The youth e-cigarette epidemic: updates and review of devices, epidemiology and regulation

Olusegun Owotomo, MD, PhD, MPH,[a] and Susan Chu Walley, MD, MHCM, NCTTP, FAAP[a,b,*]

Adolescent e-cigarette use constitutes a major public health challenge that has reversed the steady progress made in the past three decades to reduce youth tobacco use in the United States (U.S.). Although the prevalence of e-cigarette use has declined in the past two years, 24% of 12th grade students and 8.9% of 8th grade students in 2021 used e-cigarettes or engaged in vaping of any kind in the prior 30 days. The current e-cigarette landscape is dominated by discrete and stylish pod-based e-cigarettes with varying capacity for customized nicotine delivery, vapor concealment, and child-appealing e-liquid flavors. E-cigarettes continue to evolve rapidly with innovative technology as manufacturers seek loopholes in regulatory efforts and to maximize existing marketing opportunities. Regulatory efforts so far have focused largely on marketing restrictions with enforcement decisions prioritizing smoking cessation potential of e-cigarettes for adult smokers over risk of nicotine addiction in adolescents. Disposable e-cigarette products advertising synthetic nicotine and menthol-containing products remain on the market and continue to gain popularity among adolescents. This article describes e-cigarette devices, provides an overview on epidemiology of U.S. adolescent e-cigarette use, and reviews the existing federal, state, and local e-cigarette regulations with future recommendations for stakeholders.

Curr Probl Pediatr Adolesc Health Care 2022; 52:101200

Introduction

E-cigarettes constitute a major public health challenge that has reversed the steady progress made in the past three decades to reduce youth tobacco use in the United States (U.S.).[1,2] Rates of adolescent e-cigarette use remain remarkably high,[3] largely driven by rapidly evolving e-cigarette technology,[4] and aggressive youth-targeted marketing[5]—emphasizing the need for targeted prevention and control strategies.

E-cigarettes were first introduced to the U.S. in 2006[2] and in 2014 became the most common form of tobacco products used by adolescents, eclipsing other tobacco products including combustible cigarettes.[2,3] In 2018, the U.S. Surgeon General declared youth e-cigarette use an epidemic due to the rapid increase in its uptake by adolescents and proliferation of potentially addictive and youth-appealing e-cigarette brands such as JUUL®.[6,7] Most recently, the 2021 Monitoring the Future Survey indicated that nearly one in four (24%) 12th grade students and almost one in ten (8.9%) 8th grade students currently use e-cigarettes.[3]

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Although the long-term adverse effects of e-cigarette use are yet to be fully established, some of the short-term clinical and public health consequences are now well-known including risk of nicotine addiction—which is harmful to the developing adolescent brain,[2,8,9] progression to conventional cigarette smoking,[10,11] and negative effects on respiratory health as exemplified by the EVALI (e-cigarette or vaping use-associated lung injury) outbreak that resulted in over 2800 hospitalizations and sixty-eight deaths in the U.S.[12,13]

From the [a]Children's National Hospital, 111 Michigan Ave NW, Washington, DC 20010, USA; and [b]George Washington University School of Medicine and Health Sciences, Washington, DC, USA.
*Corresponding author at: Children's National Hospital, 111 Michigan Ave NW, Washington, DC 20010, USA.
E-mail: swalley@childrensnational.org

Curr Probl Pediatr Adolesc Health Care 2022;52:101200
1538-5442/$ - see front matter

https://doi.org/10.1016/j.cppeds.2022.101200

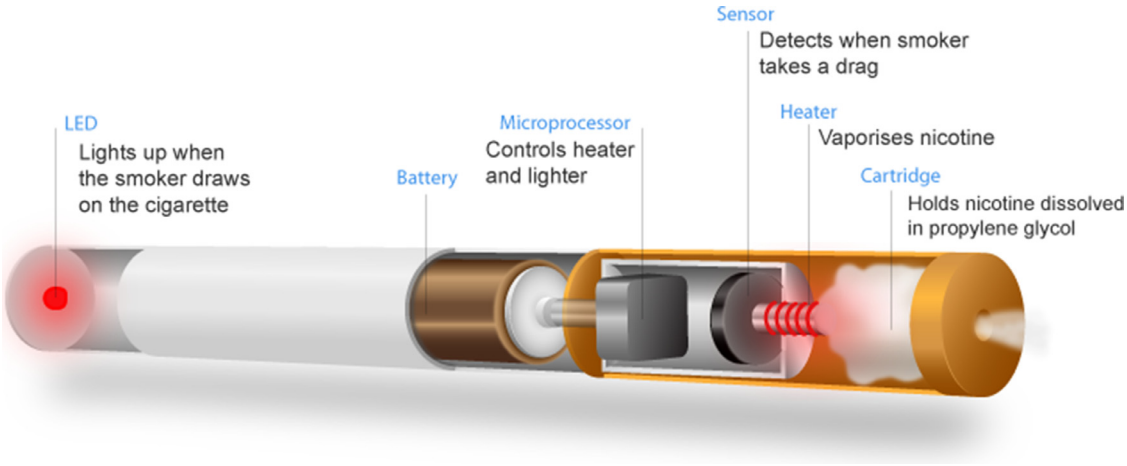

Fig. 1. Components of an e-cigarette. Courtesy US Department of Transportation.[20]

Multilevel interventions to address adolescent e-cigarette use in the U.S. have included regulatory efforts on manufacturing and marketing, age and public use restriction policies, mass media campaigns, and school-based and clinical interventions.[2,14] Regulatory efforts have been delayed due to initial ambiguity on the authority of the U.S. Food and Drug Administration (FDA) to regulate e-cigarettes,[15] with subsequent postponement in the implementation of proposed regulations,[16] and regulatory bypass by e-cigarette companies through rapidly evolving product innovation.[17,18] Policy interventions to curb adolescent e-cigarette use at state and local government levels have included prohibition of sales of flavored e-cigarettes, expansion of comprehensive public smoking bans to include e-cigarettes, and increasing age-limit of tobacco purchase to age 21 years.[7,18,19]

This article defines and describes e-cigarette devices and use, provides an overview on epidemiology of adolescent e-cigarette use in the U.S., and reviews the existing federal, state, and local regulations to curb adolescent e-cigarette use with future recommendations for stakeholders.

Background and description

E-cigarettes or vaping devices utilize battery technology to generate inhalable aerosol from a solution (often called e-liquid) that typically contains nicotine, humectants (propylene glycol or vegetable glycerin), flavored chemicals, and other additives.[2,3,20] The design and technology surrounding e-cigarettes vary widely but a typical e-cigarette has four primary components (Fig. 1)—a reservoir, cartridge or tank (containing the e-liquid); a heating coil; a sensor (to activate the heating coil); and a battery (to power the device).[2,20–22] When the heating coil of an e-cigarette is activated, e-liquid is aerosolized to form a vapor that is inhaled by the user—mimicking the act of conventional cigarette smoking.[2,21,22] E-liquids come in a variety of dessert, fruit and candy flavors that are attractive to adolescents and additional additives can be added including tetrahydrocannabinol (THC).[3,21] The nicotine content in e-liquids can be as high as 59 mg/mL (equivalent to the nicotine content in two packs of conventional cigarettes) in brands such as JUUL—raising concerns for nicotine addiction.[7,21]

History and evolution

E-cigarettes were first introduced as battery-powered devices that resemble combustible cigarettes in design and dimensions.[22] For example, first generation e-cigarette products, also called cigalikes, shared similar design with conventional cigarettes in shape, size, and color, and came with prefilled or refillable cartridges for holding the e-liquid.[2,21] Similarly, second generation e-cigarettes are often shaped like pens but bigger than the first generation e-cigarettes because they have reservoirs designed to hold larger volumes of e-liquid.[2]

Third and fourth generation e-cigarettes include vape mods and pod-based systems, respectively, represent a shift from earlier designs and ushered in user modification technology.[2,23] Vape mods, also called tank system or advanced personal vaporizers, are large flashlight-like devices that hold e-liquids in a tank

system and users have the ability to mix a blend of e-liquids and self-adjust the power and temperature of the device to modify flavor and vapor cloud size.[24] The popularity of vape mods have been overshadowed by pod-based devices, which have a sleek design and come with pre-filled or refillable cartridges. The e-liquid in pod-based devices contains nicotine salts compared to earlier generations of e-cigarette products that utilized freebase nicotine.[25] Nicotine salts in pod-based devices allow for ease of inhalation and rapid absorption into the bloodstream to produce similar effects as conventional cigarettes.[25]

The current e-cigarette landscape is dominated by discrete and stylish pod-based e-cigarettes with varying capacity for customized nicotine delivery, vapor concealment, and attractive e-liquid flavorings.[4,22,23] For example, one of the most popular e-cigarettes JUUL—which looks like a USB flash drive—represents a sub-generation of pod-based e-cigarettes with rechargeable prefilled or refillable cartridges.[7,26] More recently, disposable e-cigarettes such as Puff Bar have emerged and represent another sub-generation of pod-based devices with prefilled cartridges that are pre-charged and disposable after use.[4,27] In July 2020, FDA ordered the removal of Puff Bar from the market citing lack of required premarket authorization.[28] However, Puff Bar, officially re-entered the U.S. e-cigarette market in 2021 with the introduction of e-liquids advertising synthetic nicotine claimed to have been created in a laboratory and not derived from tobacco leaf. Puff Bar claims synthetic nicotine is not a tobacco product and thus not subject to FDA regulatory oversight.[29] Puff Bar is currently the most popular e-cigarette in the U.S., endorsed by 26.1% of high school current e-cigarette users as their usual brand compared to 5.7% who endorsed JUUL.[30] In March 2022, the U.S Congress passed legislation to expand the definition of tobacco products regulated by the FDA to include products such as Puff Bar that use synthetic nicotine.[31]

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E-cigarettes continue to evolve rapidly with innovative technology as manufacturers seek loopholes in regulatory efforts and to maximize existing marketing opportunities. Examples of current e-cigarette devices in the market are depicted in Fig. 2.

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Epidemiology

E-cigarettes are currently the most common tobacco products used by U.S. adolescents.[3,30] The prevalence of adolescent e-cigarette use has risen steeply since it was first measured by the National Youth Tobacco Survey (NYTS) in 2011.[2] Among U.S. adolescents in grades 6−12, prevalence of current e-cigarette use (past 30-day use) rose rapidly from 1.1% in 2011 to 11.3% in 2015.[2] Prevalence of e-cigarette use continued to rise, peaking in 2019, with 27.5% of high school students and 10.5% of middle school students reporting current e-cigarette use.[32]

Between 2019 and 2021, there was an overall decline in U.S. adolescent e-cigarette use. The 2021 NYTS showed a decline in prevalence of current e-cigarette use among U.S. adolescents to 7.6%−2.8% among middle school students and 11.3% among high school students.[30] This was corroborated by findings from the 2021 MTF survey, although with higher estimates.[3] In a combined national representative sample of 8th, 10th, 12th grade students, prevalence of current vaping of any kind dropped from 22.5% to 15.9%, prevalence of current nicotine vaping dropped from 18.1% to 13.3%, and prevalence of current marijuana vaping and vaping of just flavorings dropped from 10.1% to 7.8% and 9.6% to 6.1%, respectively.[3]

A combination of factors may have potentially contributed to the reported decline in adolescent e-cigarette use including the ongoing COVID-19 pandemic with change to online data collection,[3,30] the EVALI outbreak of 2019 that increased awareness on the health risks associated with e-cigarette use,[12,13] and policy and regulatory changes—such as FDA's restriction of sales of certain products,[28] state and local ordinances banning sales of flavored

Fig. 2. Examples of current e-cigarette devices in the market. A. Blu cigalike (1st generation). B. NJOY vape pen (2nd generation). C. Vape Mod (3rd generation). D. JUUL (pod-based 4th generation). E. Puff Bar Puff Jumbo (5% nicotine salt with 2500 puffs) Strawberry and cream flavored (disposable e-cigarette). F. POP mango flavored (5% nicotine with 400 puffs) mango flavored (disposable e-cigarette). G. Suorin drop refillable e-cigarette (4th generation). H. Candy King e-liquid.

e-cigarettes, and enactment of tobacco 21 legislation.[33–35] In any case, rates of e-cigarette use among U.S. adolescents remain remarkably high with most recent estimates from 2021 MTF survey indicating that nearly one in four (24%) 12th grade students and almost one in ten (8.9%) 8th grade students currently use e-cigarettes or engage in vaping of any kind.[3] Further, 7.6% of 8th grade students and 19.6% of 12th grade students currently vape nicotine; and 2.9% and 12.4% of 8th grade and 12th grade students, respectively, currently vape marijuana.[3] Trends in e-cigarette use among U.S. adolescents from 2021 MTF survey are depicted in Fig. 3.[3]

Regulation and policies

Government regulation and policies to address adolescent e-cigarette use have revolved around three central themes—regulation of e-cigarette products including manufacturing and marketing restrictions; age-restriction on sales; and broadening existing tobacco control policies to include e-cigarettes.

FDA regulation: deeming rule, premarket tobacco product applications (PMTAs), and flavor bans

E-cigarettes were largely unregulated in the U.S. at the federal level until August 2016 when the FDA finalized the Deeming Rule that extended its regulatory authority to all tobacco products including e-cigarettes.[7,21,36] With this authority, the FDA was able to establish product standards and regulate the manufacture and marketing of e-cigarettes as with cigarettes.[36] Provisions of the Deeming Rule include requirement for pre-market review of e-cigarettes products that were in the market prior to the rule, prohibition of sales to individuals <18 years, banning vending machine sales of e-cigarettes (in facilities where young people <18 years are allowed), banning distribution of free samples of e-cigarettes or its components; and requirement for product packages to display warning on nicotine addictiveness.[36,37]

The FDA proposed to grant marketing privileges only to e-cigarette products submitted through PMTAs and deemed appropriate for protecting public health.[38] Following the Deeming Rule of 2016,

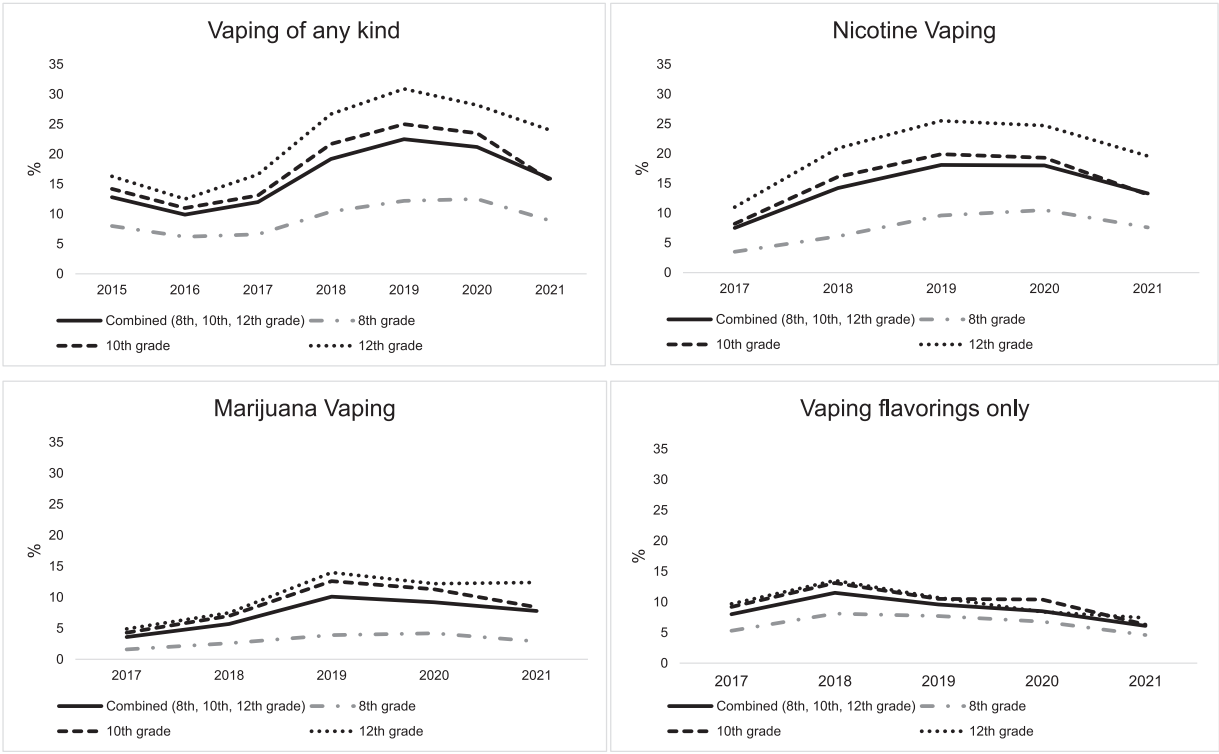

Fig. 3. Trends in past 30-day vaping among US adolescents, created from MTF survey results.[3]

e-cigarette companies initially had two years to submit their PMTAs, but the submission deadline was postponed and did not take effect until September 2020.[39,40] Products for which PMTAs were submitted remained on the market until September 2021 subject to the FDA's review and enforcement policies.[40] At the time of this publication, the FDA had taken action on approximately 99% of nearly 6.7 million e-cigarette products submitted for premarket authorization.[38] Over one million products have been issued marketing denials and only eleven products from two companies have been authorized for marketing in the U.S.—with the FDA citing potential smoking cessation benefits to adults and low risks posed to youth.[38,41] Decisions on the applications by major e-cigarette brands such as JUUL have yet to published and their products remain in the market.[38]

The FDA continues surveillance on unauthorized marketing of e-cigarette products with flavoring ingredients but has yet to take action on menthol-containing e-cigarette products.[38,41] In January 2020, the agency finalized enforcement policy on unauthorized flavored cartridge-based e-cigarettes (products with enclosed e-liquid cartridges such as JUUL) that appeal to children, including fruit and mint ingredients, but excluded menthol and tobacco-flavored products.[39] In July 2020, the FDA extended this policy to flavored disposable e-cigarettes (such as Puff Bar) and youth-appealing e-liquids which were not covered in the initial policy announcements.[27,28] The agency issued warning letters to ten e-cigarette companies that manufacture and market these products because they lacked required premarket authorization.[28] Most recently, the emergence and market proliferation of disposable e-cigarettes with e-liquids advertising synthetic nicotine (such as Puff Bar) was met by federal legislation that expands definition of tobacco products to include synthetic nicotine and gives the FDA regulatory authority over these products.[31] At the time of this publication, disposable e-cigarettes with e-liquids advertising synthetic nicotine and menthol-flavored e-cigarette products (including cartridge-based and disposables) remain on the market.[30,42] In 2021, menthol was the most common flavor used by nearly 30% of adolescent current flavored e-cigarette users—21.5% of current flavored disposable e-cigarette users, 46.5% of current flavored cartridge users, and 24.7% of current flavored mod systems users.[30]

Currently, comprehensive flavored tobacco product restriction policies that prohibit sales of all types of

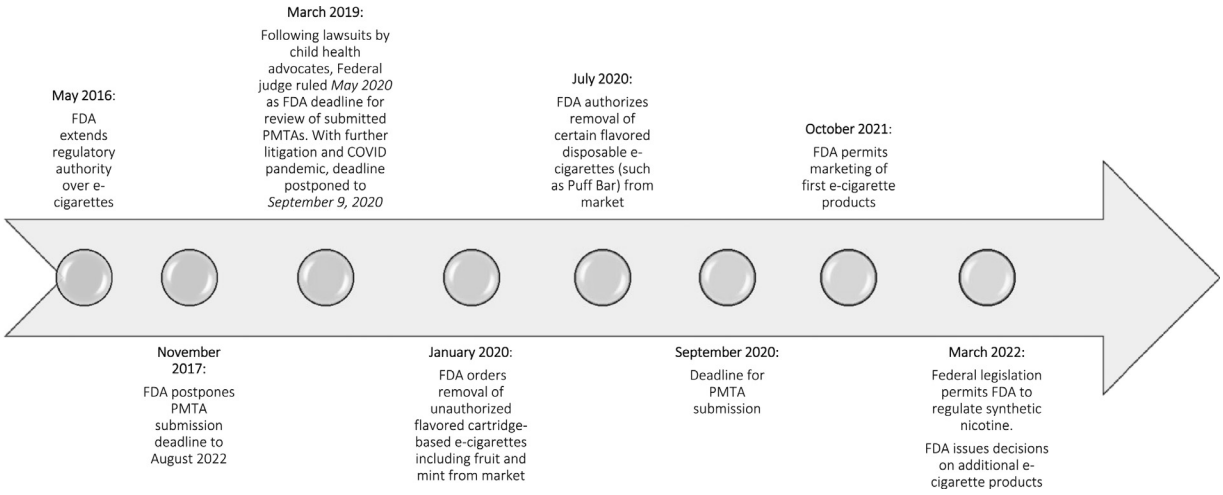

Fig. 4. Timeline of major FDA policy interventions to address e-cigarette use in the US.

flavors across all tobacco products only exist in some states and local jurisdictions.[43] The Tobacco Control Act of 2009 made provisions for states and local jurisdictions to implement their restriction policies on flavored tobacco products.[43] As of September 2021, approximately 4.4% of the U.S. population was covered by comprehensive state or local flavored tobacco sales restriction policies.[36] Thirteen states have at least one jurisdiction with a flavored tobacco sales restriction policy.[36] A timeline for major FDA policy interventions to address e-cigarette use is depicted in Fig. 4.

Age-restriction on e-cigarettes sales

In December 2019, the minimum age for sales of tobacco products including e-cigarettes was raised from 18 to 21, as part of measures to prevent youth uptake of e-cigarettes.[36,39] Over 18 states and 500 local jurisdictions have restricted sales of e-cigarettes to adults 21 years and older.[36] Emerging evidence suggest that Tobacco 21 legislation is effective is reducing adolescent e-cigarette use, particularly when implemented as part of comprehensive tobacco control strategy.[34,35]

Expanding existing comprehensive tobacco policies to include e-cigarettes

Existing tobacco control policies such as smoke-free policies and increased taxation have been effective in reducing rates of cigarette smoking. Expansion of these polices to include e-cigarettes is a strategy that has been employed by some states and local counties. At least 22 states and 970 jurisdictions have expanded their smoke-free policies to include e-cigarette use—prohibiting e-cigarette use in places where cigarette smoking is not permitted.[36] Currently, no federal smoke-free policies exist that include prohibition of e-cigarette use in public or indoor places.[36] Similarly, there is no federal excise taxation on e-cigarettes, however, at least nineteen states and the District of Columbia have imposed taxes on e-cigarettes.[36] Increased taxation of tobacco products is effective in discouraging tobacco product use and adolescents and young adults are particularly sensitive to increases in the price of tobacco products.[36]

Although the youth e-cigarette epidemic has been partly driven by aggressive youth-targeted marketing, e-cigarette marketing remains largely unrestricted in the U.S. Compared to conventional cigarettes, e-cigarette advertisements are permitted on electronic and print media. Federal restrictions are limited to cautioning e-cigarette companies about making misleading advertisements such as reduced harm or smoking cessation claims.[36]

Future recommendations

Policy recommendations

More comprehensive public policy agenda and closure of existing regulatory loopholes are needed to sustain the noted decline in adolescent e-cigarette use. The FDA should further prioritize prevention of

adolescent e-cigarette use in regulatory decision making. Current justification for permitting marketing of e-cigarette products, submitted through PMTAs, is that there are potential smoking cessation benefits for adults. However, adult smokers have FDA-approved evidence-based options for smoking cessation including over-the-counter nicotine replacement therapy (NRT) that should be prioritized ahead of e-cigarettes, particularly given inconsistencies in evidence supporting use of e-cigarettes as a reliable smoking cessation tool.[44–46] In fact, most recent study findings indicate that adult smokers may be at more risk of continued nicotine addiction if they use e-cigarettes for smoking cessation instead of NRT.[45] In another study, dual use of conventional cigarettes and e-cigarettes was found to hinder rather than facilitate smoking cessation among adult smokers interested in quitting.[46] While evidence of successful use of e-cigarettes for smoking cessation in adult smokers is mixed, the risk of nicotine addiction and smoking initiation among adolescent e-cigarette users is well-documented and should be given greater weight in regulatory considerations. In addition, the FDA should prioritize enforcement policy against menthol-containing e-cigarettes and elucidate the rationale for keeping them in the market despite high use among adolescents.[30]

While evidence of successful use of e-cigarettes for smoking cessation in adult smokers is mixed, the risk of nicotine addiction and smoking initiation among adolescent e-cigarette users is well-documented and should be given greater weight in regulatory considerations.

Comprehensive federal tobacco control policies that restrict e-cigarettes advertisements, expand existing smoke-free policies to include e-cigarettes, and tax e-cigarette products at comparable rates as conventional cigarettes should be enacted. More states and local jurisdictions should enforce Tobacco 21 legislation and enact flavored tobacco sales restriction policies that have been shown to be effective in reducing adolescent e-cigarette use.[7,21]

Clinical recommendations

Clinicians and counselors should screen adolescents for e-cigarette use and provide school and clinic-based interventions to address tobacco product use including e-cigarettes. Comprehensive smoke-free policies that include e-cigarette should be enforced at homes, schools, and other public places where children and adolescents gather.[7,21] Clinicians should recommend against use of e-cigarettes as a smoking cessation product,[7,21] and can consider NRT for adolescents with moderate to severe nicotine addiction.[21]

Conclusion

Adolescent e-cigarette use remains a major public health challenge that requires comprehensive clinical, research and policy interventions to reverse. Although the prevalence of e-cigarette use has declined in the past two years, a sizeable proportion of U.S. adolescents still use e-cigarettes and are at risk of nicotine addiction. In 2021, more than two million middle and high school students reported current e-cigarette use.[30] E-cigarettes continue to evolve rapidly with innovative technology as manufacturers seek loopholes in regulatory efforts and to maximize existing marketing opportunities. The current e-cigarette landscape is dominated by discrete and stylish pod-based devices with varying capacity for customized nicotine delivery and attractive child-appealing e-liquid flavorings. Regulatory efforts have focused largely on marketing restrictions with enforcement decisions from reviewed PMTAs prioritizing smoking cessation potential of e-cigarettes for adult smokers over risk of nicotine addiction in adolescents. Disposable e-cigarette products advertising synthetic nicotine and menthol-flavored products remain in the market and continue to gain popularity among adolescents. Federal policy interventions in areas of e-cigarette advertisement restrictions, federal taxation of e-cigarettes in comparable rates as conventional cigarettes, and smoke-free polices that include e-cigarettes are still lacking. More robust e-cigarette policy interventions have been championed by states and local jurisdictions including taxation of e-cigarettes and flavored tobacco product sales restriction policies. A more comprehensive federal policy agenda that

A more comprehensive federal policy agenda that closes existing regulatory loopholes is needed to sustain declines in adolescent e-cigarette use.

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Financial disclosures

None

Funding

None

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