users of traditional cigarettes.

To evaluate the prevalence and correlates of e-cigarette use in adolescents, Camenga *et al*[21] analysed data from three waves of a tobacco use behaviour survey administered to students in grades 9 through 12 in a suburban high school in Connecticut[xi] and in New York[xii]. Participants were surveyed in February 2010 (n=1719), October 2010 (n=1702) and June 2011 (n=1345). The prevalence of students who reported e-cigarette use in the past 30 days increased from 0.9% (n=16) in February 2010 to 2.3% (n=31) in June 2011. When adjusted for school, grade, sex, race and smoking status and compared with the first survey wave, students in the second and third waves had increased odds of past 30-day e-cigarette use. Increased adjusted odds of past 30-day e-cigarette use were identified in current traditional cigarette smokers in all study waves.

To investigate the beliefs and perceived social norms of e-cigarette use, Peters *et al*[22] posed four open-ended questions to focus groups with 47 African-American and Hispanic-American boys aged 15–17 years attending an alternative Texas[xiii] high school in the fall of 2012. The reasons for e-cigarette use in youth based on the participant responses were 'expeditious consumption and concealment' (n=19, 40%), 'high social approval' (n=12, 26%), 'healthier than cigarettes' (n=9, 19%) and 'odourless' (n=7, 15%). The participants stated they used e-cigarettes 'everywhere' (n=18, 38%), 'school bathroom' (n=12, 26%), 'home' (n=10, 21%), 'school staircases' (n=5, 11%) and 'school cafeteria' (n=2, 4%). Respondents indicated 'high social approval' from friends (n=23, 49%) and that friends think that e-cigarettes are 'healthier than cigarettes' (n=17, 36%) and provide a 'safe high' (n=7, 15%). Per the participants, e-cigarettes are popular because they are accessible (n=20, 43%), 'healthier than cigarettes' (n=14, 30%) and 'aesthetically pleasing' (n=11, 23%).

Pepper *et al*[23] published results from a state-wide survey of a sample of healthcare providers that provide preventive care to children aged 11–17 years. The survey was administered in April 2013 to 561 providers (ie, family medicine physicians (46%), nurse practitioners (34%), paediatricians (20%)) in Minnesota[xiv]. Ninety-two per cent of respondents reported being aware of e-cigarettes, and 11% reported having provided care to at least one adolescent who had used an e-cigarette. Among providers who responded that they were aware of e-cigarettes, 83% reported that they knew 'a little' or 'nothing at all' and the most frequently reported sources of information were patients (62%), news stories (39%) and advertisements (37%).

Unintentional exposure

A search by Cantrell of a single state-wide poison system database identified 35 cases of e-cigarette exposure from 2010 through 2012.[24] The number of reports increased each year, from 4 in 2010 to 19 in 2012. Fourteen cases were identified in children younger than age nine; five cases of inhalation and nine cases of ingestion. The ingestions were reported as 'taste exposures', and one case reported three episodes of vomiting. The inhalation reports were from a 'few puffs' on an e-cigarette, and one case resulted in transient coughing.

Ordonez *et al*[25] evaluated a single state-wide poison centre system database and identified 79 exposure cases reported between January 2009 and March 2013. Over the period studied, the number of reports increased each year (2 in 2009, 6 in 2010, 11 in 2011, 43 in 2012 and 17 in the first quarter of 2013). Patients aged 5 years and younger represented 46% of cases, and patients aged 6–19 years represented 3% of cases. The routes of exposure and outcomes were not reported based on age group. Exposures occurred through ingestion (73%), inhalation (18%), dermal exposure (14%), multiple routes (9%) and ocular exposure (4%). Outcomes included no effect (25%), minor effect (18%) and moderate effect (3%). In 38% of cases, the exposures were judged non-toxic or 'minimal'; these cases were not followed. An additional 13% of cases that were potentially toxic were unable to be followed. Nausea, vomiting, headache and dizziness were reported in 5% or more of patients. Exposures were unintentional in 80% of cases, intentional in 8% and adverse reactions in 13%.

[viii]The referenced US national and state surveys define current use as use on one or more days in the past 30 days.[18–20]
[ix]Florida does not have restrictions on e-cigarette sales to minors.[8]
[x]Utah passed legislation prohibiting the sale of e-cigarettes to minors in 2010.[8]
[xi]Connecticut does not have restrictions on e-cigarette sales to minors.[8]
[xii]E-cigarette sales to minors are prohibited in New York as of 1 January 2013, but were not prohibited at the time these surveys were administered.[8]
[xiii]Texas does not have restrictions on e-cigarette sales to minors.[8]
[xiv]The sale of nicotine delivery products intended for human consumption to children is prohibited in Minnesota as of 11 May 2010.[8]

Intentional misuse in children

A case of attempted suicide by a 13-year-old teen who ingested 3 mL of nicotine liquid (unknown concentration) was reported by Christensen.[26] The patient developed nausea and shivering 15 min after ingestion. Treatment included oral administration of activated charcoal, and symptoms improved 1 h after the ingestion.

CTP adverse event database analysis

FDA-CTP received its first e-cigarette AE report in August 2008 and had received 74 voluntary reports with health effect complaints related to e-cigarettes from users and non-users of these products as of 30 September 2013. Three of the 74 reports involved children: death of an infant after choking on an e-cigarette cartridge, a 'spasm/dystonic' reaction (described as a rhythmic right shoulder shrug) after secondhand exposure to e-cigarette aerosol in an 8-month-old infant, and burn injuries to a 3-year-old resulting from a fire caused by an e-cigarette that exploded during charging.

The FDA-CTP AE database has important limitations. The FDA AE reporting system is a voluntary reporting system and may only collect a small fraction of AEs related to a product. In addition, consumers have reported problems with tobacco products to FDA through MedWatch, the FDA Safety Information and Adverse Event Reporting Program, which does not collect data specific to tobacco products. Reports in the FDA-CTP AE database likely underrepresent the true number and types of AEs associated with e-cigarettes and cannot be used to calculate incidence (occurrence rates) or estimate risk.

DISCUSSION

US and international survey data reveal that youth are aware of e-cigarettes and use of these products in this population is rapidly increasing. NYTS data estimate that ever and current use of e-cigarettes by US middle and high school students doubled between 2011 and 2012 and 1.78 million US youth have used an e-cigarette.[18] Data from one US state identified that youth are more likely to report current e-cigarette use than current use of any other tobacco or nicotine-containing product.[20] US and international data reveal that although most youth who have used e-cigarettes have also used traditional cigarettes, this is not always the case. The percentage of ever users who are non-smokers may be higher in younger adolescents than in older adolescents.

Although the regulation of e-cigarettes varies across countries, the products are widely available and are accessible to youth, even in US states that have legislation banning sales to minors. Given the relatively low price of some e-cigarettes, cost is likely not a barrier to purchase. Data regarding the enforcement of sales bans to minors and comparative use rates and trends between US states are not available.

Minimal data are available regarding the reasons for youth e-cigarette initiation and ongoing use. Data from one US high school suggest that youth use e-cigarettes because they can be 'smoked quickly', are 'smokeless' and are 'easy to conceal'.[22] e-cigarettes and e-liquids are available with sweet flavourings such as chocolate, fruit and candy, but the impact of flavourings on e-cigarette appeal to children and youth initiation has not been adequately evaluated.[27] e-cigarette advertising and promotion is unregulated in the US, and the impact of the marketing of these products on youth has not been adequately explored. A 2008 survey of South Korean youth identified that the internet was the most common source of exposure to e-cigarettes. e-cigarette advertisements on the internet, television and other entertainment media, celebrity product endorsements, portrayal of use in movies and product packaging may promote youth initiation.[28] In addition, e-cigarettes are often portrayed and perceived as less harmful than traditional tobacco products or as 'safe'. Additional data on youth perceptions are needed to evaluate initiation risks and to inform the development of educational messaging to prevent use.

Data describing the types of e-cigarette devices and products that are being purchased and used by youth are not available. In addition, information about frequency and patterns of e-cigarette use, and how youth are using these products, is lacking. Unlike traditional tobacco products for which use can be described based on a unit (eg, smoking one traditional cigarette), a standardised method or strategy to quantify e-cigarette use is not available.

The extent to which teens are modifying or using e-cigarettes in ways other than intended, such as battery stacking or dripping e-liquids directly on the atomiser to increase nicotine delivery, is unknown. Not only are e-cigarette products designed specifically to aerosolise marijuana or hashish concentrates and oils available in some states,[29] social media sites provide instructions on how to prepare marijuana-derived oils or waxes for use in e-cigarette devices.[30–32] The extent to which youth are using e-cigarettes to aerosolise e-liquids or other substances that are not derived from tobacco is not known. Although 7 of the 13 publications that reported youth use data provided the survey or focus group question(s) regarding e-cigarettes, none of the questions asked about what substances are being used in the e-cigarettes and only one publication provided a survey question that defined e-cigarettes (ie, 'an electronic cigarette that is filled with liquid nicotine').

The abuse liability of e-cigarettes in youth is unknown. Non-clinical studies have identified that exposure to nicotine can cause neuroplastic changes in the developing brain that favour continued use and can impact executive cognitive function later in life.[33] The extent to which e-cigarette use in youth will result in nicotine dependence and subsequent use of other tobacco products is unknown.

Unintentional exposures, including ingestion of e-liquids and inhalation of e-cigarette aerosols, have been reported in paediatric patients, and the number of e-cigarette-related reports received by poison centres is increasing. Nicotine is rapidly absorbed from the lungs and is readily absorbed through the skin, mucous membranes and gastrointestinal tract. The estimated mean lethal dose of nicotine is estimated to be 30–60 mg for adults, and the lethal dose for children is considered to be 10 mg.[34] Although serious nicotine poisoning due to traditional cigarettes is relatively rare, the high concentrations of nicotine in the e-liquids (eg, e-liquids with concentrations up to 100 mg/mL are available) may pose greater risk of nicotine toxicity following inhalation, ingestion or dermal exposure.

Choking on e-cigarette components has been reported and is a potential paediatric hazard. In addition, e-cigarette explosions during use and charging have been reported to FDA and by the media.[35–38] The risk of injury resulting from e-cigarette explosions is of concern for children and adults. Intentional misuse of e-liquid products (eg, e-liquid ingestion to commit suicide) has been reported in adults and one adolescent.

The potential toxicological liabilities and health risks of paediatric exposure to secondhand and thirdhand e-cigarette aerosols is unknown. FDA has received reports of adverse health effects due to secondhand exposure in an infant and in adults[35]; however, published studies evaluating the impact of

secondhand and thirdhand e-cigarette aerosol exposures in children were not identified. To better understand the risks associated with secondhand and thirdhand e-cigarette aerosol exposure, additional research is needed to characterise the chemical constituents of e-liquids and aerosols and evaluate their health effects in adults and children.

CONCLUSIONS

Data on the impact of e-cigarettes on children are limited. The available data indicate that youth awareness is high, use is increasing rapidly and use in youth is not limited to current smokers. The extent to which experimentation with e-cigarettes in youth will result in nicotine dependence and subsequent use of other tobacco products is unknown. The impact of product flavourings and marketing on youth e-cigarette initiation and ongoing use is also inadequately characterised.

In addition to e-cigarette initiation by youth, e-cigarettes present risks of unintentional nicotine exposure and some product parts are potential choking hazards. The impact of secondhand and thirdhand aerosols on children has not been systematically evaluated.

More research is needed to adequately understand the risks of e-cigarettes to children and to evaluate the impact of these products on the public health. Programs to educate children, parents, paediatric care providers and the general public about what is known about e-cigarettes are needed. In addition, more robust implementation of effective tobacco control strategies focused on preventing youth initiation and use of traditional and novel tobacco products is needed.

What this paper adds

- This is the first paper to provide a summary of the available data (including adverse events reported voluntarily to FDA) on the impact of e-cigarettes on children.
- Data from several studies indicate that youth use of e-cigarettes is increasing and is not limited to current smokers of traditional cigarettes.
- Poison control centres are receiving increasing numbers of reports of e-cigarette exposures.
- These concerning trends underscore the fact that additional information about the impact of e-cigarettes on children is needed to protect the public health.

Contributors ELD conducted the literature search, reviewed abstracts and composed this paper. She is the guarantor.

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