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Prevalence of Adolescent Cannabis Vaping
A Systematic Review and Meta-analysis of US and Canadian Studies

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IMPORTANCE Vaping products were initially designed to deliver nicotine as a tobacco cigarette substitute (eg, electronic cigarettes) but are now frequently used to deliver psychoactive substances, such as cannabis and its derivatives. Large, nationally representative surveys, such as Monitoring the Future, found that approximately 1 in 3 grade-12 students vaped cannabis in 2018 alone.

OBJECTIVE To summarize the findings of epidemiological studies that reported the global prevalence of cannabis vaping in adolescents by survey year and school grades.

DATA SOURCES PubMed, PsycINFO, Scopus, and Web of Science were searched systematically on August 19, 2020, for studies published globally between January 1, 2003, and August 19, 2020.

STUDY SELECTION Publications that reported the prevalence of cannabis vaping in adolescents in the general population were included.

DATA EXTRACTION AND SYNTHESIS Study characteristics and prevalence estimates were extracted from each article. Random-effects meta-analysis based on the DerSimonian and Laird method and meta-regression were performed on lifetime, 12-month, and 30-day prevalence estimates. Meta-regression was also conducted using survey year and school grades as moderators.

MAIN OUTCOMES AND MEASURES Prevalence of cannabis vaping.

RESULTS Seventeen studies met the eligibility criteria (n = 198 845 adolescents). Although no restrictions were imposed on study location, all 17 studies were from the US and Canada. Across all school grades, the pooled prevalence increased for lifetime use (6.1% in 2013-2016 to 13.6% in 2019-2020), use in the past 12 months (7.2% in 2017-2018 to 13.2% in 2019-2020), and use in the past 30 days (1.6% in 2013-2016 to 8.4% in 2019-2020). Heterogeneity across studies was large. The limited evidence from studies using similar survey and study designs suggested that adolescents' preference for cannabis products other than dried herbs, which usually contain higher Δ9-tetrahydrocannabinol levels, may have shifted over time.

CONCLUSIONS AND RELEVANCE The findings of this study suggest that the prevalence of cannabis vaping has increased among adolescents in the US and Canada and that more effective preventive and response measures are required.

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Supplemental content

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The use of vaping products, such as electronic cigarettes, increased 13-fold in the US among middle and high school students from 2011 to 2018.[1] The popularity is driven by the accessibility of vaping devices,[2] enjoyable flavors,[1] and promotion of their use on social media platforms.[2] Vaping products were originally designed to deliver nicotine via vapor as a substitute for tobacco cigarettes. More recently, they have been used to deliver psychoactive substances, such as cannabis and its derivatives.[3] Cannabis vaping involves the use of vaporizers to heat dried cannabis herb or cannabis oil to a temperature that releases Δ9-tetrahydrocannabinol (THC) and cannabidiol into vapor for inhalation.

The literature reports the prevalence of cannabis vaping in the adolescent population,[4-9] with estimated prevalence varying greatly among studies. For example, 2 nationally representative surveys of US adolescents conducted in 2018—the National Youth Tobacco Survey[10] and Monitoring the Future[6]—estimated lifetime prevalence among grade-12 students as 15.6% and 28.3%, respectively. Despite this large discrepancy, both studies found that cannabis vaping among adolescents has increased and has become a major public health concern in adolescent health because of potential adverse respiratory, psychological, and social impacts.[11-16] When considering how vaping fits into the overall picture of adolescent cannabis use, the 2018 Monitoring the Future survey[17] reported the lifetime prevalence of any cannabis use among 12th graders was 43.6%, that is, 64.9% of adolescents who reported ever having used cannabis also reported having vaped it. Understanding the epidemiology of cannabis use through vaping is critical to planning and allocating funds for preventive programs to reduce the incidence of adolescent cannabis use.

The objectives of this meta-analysis and systematic review were to collate the findings of epidemiological studies that reported the lifetime, 12-month, and 30-day prevalence of cannabis vaping among adolescents and to investigate survey year and school grades as sources of variability. Adolescents in this study were defined as school-grade children or those 18 years or younger, which is within the World Health Organization's threshold of the ages of 10 to 19 years.[18]

Key Points

Question What is the prevalence of adolescent cannabis vaping in the US and Canada?

Findings This systematic review and meta-analysis reviewed 17 unique studies from the US and Canada, with a total of 198 845 adolescents, and found that the lifetime prevalence of cannabis vaping doubled from 2013 to 2020 (6.1% to 13.6%), past 12-month use doubled from 2017 to 2020 (7.2% to 13.2%), and the 30-day prevalence of cannabis vaping increased 7-fold from 2013 to 2020 (1.6% to 8.4%). Preference for cannabis products may be shifting from dried herb to cannabis oil.

Meaning The findings of this study suggest that more effective prevention and response measures are required to mitigate the increasing prevalence of cannabis vaping among adolescents.

Methods

The original scope of this study was the global prevalence of cannabis vaping. However, the current study is limited to the US and Canada because no studies were found outside these countries. This reporting followed the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) reporting guideline (eAppendix 1 in the Supplement)[19,20] and the Meta-analysis of Observational Studies in Epidemiology (MOOSE) reporting guideline (eAppendix 2 in the Supplement).[21] This review was registered on PROSPERO (CRD42020219644).

Eligibility Criteria

Our inclusion criteria were as follows: (1) studies that reported the prevalence of cannabis vaping; (2) study participants 18 years or younger or school samples from the general population; (3) observational studies because randomized clinical trials are usually focused on clinical populations with strict inclusion and exclusion criteria; (4) all locations; and (5) all languages. Our exclusion criteria were as follows: (1) specific subpopulations (eg, patients with cancer); (2) animal studies; (3) laboratory studies; (4) experimental studies; (5) commentaries, reviews, and conference proceedings; and (6) publications before 2003, the year when a vaping device was first registered for a patent.

Data Sources and Search Strategy

An electronic search was performed on August 19, 2020, of the PubMed, PsycINFO, Scopus, and Web of Science databases using the terms for vaping (eg, *vap** OR *eliquid*) and cannabis (eg, *marijuana*) as part of a larger systematic review on cannabis vaping. A subject expert librarian was consulted to finalize these search terms. Studies published globally between January 1, 2003, and August 19, 2020, were eligible for inclusion in this review. Detailed search strategies are given in eAppendix 3 in the Supplement. The reference list for all included studies, existing published cannabis reviews, and email alerts from substance use journals after August 2020 were reviewed for more studies. Authors were contacted to obtain prevalence estimates when they were not available in the publication.

Data Abstraction

All studies were exported into EndNote X9[22] to remove duplicates and uploaded to Covidence[23] for title and abstract screening. All titles and abstracts were independently reviewed by 2 reviewers (C.C.W.L. and T.S.), followed by full-text screening, also completed independently by 2 reviewers (C.C.W.L. and J.Y.C.C.). Any discrepancy at either stage was resolved by the consensus of the 2 authors (C.C.W.L., T.S, and J.Y.C.C.) who performed the screening and a third author (V.C.) who was not involved in original screening. The number of conflicts was small, and the reviewers met 3 times face to face at the end of each screening stage, with each meeting lasting 30 minutes to 1 hour.

Data Extraction

Information on study characteristics, cannabis vaping measure (eg, "Have you ever used marijuana, marijuana concentrates, marijuana waxes, THC, or hash oils in an e-cigarette?"),

and prevalence estimate for each study was extracted (eAppendix 4 in the Supplement). For prospective cohort studies, cross-sectional estimates of all waves were extracted. When studies reported the same set of estimates using the same data set, we retained the study that reported the most comprehensive set of estimates. During the review process, we found that prevalence estimates were not published for all years, despite available survey data (the Florida Youth Tobacco Survey,[24] the Healthy Kids Colorado Survey,[25] the Ontario Student Drug Use and Health Survey,[26] the National Youth Tobacco Survey,[27] Monitoring the Future,[28] and the Population Assessment of Tobacco and Health Study[29]). Hence, we calculated weighted prevalence estimates for youth cannabis vaping directly from these survey data sets for missing years.

Quality Assessment

A modified version of the Newcastle-Ottawa Quality Assessment for cross-sectional studies was used to assess bias.[30] This adopted instrument classified the collected articles into 5 distinct domains: A (representative of the study sample), B (adequacy of sample size), C (nonrespondents), D (assessment of cannabis vaping), and E (appropriate reporting of prevalence and sample size). Detailed assessments for each study are included in eAppendix 5 in the Supplement.

Statistical Analysis

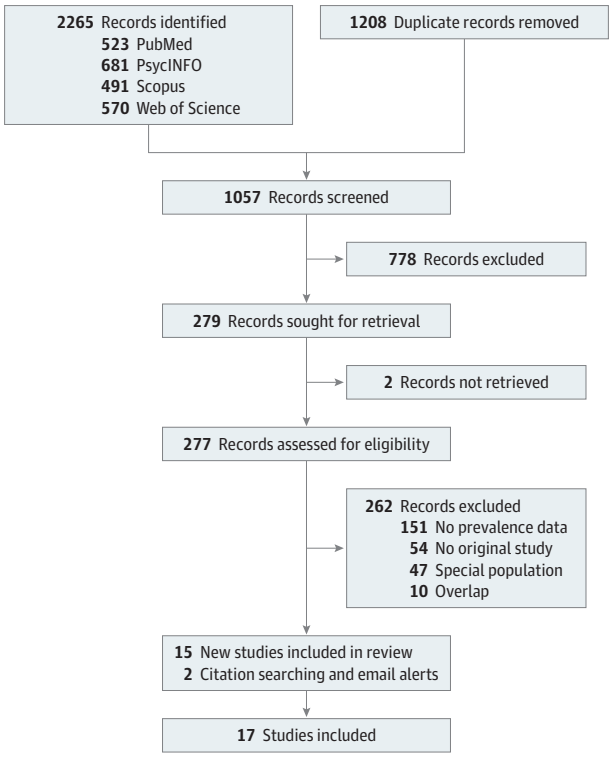
Meta-analysis was performed on lifetime, 12-month, and 30-day prevalence via random-effects models using the DerSimonian and Laird method.[31] Estimates were transformed to logits to keep the estimates bounded between 0 and 1 (0% and 100%).[32] The pooled prevalence and its 95% CI from the meta-analysis were back-transformed. Heterogeneity among studies was assessed using Q statistics and I^2.[33] Because of the nature of observational studies, the Q statistic was significant at the 0.05 level, the P values were significant at $P < .05$, and the I^2 is large, as expected (ie, 92.3%-99.7%). Publication bias was assessed using funnel plots and an unweighted regression test.[34] Univariable meta-regression (using study as the unit of analysis) was performed on 2 moderators: survey year and school grades. Analysis was conducted using the metafor package in R software, version 3.8.1 (R Foundation for Statistical Computing) using the rma command. Code and data are available on Github.[35]

Results

Screening

A total of 2265 titles were retrieved from databases. After removing duplicates, a total of 1057 titles were available for title and abstract screening and 778 were excluded for not meeting inclusion criteria. Of the 277 studies that were eligible for full-text screening, we excluded editorials, commentaries, and conference abstracts (n = 54), special populations (eg, treatment-seeking patients) (n = 47), and those that did not contain prevalence data (n = 151). A full list of excluded studies is included in eAppendixes 7 and 8 in the Supplement. Ten other studies met our inclusion criteria but were excluded because of overlapping estimates calculated from the same survey data sets. Two additional studies were found from citation searching and email alerts, bringing the total number of included studies to 17 (**Figure 1**).

Figure 1. PRISMA Flow Diagram



Study Characteristics and Quality

Despite no country or location restrictions (**Table 1** [4-7,10,36-47]), all studies were from the US[4,6,7,10,36-43,47] or Canada,[5,44,45] and 1 study[46] contained both countries (ie, US and Canada). Ten of these studies were cross-sectional,[4-7,10,36,40,41,45,47] and the remaining 7 studies were prospective cohort studies.[37-39,42-44,46] All studies were school based and representative at the national level[6,10,36,42,46] or at the state or region level.[4,5,7,37-41,43-45,47] The sample sizes ranged from 2630 to 45 677 adolescents, with a combined sample size of 198 845 adolescents. All published studies were based on survey data collected between 2013 and 2019, with most based on surveys from 2016 onward. Fourteen studies[4-6,10,36-45] reported prevalence stratified by survey year or school grades, 3 studies[7,46,47] reported prevalence stratified by cannabis products, and 1 study[7] contained prevalence by survey year and cannabis products. Five studies[4,5,7,10,36] specifically asked if the respondent had vaped cannabis using an e-cigarette device, whereas other studies[4,6,7,10,36,37,41,42,47] asked how many days the respondents had vaped marijuana. Nine studies[4,6,7,10,36,37,41,42,47] provided 29 lifetime use estimates, 4 studies[5,6,44,45] provided 12 past-year use, and 7 studies[6,37-40,43,46] provided 36 past-month use prevalence estimates. The mean (SD) quality score of the studies was 4.6 (0.9) of 6. The quality

Table 1. Characteristics of Included Studies, Prevalence of Cannabis Vaping, and Quality Assessment

Source	Cohort	Method	Sampling	RR, %	No.	Year	Timing	Prevalence, % (95% CI) or No./total No.	NOS[a]
Studies of prevalence by survey year or school grades (n = 15)[b]									
Trivers et al,[36] 2018, US (national)	NYTS	Paper	Multistage cluster	71.6	20 675	2016	LT	All: 8.9 (8.1-10)	6
Peters et al,[37] 2018, US (Los Angeles, California)	HHS	Paper	NS	82.8	3177	2015	LT	All (333/3177)	5
							30 d	All (156/3177)	5
Nguyen et al,[38] 2019, US (Los Angeles, California)	HHS	Paper	Convenience	92.5	3008	2017	30 d	All (291/3008)	5[c]
Morean et al,[7] 2015, US (Connecticut)	NS	Paper	Convenience	51.7	3847	2014	LT	All (208/3847)	4
Miech et al,[6] 2020, US (national)	MTF	Paper	Random	80.0-88.0	14 560	2017	30 d	Grade 8: 1.6 (1.3-2.1); grade 10: 4.3 (3.5-5.3); grade 12: 5 (4.1-6.0)	6
						2017	12 mo	Grade 8: 3 (2.5-3.7); grade 10: 8.1 (6.9-9.6); grade 12: 9.5 (8.1-11.2)	6
						2017	LT	Grade 8: 4 (3.3-4.9); grade 10: 9.8 (8.5-11.4); grade 12: 11.9 (10.2-13.8)	6
						2018	30 d	Grade 8: 2.6 (2.0-3.4) grade 10: 7 (5.9-8.3); grade 12: 7.5 (6.2-8.9)	6
						2018	12 mo	Grade 8: 4.4 (3.6-5.4); grade 10: 12.4 (10.8-14.4); grade 12: 13.1 (11-15.1)	6
						2018	LT	Grade 8: 5.5 (5.0-6.7); grade 10: 14.2 (12.6-16.0); grade 12: 15.6 (13.9-17.6)	6
						2019	30 d	Grade 8: 3.9 (3.3-4.7); grade 10: 12.6 (11.1-14.3); grade 12: 14 (12.6-15.5)	6
						2019	12 mo	Grade 8: 7 (6-8); grade 10: 19.4 (17.4-22.0); grade 12: 20.8 (19-23)	6
						2019	LT	Grade 8: 9 (7.8-10.0); grade 10: 21.8 (19.8-24.0); grade 12: 23.7 (21.7-25.9)	6
Leventhal et al,[39] 2020, US (Los Angeles, California)	HHS	Paper	NS	82.8	3177	2015	30 d	All (146/3177)	5[c]
Kowitt et al,[4] 2019, US (North Carolina)	NCYTS	Paper	Multistage cluster	64.5	2835	2017	LT	All (253/2835)	4
Johnson et al,[40] 2016, US (Colorado)	HKCS	Paper	Multistage stratified	58.2	2637	2013	30 d	All (163/12 526); grade 9 (126/3395); grade 10 (170/3270); grade 11 (189/3257); grade 12 (250/2606)	4
Eggers et al,[41] 2017 US (Florida)	FYTS	Paper	Unclear	NS	12 320	2015	LT	Grade 6: 3 (2.3-4.1); grade 7: 2.8 (2.1-3.7); grade 8: 4.4 (3.6-5.5); grade 9: 9 (7.7-10.5); grade 10: 10.9 (9.5-12.6); grade 11: 12.8 (11.0-14.8); grade 12: 13.5 (11.7-15.6)	3
Dai,[10] 2020, US (national)	NYTS	Paper	Multistage cluster	68.1	17 872	2017	LT	All: 11.1 (9.8-12.5)	5
				68.2	20 189	2018	LT	All: 14.7 (13.0-16.1)	5
Bentivegna et al,[42] 2021, US (national)	PATH	Face to face	Unclear	80.9	7551	2015-2016	LT	All (622/7551)	6[c]
Barrington-Trimis et al,[43] 2020, US (California)	NS	Unclear	Unclear	74.8	2685	2013	30 d	Grade 9 (17/2685)	5[a]
Mammen et al,[5] 2016, Canada (Ontario)	OSDUHS	Unclear	Multistage cluster	61	3171	2015	12 mo	All (267/3171)	4

(continued)

Table 1. Characteristics of Included Studies, Prevalence of Cannabis Vaping, and Quality Assessment (continued)

Source	Cohort	Method	Sampling	RR, %	No.	Year	Timing	Prevalence, % (95% CI) or No./total No.	NOS[a]
Doggett et al,[44] 2020, Canada (multiregion)	COMPASS	Paper	Cluster	79.1	45 677	2017-2018	12 mo	All (2611/45 677)	5[c]
Wardell et al,[45] 2021, Canada (Ontario)	OSDUHS	Unclear	Multistage cluster	61	3221	2016-2017	12 mo	All (181/3221)	4
Studies that contain product prevalence (n = 3)									
Morean et al,[7] 2015, US (Connecticut)	NS	Paper	Convenience	51.7	3847	2014	LT	Herbs (258/3847), oil (173/3847), concentrates (115/3847)	4
Hammond et al,[46] 2021, US and Canada[d]	ITC	Web based	Mixed sampling	1.6-3.7	35 490	2017	30 d	Canada: herbs (79/502), oil (64/502), concentrates (106/502); US: herbs (97/474), oil (115/474), concentrates (126/474)	5
						2018	30 d	Canada: herbs (99/516), oil (96/516), concentrates (115/516); US: herbs (114/531), oil (164/531), concentrates (159/531)	
						2019	30 d	Canada: herbs (134/711), oil (182/711), concentrates (211/711); US: herbs (163/710), oil (369/710), concentrates (291/710)	
Knapp et al,[47] 2019, US	NS	Web based	Convenience	NS	2630	2016	LT	Herbs (857/1156), oil (336/1156), concentrates (788/1156)	3

Abbreviations: COMPASS, Cannabis Use, Obesity, Mental Health, Physical Activity, Alcohol Use, Smoking, and Sedentary Behaviour Study; FYTS, Florida Youth Tobacco Survey; HHS, Happiness and Health Study; HKCS, Health Kids Colorado Survey; ITC, ITC Youth Tobacco and Vaping Survey; LT, lifetime; MTF, Monitoring the Future; NCYTS, North Carolina Youth Tobacco Survey; NOS, Newcastle-Ottawa Scale; NS, not specified; NYTS, National Youth Tobacco Survey; OSDUHS, Ontario Student Drug Use and Health Survey; PATH, Population Assessment of Tobacco and Health; RR, response rate.

[a] Quality assessment was based on the modified Newcastle-Ottawa for cross-sectional studies.

[b] Total of 17 unique studies included. The study by Morean et al[7] contains both prevalence by survey year and product.

[c] Prospective cohort study but prevalence is from a specific wave of the study.

[d] Data from England were excluded in the study by Hammond et al.[46] The scope of this study is restricted to US and Canada only.

score ranged from 3 to 6, indicating moderate to excellent quality. The most common reasons that studies were rated as moderate quality were low response rates and incomplete reporting of prevalence and sample sizes.

Meta-analysis

Pooled Prevalence by Survey Year and School Grades

Table 2 gives the pooled lifetime, 12-month, and 30-day prevalence of cannabis vaping by survey year and school grades. Within school grades, the pooled lifetime prevalence doubled between 2013-2016 and 2019-2020. For example, the lifetime prevalence in grade-12 students was 14.6% (95% CI, 11.3-18.6) in 2013-2016 and 28.1% (95% CI, 21.5%-35.8%) in 2019-2020. Similarly, the pooled 12-month prevalence had increased from 11.2% (95% CI, 8.1%-15.2%) to 20.8% (95% CI, 19.9%-21.7%), and the pooled 30-day prevalence increased exponentially from 2.3% (95% CI, 1.8%-3.0%) to 14.0% (95% CI, 13.3%-14.8%) during the same period.

Across school grades, the pooled lifetime prevalence of adolescent cannabis vaping increased from 6.1% (95% CI, 4.8%-7.7%) in 2013-2016 to 13.6% (95% CI, 10.9%-16.8%) in 2019-2020. The pooled prevalence for 12-month and 30-day use also showed an increasing trend (12-month: from 7.2% in 2017-2018 to 13.2% in 2019-2020; 30-day: 1.6% in 2013-2016 to 8.4% in 2019-2020). (Table 2). Estimates from the US and Canada were not analyzed separately because only three 12-month data points were drawn from Canadian samples. Sensitivity analysis that excluded data from Canada found that prevalence estimates differed by 1 decimal point (eAppendix 6 in the Supplement).

Examination of funnel plots found no conclusive evidence of heterogeneity and funnel plot asymmetry (lifetime: $z = -0.60$, $P = .55$; past year: $z = -0.01$, $P = .99$; past month: $z = 0.99$, $P = .32$) (eFigure in the Supplement).

Pooled Prevalence by Cannabis Products

Meta-analysis was not performed by different cannabis product used because only a limited number of studies reported which specific products were used.[7,46,47] We found 2 surveys[7,47] that reported lifetime prevalence, and 1 other study[46] reported 30-day prevalence of herbal cannabis, cannabis oil, and concentrates. **Figure 2** shows that the popularity of cannabis oil and concentrates has increased in recent years (eg, 2018 and 2019) for both lifetime and past-month use. In the included study from Canada,[46] cannabis concentrates were the most prevalent products. In the US, 2 studies[7,47] found

Table 2. Pooled Prevalence by Survey Year and School Grades (US and Canada)[a]

	No. (%) [95% CI][b]				
	Grade				
Survey year	6-9	10	11	12	All
Lifetime[c]					
2013-2016	16 (3.4) [2.6-4.6]	4 (10.5) [8.1-13.6]	4 (13.2) [10.2-16.9]	4 (14.6) [11.3-18.6]	18 (6.1) [4.8-7.7]
2017-2018	14 (3.9) [2.9-5.1]	7 (11.7) [9.0-15.1]	5 (15.6) [11.4-20.8]	7 (17.0) [13.4-21.2]	30 (6.5) [5.4-7.9]
2019-2020	13 (7.2) [5.0-10.1]	4 (22.9) [17.3-29.6]	3 (26.9) [18.2-37.9]	4 (28.1) [21.5-35.8]	25 (13.6) [10.9-16.8]
12 Months					
2013-2016	NR	NR	NR	NR	NR
2017-2018	2 (3.6) [2.5-5.3]	2 (10.1) [6.6-15.1]	NR	2 (11.2) [8.1-15.2]	8 (7.2) [5.2-9.8]
2019-2020	1 (7.0) [6.4-7.6]	1 (19.4) [18.6-20.2]	NR	1 (20.8) [19.9-21.7]	4 (13.2) [8.0-20.9]
30 Days[c]					
2013-2016	1 (0.5) [0.3-0.8]	1 (1.0) [0.7-1.4]	1 (1.3) [1.0-1.7]	1 (2.3) [1.8-3.0]	7 (1.6) [0.8-2.9]
2017-2018	2 (2.1) [1.3-3.3]	2 (5.5) [3.4-8.8]	NR	2 (6.2) [4.1-9.1]	8 (4.6) [3.2-6.5]
2019-2020	1 (3.9) [3.5-4.3]	1 (12.6) [11.9-13.3]	NR	1 (14.0) [13.3-14.8]	4 (8.4) [5.0-13.8]

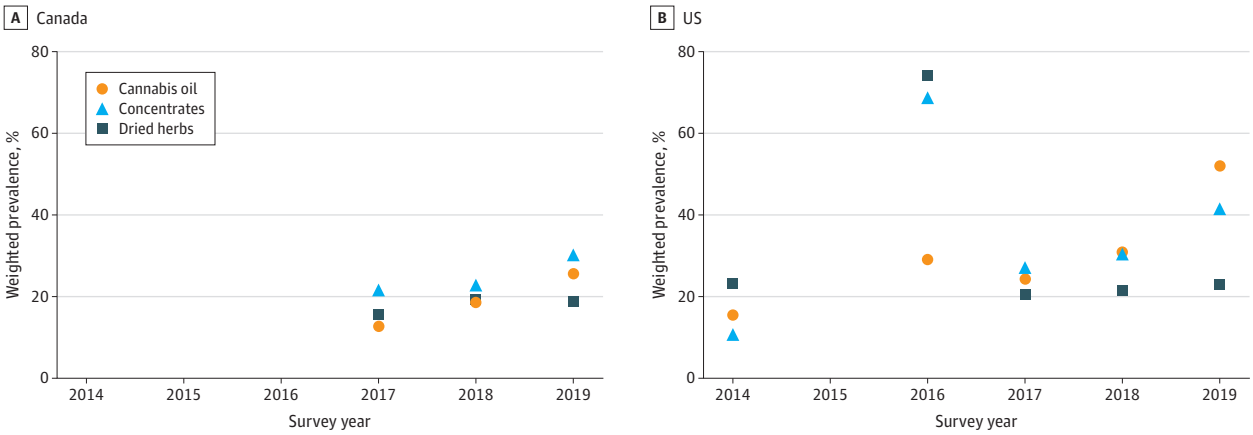
Abbreviation: NR, not reported.

[a] I^2 ranges from 92.3% to 99.7% ($P < .001$).

[b] Number of estimates from surveys and weighted prevalence sourced from publicly available data sets. Numbers do not sum across the row because some surveys administered questions to all school grades.

[c] Estimates were not reported for Canada.

Figure 2. Observed Prevalence by Cannabis Product and Survey Year for Canada and the US



that dried herb vaping was the most common mode of use between 2014 and 2016, but a separate study[46] reported that cannabis oil and concentrates were the most used products between 2017 and 2019.

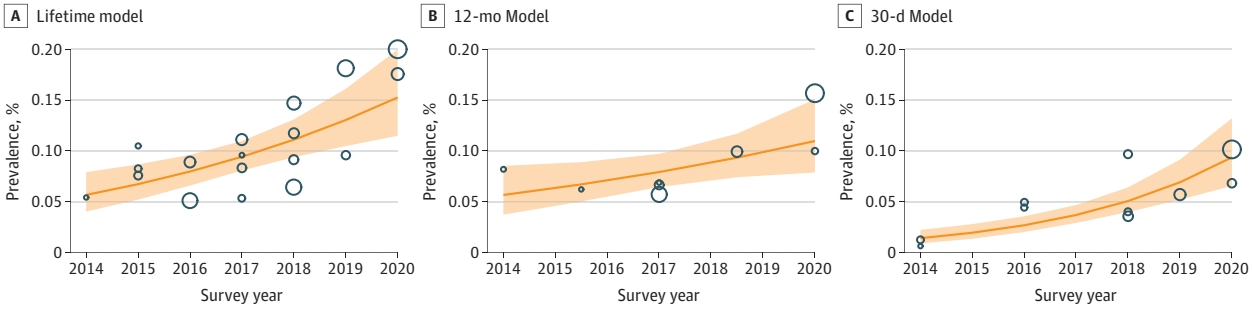
Meta-regression

We performed 3 univariable meta-regressions using survey year as a continuous moderator. The association of survey year was significant in the lifetime model (β = 0.18, SE = 0.05, $P < .001$), 12-month model (β = 0.18, SE = 0.09, $P = .37$), and 30-day model (β = 0.33, SE = 0.06, $P < .001$). The scatterplot of the observed weighted prevalence against survey year showed an upward trend in the lifetime prevalence of cannabis vaping from 2014 to 2020. Similar trends were detected for 12-month and 30-day prevalence (**Figure 3**). We also performed univariate meta-regressions using school grades as a moderator. This variable was also significant in the lifetime model (β = 0.44, SE = 0.03, $P < .001$). As expected, the scatterplot of the observed weighted prevalence against school grades increased from young adolescents (grade 6) to older adolescents (grade 12) irrespective of survey year (**Figure 4**).

Discussion

This systematic review and meta-analysis aimed to collate the existing evidence on the global prevalence of adolescent cannabis vaping and found that all published evidence is exclusively from the US and Canada. The lifetime prevalence of cannabis vaping doubled from 2013 to 2020 (6.1% to 13.6%), as did past 12-month use from 2017 to 2020 (7.2% to 13.2%); 30-day prevalence of cannabis vaping increased 7-fold from 2013 to 2020 (1.6% to 8.4%). The prevalence was also higher in older adolescents (grade 12) compared with their younger counterparts irrespective of survey year. Preference for can-

Figure 3. Observed Prevalence and Survey Year



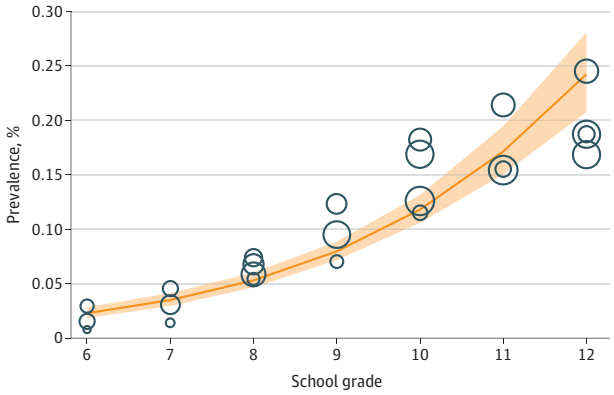
nabis products may be shifting from dried herb to cannabis oil. A key strength of this study was our attempt to reduce publication bias by directly calculating weighted prevalence estimates for unpublished survey data.

A possible explanation for the upward trajectory in the prevalence of cannabis vaping observed in our study timeframe is the increasing uptake of vaping products generally used among youth and young adults,[42] widening access to cannabis vaping products through legalization of cannabis, and the decrease in perceived risk of harm toward cannabis in the last decade.[48] The common route of administration through inhalation of cannabis and nicotine vaping products has led some to hypothesize a gateway effect between nicotine and cannabis vaping.[49] A longitudinal study[50] found adolescent nicotine e-cigarette use was associated with an increased risk of vaping cannabis. Adolescents are also more susceptible to the initiation of cannabis vaping if they have peers who vape cannabis.[50] Like nicotine vaping, cannabis vaping is perceived as the healthier alternative to smoking cannabis because of the lower exposure to toxic combustion products.[51] The flavor profile and the discreetness of new-generation vaping products, coupled with the ability to customize devices for use with other nonnicotine substances,[52] could increase the appeal of cannabis vaping. JUUL, an exceptionally popular nicotine vaping device among adolescents, can be refilled with cannabis e-liquids.[53]

The limited evidence suggests that adolescents' cannabis product preferences may have shifted over time to more potent products. A study by Hammond et al[46] found that the 30-day prevalence of cannabis oil vaping had increased in the US and Canada, particularly in the US, where it doubled from 2017 to 2019. Cannabis potency is defined as the amount of psychoactive ingredient, primarily THC in the product. Products such as cannabis oil and concentrates typically contain a higher proportion of THC than herbal cannabis. The typical THC concentration sold in licensed retail stores for oils is approximately 70.3% compared with the 21.4% concentration in herbal cannabis.[54] The ready accessibility of non–age-restricted video tutorials[55] on how to vape cannabis products[3] may also facilitate adolescent experimentation with cannabis.[56]

It is unlikely that adolescents would generally restrict their route of cannabis administration to one form or the other. Kolar et al[16] found that 70% of adolescents reported 2 or more routes of administration. Substantial overlap exists between vaping

Figure 4. Observed Prevalence and School Grades



cannabis and other routes of administration, particularly smoking.[9,16] The Healthy Kids Colorado Survey found that among those who usually vaped, 54.6% have also smoked cannabis.[9] Existing preventive measures should focus on both smoking and vaping cannabis and develop specific health messages for vaping cannabis by highlighting the potential harms of using highly potent cannabis vaping products, such as butane hash oil, which can produce stronger psychoactive effects than smoking cannabis.[13]

Cannabis vaping is associated with a range of adverse health outcomes. Boyd et al[12] found that adolescent cannabis vaping is associated with a 1.8-fold increase in respiratory symptoms (such as wheezing and dry cough not associated with chest infection) compared with those who had never vaped even after controlling for other recent e-cigarette and cannabis use. Because cannabis vaping is a relatively new phenomenon, little is known about its potential long-term harms to adolescents. However, the regular use of cannabis is associated with a broad range of adverse health outcomes[11,13-15] that may be more pronounced in those who initiate use in adolescence. Heavy cannabis use is associated with poorer cognitive development in adolescents.[57] In an animal study[58] of female rats, adolescent exposure to high THC delays the maturation of prefrontal cortex, a region involved in complex behaviors and decision-making. The human brain goes through major remodeling during adolescence.[59] With cannabis products now containing a higher level of THC compared with 5 decades ago,[60] their association with neurodevelopment could

be stronger. The Christchurch Health and Developmental Study, which examined the life-course trajectories of cannabis use (for those 15-35 years of age) found that long-term use is associated with an increased odds of other illicit drug dependence and many other health, social, and behavioral problems later in life. Hence, physicians should be encouraged to ask about cannabis vaping in adolescents with a history of vaping or of other cannabis use.

With increasing changes in cannabis policy and legalization of adult use, the increasing prevalence of adolescent cannabis vaping indicates a need for more studies to understand the potential harms. This information should inform the development of effective prevention strategies that specifically target adolescent cannabis vaping, with a focus on the risks associated with the use of high-potency products, such as cannabis extracts and oils. This review also revealed gaps in existing surveys. Most surveys only reported lifetime prevalence. Future surveys should collect and report data on past-year estimates (better known as period prevalence). Adolescents who continue to use cannabis frequently may be at risk of developing cannabis use disorders and harms.[13] With health care systems planning on an annual basis, past-year estimates are more useful for policy makers.

Limitations

This study has limitations. The estimates had substantial heterogeneity because of differences between surveys in how they defined cannabis vaping and the questions used to measure it. Some questions combined hash and leaves when the former is more potent than the latter. Others also asked about the use of e-cigarettes to vape cannabis, which may underestimate the prevalence of cannabis vaping using tabletop vaporizers. All studies were from the US and Canada, which limits our ability to make a comprehensive summary of the prevalence of cannabis vaping around the world. This study is also based on adolescents in the general population using cannabis for nonmedical reasons. We have not considered adolescents who may use cannabis for medical purposes, such as epilepsy control, although their numbers are likely to be small. We have not collected information on the overall cannabis use and other routes of administration to observe whether vaping is contributing to the larger picture of adolescent cannabis use. With increasing legalization around the world, future studies need to collect more information on this increasingly used route of cannabis administration and continue to monitor the long-term harms associated with cannabis vaping.

Conclusions

This meta-analysis found that adolescent cannabis vaping prevalence increased from 2013 to 2020 and within school grades from grade 6 to grade 12. The study also found that the preference for cannabis products has shifted (from dried herb vaping to cannabis oil vaping), although evidence for this was more limited. These findings indicate that the prevalence of cannabis vaping in adolescents is on a strong upward trajectory in the US and Canada. Because cannabis oil contains a greater level of THC than cannabis flower products, intervention and prevention measures are urgently needed, such as better regulation of cannabis vaping products and bans on advertising that targets young people to mitigate the increasing prevalence of cannabis vaping among adolescents.

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