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Prevalence and use of cannabis products and routes of administration among youth and young adults in Canada and the United States: A systematic review

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ABSTRACT

Background: The current systematic review aimed to summarize the literature on the prevalence of routes of administration and cannabis products used among youth and young adults in Canada and the United States (US).
Methods: Five academic databases were searched in April 2020 and February 2021. Peer-reviewed articles were included if they were a population-based quantitative observational study describing the prevalence of a cannabis product or route of administration among youth and young adults in Canada or the US. Risk of bias was assessed using Hoy and colleagues' risk of bias assessment tool. A narrative review was conducted.
Results: Twenty-six studies were identified for the following routes of administration: smoking (n = 16), vaping (n = 21), dabbing (n = 3), oral (n = 13), topical (n = 1); and products: dried flower (n = 2), and concentrates (n = 8). Smoking had the highest prevalence rates among youth and young adults; however, rates of use appeared to reduce over time. Conversely, prevalence of vaping appeared to increase over time. Fewer studies focused on oral or dabbed cannabis but those that did reported prevalence estimates of approximately a third among recent cannabis consumers.
Discussion: The heterogeneity of cannabis routes of administration restricted our ability to collate average prevalence estimates. In jurisdictions where non-medical cannabis is legal, policymakers should provide guidance and education to youth on each type of product and routes of administration.
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1. Introduction

Canada and the United States (US) have some of the highest rates of cannabis ("marijuana") use in the world (United Nations Office on Drugs and Crime [UNODC], 2021). In the 2021 United Nations Office of Drugs and Crime, North America had the highest prevalence of past year cannabis use compared to other sub-regions globally at 14.5% (UNODC, 2021). In Canada and the U.S., cannabis use is most prevalent among youth and young adults (UNODC, 2021). In 2019 and 2020, Canadians between 16 and 24 years old reported double the past 12-month cannabis use compared with Canadians over 25 years old (Government of Canada, 2019; 2020). In the 2019 US National Survey on Drug Use and Health, 13% of youth (12–17-year-olds) and 35% of young adults (18–25-year-olds) reported consuming cannabis in the past year (Substance Abuse and Mental Health Services Administration [SAMHSA], 2019). Cannabis use has remained steady among US youth over recent years for past-year use and daily-use (National Institute on Drug Abuse, 2020).

In recent years, several jurisdictions have legalized recreational ("non-medical") cannabis, including Canada and 19 US states and the District of Columbia. Although research suggests that medical cannabis legalization in the U.S. has not resulted in increased prevalence of youth cannabis use, the research on recreational legalization and its association with youth cannabis use is mixed (Anderson et al., 2019; Borodovsky et al., 2016; Brooks-Russell et al., 2019; Carliner et al., 2017; Dilley et al., 2019; Midgette & Reuter, 2020; Paschall & Grube, 2020;

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Rusby et al., 2018; Sarvet et al., 2018). Indeed, recreational cannabis legalization can impact availability of cannabis for youth and young adults, as well as the types of products available to purchase. The minimum legal age (MLA) to purchase recreational cannabis varies; in all US states that have legalized recreational cannabis the MLA is 21 years, aligning with alcohol laws (ProCon, 2021). In Canada, the province of Alberta has an MLA of 18 years compared with 21 years in Quebec, which changed from 18 years in 2020 (CBC News, 2020). The rest of the provinces and territories have an MLA of 19 years (Canadian Centre on Substance Use and Addiction, 2021).

Cannabis can be consumed through different routes of administration, including smoked, vaped, dabbed, sublingually, and ingested orally. "Dabbing" is the process of vaporizing high-potency concentrates using a 'dab rig' at temperatures of approximately 400–600 degrees Fahrenheit (Stogner & Miller, 2015). Similarly, consumers use different cannabis products, such as dried flower (with or without tobacco), oils, solid concentrates (e.g., hash, shatter), edibles, and topical creams. In addition, products are consumed using different cannabis devices, such as bongs, joints, vape pens, or blunts. The health and acute psychoactive effects of cannabis may be influenced by the route of administration and type of product and device used (Pertwee, 2014; Craft et al., 2020). Consumers who smoke or vape cannabis may feel the acute psychoactive effects quicker but for a shorter duration than those orally consuming cannabis (Pertwee, 2014). Similarly, consumers of high-potency solid concentrates may experience more intense psychoactive effects than those using low-potency topical creams. Smoking dried flower remains the most common route of administration in Canada and the US (Goodman et al., 2020); however, other routes of administration are increasing (Caulkins et al., 2018; Government of Canada, 2017; 2020; Patrick et al., 2020). High-potency products such as edibles and other cannabis concentrates are more prevalent in jurisdictions where recreational cannabis is legal, such as Canada and US states that have legalized recreational cannabis (Borodovsky et al., 2016; Borodovsky & Budney, 2017; Caulkins et al., 2018; Goodman et al., 2020; Lee et al., 2016).

Vaping is an increasingly common way to consume cannabis, and the use of delta9-tetrahydrocannabinol (THC) vape oils is among the fastest growing routes of administration, particularly among youth (Chadi et al., 2019; Dai & Siahpush, 2020; Fataar & Hammond, 2019; Jones et al., 2016; Miech et al., 2020; Patrick et al., 2020). In the US Monitoring the Future survey, past month THC vaping increased significantly between 2017 and 2019 among youth in 8th (13–14 years), 10th (15–16 years), and 12th grade (17–18 years) (Johnston et al., 2019). The prevalence of any cannabis use remained steady, which the authors suggest other routes (e.g., smoking dried flower) might be substituted for vaping cannabis (Johnston et al., 2019). Alternatively, this could also represent complementary use among youth already consuming cannabis through other routes of administration.

The increasing popularity of vaping and non-combustible cannabis products such as edibles reflects a combination of greater commercial availability, lower perceptions of risk, and more positive social norms compared to smoking (East et al., 2019; Shiplo et al., 2016; Zare et al., 2018). As well as being more discreet to use, edible cannabis products may be attractive to youth due to the similarities to standard confectionary, such as chocolate or gummies (Goodman et al., 2019). Indeed, the Canadian province of Quebec restricted legal edibles to products that do not appeal to children (CBC News, 2019). Non-combustible routes of administration and cannabis products are not without health risks. For example, vaping THC oils were recently linked to over 60 deaths and over 2,500 cases of pulmonary disease in the US, although it is worth noting that these cases were attributed to an adulterant (vitamin E acetate) rather than to THC (Centers for Disease Control and Prevention, 2020). A separate concern with edible cannabis is accidental overconsumption due to delayed onset of effects (Wang et al., 2016), and the association between high-potency products and problematic use (Arterberry et al., 2019; Di Forti et al., 2019; Freeman & Winstock, 2015).

1.1. Rationale

Although the use of non-combustible cannabis products has the potential to reduce toxic exposure from smoke inhalation, there are concerns, particularly regarding vape oils and solid concentrates. Previous systematic reviews have explored prevalence and use of specific cannabis products or routes of administration, e.g., vaped cannabis or cannabis with tobacco (Chadi et al., 2019; Lim et al., 2021; Ramo et al., 2012); however, no systematic review has examined all products, all routes of administration and their devices together. A scoping review examined routes of administration and health related outcomes until 2017 (Russell et al., 2018); however, since the scoping review was conducted, cannabis policies have changed in North America. Canada and nine additional U.S. states legalized recreational cannabis, which potentially changed access and availability of cannabis for youth and young adults. Such a shift in cannabis legislation warrants a revisit to cannabis product and device use and their routes of administration, especially among populations with the highest rates of cannabis consumption.

1.2. Objective

The objective of this systematic review is to systematically and critically review the literature on the prevalence and use of routes of administration, cannabis products and devices used among youth and young adults in Canada and the US.

2. Methods

2.1. Protocol and registration

This study is reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (Page et al., 2021), and registered with PROSPERO, the international prospective register of systematic reviews (CRD42020169275). The original submission to PROSPERO presented inclusion criteria that was deemed to broad and so the submission to PROSPERO was updated to refine and narrow our search criteria, e.g., to only include representative samples to at least the city-level and only include peer-reviewed published articles (see Section 2.2); however, identical search strategies were used throughout the process.

2.2. Eligibility criteria

Studies were included if they met the following criteria: 1) observational study that used quantitative methods; 2) reported the route of administration, type of cannabis product or device; 3) conducted in Canada or in the US; 4) used a sample representative, or weighted to be representative, of at least a city-level population; 5) reported data from youth and/or young adults; 6) peer-reviewed published article; 7) published in the English language; 8) conducted with humans, i.e., not an animal study. Studies conducted with only adults (18 +) were incorporated if authors provided a breakdown of prevalence across age. The age of young adults was adapted to align with studies depending on their definition of young adults. To note, studies that only included synthetic cannabis products, i.e., prescribed cannabis-based products (e.g., Sativex) or synthetic cannabinoids (e.g., Spice) were not included. Studies were deemed to be representative if they compared and stated they were representative to the population they were sampling for (e.g., national, provincial/state, county, city) and their study used random sampling techniques, or if they did not use random sampling techniques, they weighted their sample to the targeted population.

2.3. Search strategy and information sources

Articles were identified using the following databases from inception to April 9th, 2020: EMBASE, Medline, PsychINFO, Global Health, and Web of Science. Searches were repeated on February 22nd, 2021 to add any studies published since April 2020 and identical methods were used to complete the search. The two authors (EW, SC) independently carried out the searches in April 2020 and February 2021. For search terms used, see Supplemental File 1.

2.4. Selection process

Two authors (EW, SC) independently extracted the articles to EndNote reference management software (v9.3.3). Duplicate articles were electronically identified and removed. Two authors (EW, SC) independently assessed the titles and abstracts for eligibility and then assessed the remaining articles in full-text, recording reasons for exclusion. All conflicts were discussed between the two authors until resolved. For conflicts that could not be resolved, a third reviewer decided (RC). Reference lists of included articles were reviewed for extra citations.

2.5. Data collection process

Two authors (EW, SC) independently extracted the data from the final articles using a prepared data extraction tool in Microsoft Excel. The two datasets of extracted data were merged, and discrepancies were identified. All discrepancies were discussed between the two authors until resolved, those were decided by the third author (RC).

2.6. Data items

The main outcome extracted was prevalence of cannabis products, devices, or routes of administration (%) and the respective time period (i.e., past 12-month). Other data collected were date of study period, study location, observational study type, sample size, mean age, and ethnicity/race. All prevalence estimates were extracted in articles with multiple estimates in the same sample of participants, i.e., different cannabis products or time periods of use.

2.7. Data assumptions

First, cannabis devices used to consume cannabis (e.g., blunts used to consume dried flower) were categorized with the route of administration. For example, blunts (i.e., cannabis wrapped in tobacco casing) were assumed to be smoked; however, no study explicitly outlined that the respondent *smoked* blunts. Second, studies using terms 'concentrates' and 'extracts' were assumed comparable. Third, where studies did not outline the age range of participants, school-based surveys were assumed to be youth (up to 18 years). Similarly, young adults were assumed to be aged between 18 and upwards of 24 depending on respective studies definition of young adults, i.e., some studies incorporated young adults up to 25 years, others 34 years. Finally, time frames of past 30-days and past-month were assumed comparable and referred to as "past 30-days" and time frames of past 12-months and past-year were assumed comparable and referred to as "past 12-months".

2.8. Study risk of bias assessment

Two authors (EW, SC) adapted Hoy and colleagues' risk of bias assessment tool to assess the quality of studies (see Table S1): three questions were removed from the original tool as they did not suit the current review, and examples were changed to reflect the topic (Hoy et al., 2012). If a question on the assessment tool could not be answered from the information presented in a manuscript, the category was treated as high risk. Conflicts were discussed between authors (EW, SC) and a third author decided (RC) for conflicts that could not be resolved.

2.9. Effect measures

Not included as the current study does not examine an intervention with an effect.

2.10. Synthesis methods

Due to the predicted heterogeneity of the studies and the outcome measure, a narrative overview was used. As studies often provided multiple prevalence rates for different specified sub-samples of participants, results were reported separately for youth and young adults. Additionally, within both youth and young adult sections, prevalence estimates were reported among the total population and among cannabis consumers (defined as those who had ever consumed cannabis, consumed cannabis in the past 12-months, or consumed cannabis in the past-month).

2.11. Reporting bias and certainty assessment

No additional methods were used to assess the risk of bias of missing results or certainty in the body of evidence. Overall, the literature was heterogeneous and involved many different and compromised samples, and so the certainty of the body of evidence is fairly low, but a more formal assessment wasn't conducted due to the difficulties in assessing publication bias in prevalence studies where small studies were, by design, excluded.

3. Results

3.1. Study selection

A total of 8,427 studies were identified by the original search, with a further 36 identified through reference lists. After deduplication (n = 3,565), 4,862 titles and abstracts were screened. After 4,263 records were removed for eligibility, 599 full text articles were screened. Five hundred and seventy-two records were excluded at full-text level for having no breakdown of cannabis (n = 307); no breakdown of age or ineligible age (n = 63); abstract only (n = 32); clinical sample (n = 30); incorrect study type (n = 23); incorrect product type (n = 15); no prevalence estimates (n = 21); not US or Canada based (n = 21); pooled year of prevalence (n = 5); sample not representative of population (n = 42); and duplicates (n = 6). A total of 26 studies were retained for extraction. See Figure 1 for PRISMA flow diagram.

3.2. Cohen's kappa

Cohen's kappa of inter-reviewer agreement for full-text screening was: 0.90 (SE:0.03). Cohen's kappa of inter-reviewer agreement for risk of bias was: 0.80 (SE:0.03).

3.3. Study characteristics

Table S2 and S3 detail the characteristics of all 26 articles. Most studies were US based (n = 20) (Ben Taleb et al., 2020; Delnevo & Hrywna, 2006; Eggers et al., 2017; Farsalinos et al., 2021; Kowitt et al., 2019; Krauss et al., 2017a; 2017b; Kritikos et al., 2021; Meier et al., 2019; Miech et al., 2020; Patrick et al., 2020; Schauer et al., 2016; Seaman et al., 2020; Steigerwald et al., 2018; Tai et al., 2021; Tormohlen et al., 2019a; 2019b; Trapl et al., 2018; Trivers et al., 2018; Wadsworth & Hammond, 2018), with three from Canada (Kolar et al., 2019; Mammen et al., 2016; Wardell et al., 2021), and three including both US and Canada (Fataar & Hammond, 2019; Hammond et al., 2021; Smith et al., 2020). Most studies were conducted among youth (n = 21)

(Ben Taleb et al., 2020; Delnevo & Hrywna, 2006; Eggers et al., 2017; Farsalinos et al., 2021; Fataar & Hammond, 2019; Hammond et al., 2021; Kolar et al., 2019; Kowitt et al., 2019; Kritikos et al., 2021; Mammen et al., 2016; Meier et al., 2019; Miech et al., 2020; Patrick et al., 2020; Smith et al., 2020; Tai et al., 2021; Tormohlen et al., 2019a; 2019b; Trapl et al., 2018; Trivers et al., 2018; Wadsworth & Hammond, 2018; Wardell et al., 2021), with six among young adults (Schauer et al., 2016; Seaman et al., 2020; Steigerwald et al., 2018; Krauss et al., 2017a; 2017b). Nineteen were cross-sectional (Ben Taleb et al., 2020; Delnevo & Hrywna, 2006; Eggers et al., 2017; Fataar & Hammond, 2019; Kolar et al., 2019; Kowitt et al., 2019; Krauss et al., 2017a; 2017b; Kritikos et al., 2021; Mammen et al., 2016; Meier et al., 2019; Schauer et al., 2016; Seaman et al., 2020; Smith et al., 2020; Steigerwald et al., 2018; Trapl et al., 2018; Trivers et al., 2018; Wadsworth & Hammond, 2018; Wardell et al., 2021), and seven were repeat cross-sectional (Farsalinos et al., 2021; Hammond et al., 2021; Miech et al., 2020; Patrick et al., 2020; Tai et al., 2021; Tormohlen et al., 2019a; 2019b). Most studies recruited a national sample (n = 17) (Ben Taleb et al., 2020; Delnevo & Hrywna, 2006; Farsalinos et al., 2021; Fataar & Hammond, 2019; Hammond et al., 2021; Krauss et al., 2017a; 2017b; Kritikos et al., 2021; Miech et al., 2020; Patrick et al., 2020; Schauer et al., 2016; Seaman et al., 2020; Smith et al., 2020; Steigerwald et al., 2018; Tai et al., 2021; Trivers et al., 2018; Wadsworth & Hammond, 2018), eight recruited a state/provincial sample (Eggers et al., 2017; Kolar et al., 2019; Kowitt et al., 2019; Mammen et al., 2016; Meier et al., 2019; Tormohlen et al., 2019a; 2019b; Wardell et al., 2021), and one recruited a county-level sample (Trapl et al., 2018). Sample sizes ranged from n = 42 to n = 20,675.

Most articles reported prevalence of routes of administration or cannabis device (Table S2); these comprised smoking/combustible (n = 16) (Delnevo & Hrynwa, 2006; Eggers et al., 2017; Fataar & Hammond, 2019; Hammond et al., 2021; Kolar et al., 2019; Patrick et al., 2020; Schauer et al., 2016; Seaman et al., 2020; Smith et al., 2020; Steigerwald et al., 2018; Tai et al., 2021; Tormohlen et al., 2019a; 2019b; Trapl et al., 2018; Wadsworth & Hammond, 2018; Wardell et al., 2021), vaping (n = 21) (Ben Taleb et al. 2020; Eggers et al., 2017; Farsalinos et al., 2021; Fataar & Hammond, 2019; Hammond et al., 2021; Kolar et al., 2019; Kowitt et al., 2019; Kritikos et al., 2021; Mammen et al., 2016; Miech et al., 2020; Patrick et al., 2020; Schauer et al., 2016; Seaman et al., 2020; Smith et al., 2020; Steigerwald et al., 2018; Tai et al., 2021; Tormohlen et al., 2019a; 2019b; Trivers et al., 2018; Wadsworth & Hammond, 2018; Wardell et al., 2021), dabbing (n = 3) (Patrick et al., 2020; Tormohlen et al., 2019a; 2019b), oral ingestion (n = 13) (Fataar & Hammond, 2019; Hammond et al., 2021; Kolar et al., 2019; Krauss et al., 2017a; 2017b; Patrick et al., 2020; Schauer et al., 2016; Smith et al., 2020; Steigerwald et al., 2018; Tormohlen et al., 2019a; 2019b; Wadsworth & Hammond, 2018; Wardell et al., 2021), and topical (n = 1) (Steigerwald et al., 2018). Cannabis products reported without a specific route of administration (Table S3) were dried flower (n = 2) (Krauss et al., 2017a; 2017b) and concentrates (n = 8) (Fataar & Hammond, 2019; Hammond et al., 2021; Krauss et al., 2017a; 2017b; Meier et al., 2019; Smith et al., 2020; Steigerwald et al., 2018; Wadsworth & Hammond, 2018). Time period of cannabis product or route of administration varied: past-30-day or past-month (n = 15) (Delnevo & Hrywna, 2006; Fataar & Hammond, 2019; Hammond et al., 2021; Krauss et al., 2017a; 2017b; Kritikos et al., 2021; Meier et al., 2019; Miech et al., 2020; Schauer et al., 2016; Smith et al., 2020; Tai et al., 2021; Tormohlen et al., 2019a; 2019b; Wadsworth & Hammond, 2018); past-12-months or past-year (n = 6) (Kolar et al., 2019; Mammen et al., 2016; Miech et al., 2020; Patrick et al., 2020; Steigerwald, et al., 2018; Wardell et al., 2021); ever (n = 9) (Ben Taleb et al., 2020; Eggers et al., 2017; Farsalinos et al., 2021; Kowitt et al., 2019; Meier et al., 2019; Miech et al., 2020; Schauer et al., 2016; Seaman et al., 2020; Trivers et al., 2018).

3.4. Risk of bias within studies

Hoy and colleagues' risk of bias assessment was adapted to fit the scope of the current review (Table S1) (Hoy et al., 2012). Twenty-four studies were categorized as low risk, two as moderate risk, and none as high risk. A criterion that was commonly rated as 'high risk' was the likelihood of non-response bias.

3.5. Results of individual studies

3.5.1. Route of administration and/or device: Smoking/combustible

3.5.1.1. Youth. One study examined 'ever' blunt use among youth. In Florida, 6% and 24% of middle and high school students respectively reported ever blunt use in 2017 (Eggers et al., 2017). Two studies examined past 30-day blunt use among youth. In a 2001 national survey, 5% of youth (12–17 years) reported past 30-day blunt use (Delnevo & Hrywna, 2006). In a survey of US high school students from Cuyahoga County, Ohio, 19% reported past 30-day blunt use in 2013 (Trapl et al., 2018).

Nine studies examined smoked/combustible cannabis prevalence among youth who had recently used cannabis (Fataar & Hammond, 2019; Hammond et al., 2021; Kolar et al., 2019; Patrick et al., 2020; Smith et al., 2020; Tai et al., 2021; Tormohlen et al., 2019a; 2019b; Wadsworth, & Hammond, 2018). Two studies used the same repeat cross-sectional data from the Monitoring the Future Survey (Patrick et al., 2020; Tai et al., 2021). Among Grade 12 students reporting past 12-month cannabis use, 95%, 95%, 94%, and 89% reported smoking cannabis in the past 30-days in 2015, 2016, 2017, and 2018, respectively (Patrick et al., 2020; Tai et al., 2021. Four studies used cross-sectional data among US youth (16–19 years) reporting past 30-day cannabis use from the International Tobacco Control Evaluation Project (ITC) Youth Tobacco and Vaping Survey (Fataar & Hammond, 2019; Hammond et al., 2021; Smith et al., 2020; Wadsworth & Hammond, 2018). Among these US youth, 89%, 85%, and 81% smoked cannabis without tobacco in the past 30 days in 2017, 2018, and 2019, respectively (Fataar & Hammond, 2019; Hammond et al., 2021; Smith et al., 2020). Two studies found that among Colorado high school students reporting past 30-day cannabis use, 92% and 88% reported smoking cannabis in the past 30-days in 2015 and 2018, respectively (Tormohlen et al., 2019a; 2019b).

Five studies examined combustible cannabis use among Canadian youth at national or provincial levels. Among Ontario high school students reporting past 12-month cannabis use, 74%, 35%, and 82% smoked cannabis in a joint, blunt, or pipe/bong/waterpipe, respectively, in the past 12-months in 2017 (Kolar et al., 2019). Among Ontario high school students reporting past year cannabis use, between 94% and 96% smoked cannabis in the past 12-months (Wardell et al., 2021). Among Canadian youth (16–19 years) reporting past 30-day cannabis use, 82%, 80% and 80% smoked cannabis without tobacco, 37%, 33% and 35% smoked cannabis with tobacco, and 55%, 52% and 49% smoked cannabis in a waterpipe or bong in the past 30-days in 2017, 2018, and 2019, respectively (Fataar & Hammond, 2019; Hammond et al., 2021; Smith et al., 2020).

3.5.1.2. Young adults. One study examined the prevalence of smoked/combustible cannabis among young adults (Steigerwald et al., 2018). In a national survey of US adults, 21% of young adults (18–34 years) reported smoking cannabis in the past 12 months in 2017 (Steigerwald et al., 2018). Two national cross-sectional studies examined combustible cannabis consumption among US young adults (18–24 years) who had ever used cannabis (Schauer et al., 2016; Seaman et al., 2020). Schauer and colleagues found that 70% reported ever consuming cannabis in a joint; 55% in a bowl/pipe; 45% in a bong/waterpipe/hookah; and 37% in a blunt, in 2014 (Schauer et al., 2016). In 2015–2016, 25% of young

adults who had ever used cannabis reported ever using hookah and 74% reported using cigar products for cannabis consumption (Seaman et al., 2020). One national cross-sectional study examined combustible cannabis consumption among US young adults who had recently used cannabis in 2014 (Schauer et al., 2016). Schauer and colleagues that nearly half of 18–24-year-olds reported consuming cannabis in a joint or a bowl/pipe in the past 30-days (Schauer et al., 2016).

3.5.2. Route of administration and/or device: Vaping

3.5.2.1. Youth. Eight studies examined the prevalence of vaped cannabis among youth (Ben Taleb et al., 2020; Eggers et al., 2017; Farsalinos et al., 2021; Kowitt et al., 2019; Kritikos et al., 2021; Mammen et al., 2016; Miech et al., 2020; Trivers et al., 2018). Five studies examined middle and high school students using the National Youth Tobacco Survey (NYTS) or its state equivalent (e.g., Florida Youth Tobacco Survey) (Ben Taleb et al., 2020; Eggers et al., 2017; Farsalinos et al., 2021; Kowitt et al., 2019; Trivers et al., 2018). Among middle and high school students, 9%, 11%, and 14% reported ever using an e-cigarette to vape cannabis in 2016, 2017, and 2018, respectively (Farsalinos et al., 2021; Trivers et al., 2018). Using the same 2018 NYTS data but among middle and high school students who had responded to a question on vaping cannabis (i.e., excluding missing data), 26% of students reported ever vaping cannabis in 2018 (Ben Taleb et al., 2020). In Florida, 3% and 12% of middle and high school students respectively reported ever using an electronic vaping product for cannabis in 2015 (Eggers et al., 2017). In North Carolina, 10% reported ever using an e-cigarette to vape cannabis in 2017 (Kowitt et al., 2019).

Two studies used the same data across different time points from the Monitoring the Future Survey (Miech et al., 2020; Kritikos et al., 2021). Miech and colleagues (2020) examined vaped cannabis use among Grade 8, 10, and 12 students in 2017, 2018, and 2019. The percentage of Grade 8, 10, and 12 students who reported vaping cannabis ever (4% to 9%; 10% to 22%; 12% to 24%), in the past 12-months (3% to 7%; 8% to 19%; 10% to 21%), and in the past 30-days increased from 2017 to 2019, respectively (2% to 4%; 4% to 13%; 5% to 14%) (Miech et al., 2020). In a study of public high school students in Ontario in 2015, 8% reported vaping cannabis in the past 12-months (Mammen et al., 2016).

Ten studies examined the prevalence of vaped cannabis among youth who had recently used cannabis (Fataar & Hammond, 2019; Hammond et al., 2021; Kolar et al., 2019; Patrick et al., 2020; Smith et al., 2020; Tai et al., 2021; Tormohlen et al., 2019a; 2019b; Wadsworth & Hammond, 2018; Wardell et al., 2021). Two studies used the same data across different time points from Monitoring the Future Survey among 12th graders in the US reporting past 12-month cannabis use (Patrick et al., 2020; Tai et al., 2021). In 2015, 2016, 2017, and 2018, 27%, 20%, 22%, and 35% reported vaping cannabis in the past 30-days, respectively (Patrick et al., 2020; Tai et al., 2021). From the ITC Youth Tobacco and Vaping Survey among US youth (16–19 years) reporting past 30-day cannabis use, 21%, 22%, and 23% reported using a vaporizer to heat dried flower and 24%, 31%, and 52% reported using an e-cigarette to vape cannabis in the past 30-days in 2017, 2018, and 2019, respectively (Fataar & Hammond, 2019; Hammond et al., 2021; Smith et al., 2020). Among Colorado high school students reporting past-30-day cannabis use, 22% and 20% reported vaping cannabis in the past 30-days in 2015 and 2018, respectively (Tormohlen et al., 2019a; 2019b).

Five studies examined cannabis vaping among Canadian youth at national or provincial levels. In a school-based survey among Ontario high school students reporting past 12-month cannabis use, 26% reported using cannabis in a vaping device in the past 12-months in 2017 (Kolar et al., 2019). Among Ontario high school students reporting past 12-month cannabis use, between 19% and 46% reported vaporizing cannabis in the past 12-months (Wardell et al., 2021). Among Canadian youth reporting past 30-day cannabis use, 16%, 19% and 19% reported using a vaporizer to heat dried flower, and 13%, 19% and 26% reported using an e-cigarette to vape cannabis in the past 30-days in 2017, 2018, and 2019, respectively (Fataar & Hammond, 2019; Hammond et al., 2021; Smith et al., 2020).

3.5.2.2. Young adults. In a national survey among young adults (18–34 years), 8% reported vaping cannabis in the past 12-months in 2017 (Steigerwald et al., 2018). Two national surveys examined cannabis vaping among young adults (18–24 years) who had ever used cannabis (Schauer et al., 2016; Seaman et al., 2020). In 2014, 19% of young adults who had ever used cannabis reported ever consuming cannabis in a vaporizer or electronic device (Schauer et al., 2016). In 2015–2016, 25% of young adults who had ever used cannabis reported ever using ENDS for cannabis consumption (Seaman et al., 2020).

3.5.3. Route of administration and/or device: Dabbing

3.5.3.1. Youth. In the 2018 Monitoring the Future survey in the US, 31% of Grade 12 students reporting past 12-month cannabis use reported dabbing cannabis in the past 12-months (Patrick et al., 2020). Among Colorado high school students reporting past 30-day cannabis use, 28% and 34% reported dabbing cannabis in the past 30-days in 2015 and 2018, respectively (Tormohlen et al., 2019a; 2019b).

3.5.4. Route of administration and/or device: Oral ingestion

3.5.4.1. Youth. Nine studies examined the prevalence of orally ingesting cannabis among youth who had recently used cannabis (Fataar & Hammond, 2019; Hammond et al., 2021; Kolar et al., 2019; Patrick et al., 2020; Smith et al., 2020; Tormohlen et al., 2019a; 2019b; Wadsworth & Hammond, 2018; Wardell et al., 2021). Three cross-sectional studies examined edible cannabis consumption among high school students reporting past 12-month cannabis use (Kolar et al., 2019; Patrick et al., 2020; Wardell et al., 2021). Among US Grade 12 students, 32% and 40% reported eating cannabis in the past 12-months in 2015 and 2018, respectively (Patrick et al., 2020). Slightly higher percentages of past 12-month edible cannabis consumption were found among Ontario high school students in 2017 (42%) (Kolar et al., 2019). Among Ontario high school students reporting past 12-month cannabis use, between 33% and 67% reported eating cannabis in the past 12-months (Wardell et al., 2021).

Four studies used the same repeat cross-sectional data from the ITC Tobacco and Youth E-cigarette Survey in different years (Fataar & Hammond, 2019; Hammond et al., 2021; Smith et al., 2020; Wadsworth & Hammond, 2018). Nearly one third of Canadian and US youth (16–19 years) reporting past 30-day cannabis use, reported eating or drinking cannabis in the past 30 days in 2017, 2018, and 2019 (Fataar & Hammond, 2019; Hammond et al., 2021; Smith et al., 2020). Similarly, among Colorado high school students reporting past 30-day cannabis use, 28% and 36% reported ingesting cannabis in the past 30-days in 2015 and 2018, respectively (Tormohlen et al., 2019a; 2019b).

3.5.4.2. Young adults. In a national study of US adults, 10% of young adults (18–34 years) reported consuming edible cannabis in the past 12-months in 2017 (Steigerwald et al., 2018). In a national study of US adults, 30% of 18–24-year-olds who had ever used cannabis reported ever eating or drinking cannabis in 2014 (Schauer et al., 2016). Two studies using data from the same cross-sectional online survey in the US found 30% and 32% of past-30-day young adult (18–34 years) cannabis consumers reported edible cannabis consumption in the past 30-days in 2015 (Krauss et al., 2017a; 2017b).

3.5.5. Route of administration and/or device: Topically

3.5.5.1. Young adults. In a national study among US adults, 1.3% of young adults (18–34 years) reported consuming cannabis topically in in

the past 12-months in 2017 (Steigerwald et al., 2018).

3.5.6. Cannabis products

3.5.6.1. Youth. Among high school students in Arizona, US, 24% and 12.7% reported consuming concentrates 'ever' and in the past 30-days, respectively (Meier et al., 2019). Four studies used repeat cross-sectional data from the ITC Youth Tobacco and Vaping Survey (Fataar & Hammond, 2019; Hammond et al., 2021; Smith et al., 2020; Wadsworth & Hammond, 2018). Among Canadian and US youth (16–19 years) reporting past 30-day cannabis use, consumption of cannabis concentrates in the past 30-days increased from 2017 to 2019 (21% to 26% in Canada; 27% to 41% in US) (Fataar & Hammond, 2019; Hammond et al., 2021; Smith et al., 2020).

3.5.6.2. Young adults. In a 2017 national sample of US adults, 4% of young adults (18–34 years) reported consuming concentrates in the past 12-months (Steigerwald et al., 2018). Among US young adult (18–34 years) past 30-day cannabis consumers, 31% and 29% reported consuming concentrates in the past 30-days in 2015 (Krauss et al., 2017a; 2017b).

Among past 30-day young adult (18–34 years) cannabis consumers in the US, 96% reported consuming dried flower in the past 30-days in 2015 (Krauss et al., 2017a; 2017b).

3.6. Reporting biases and certainty of evidence

As mentioned previously, assessments of risk of bias of missing results and the certainty of evidence was not conducted (see Section 2.11).

4. Discussion

The majority of studies included in the current review were US based, conducted among youth, and examined smoking/combustible cannabis or vaped cannabis. The heterogeneity of reporting for each route of administration, product, and device prevented the authors from reporting an overall prevalence for each category. For example, studies examining smoked cannabis included responses on joints, bowls, blunts, pipes, waterpipes/hookah, smoking with or without tobacco, as well as overall 'smoking'. Similarly, studies examining vaped cannabis included responses on vaping dried flower, oils, concentrates, and overall 'vaping'. Caulkins and colleagues commented that cannabis should be considered an umbrella term for many products (Caulkins et al., 2018). More research is needed to reflect the expanding range of cannabis products, devices, and routes of administration, especially as more jurisdictions open legal retail markets. Future research should also use standardized tools for measuring cannabis products and time-frames in order to facilitate comparisons and estimates across years and jurisdictions. Indeed, a recent framework was proposed for minimum standards in measuring cannabis consumption and suggested time-frames including 'ever' and 'past-month' (e.g., "in the past month, on how many days have you used cannabis?"); however, this does not breakdown by products, devices, nor routes of administration (Lorenzetti et al., 2021).

Smoking cannabis had the highest prevalence of use among youth and young adults across all routes of administration and products. Among youth who had recently consumed cannabis, approximately 89% to 95% reported having smoked cannabis in the past 12-months and approximately 81% to 92% in the past 30-days, at the national and state/provincial level. These estimates varied when smoked cannabis devices (such as blunts or joints) were specified. The high prevalence of smoking mirrors findings for adult cannabis consumers as well as youth and young adult sub-populations, such as university students (Goodman et al., 2020; Government of Canada, 2017; 2018; 2019; 2020; Hindocha et al., 2016). Among youth who had recently consumed cannabis, smoking cannabis rates appeared to decline over the period captured by the current review, at the national and state (e.g., Colorado) level (Hammond et al., 2021; Patrick et al., 2020; Tai et al., 2021). This apparent reduction in smoking cannabis reflects national surveys and literature in Canada and the US, particularly in jurisdictions where non-medical cannabis is legal for adult use (Borodovsky & Budney, 2017; Borodovsky et al., 2016; Government of Canada, 2017; 2018; 2019; 2020; Johnston et al., 2019; Lee et al., 2016; Miech et al., 2020; Patrick et al., 2020).

The prevalence of vaping cannabis appeared to increase over time at the national level. For example, prevalence rates among US Grade 8, 10, and 12 students who reported vaping cannabis ever, in the past 12-months, and in the past 30-days increased from 2017 to 2019 (Miech et al., 2020). Previous research from national surveys suggests that vaping cannabis is becoming more popular in youth and young adult populations (Borodovsky & Budney, 2017; Borodovsky et al., 2016; Government of Canada, 2017; 2018; 2019; 2020; Miech et al., 2020; Patrick et al., 2020), mirroring the increase in popularity for vaping nicotine, perhaps due to the discreet nature of vaping devices compared to smoking (Hammond et al., 2020).

Decreased prevalence of smoked cannabis and increases in non-smoked cannabis could be beneficial for public health by reducing the harms of smoking (Russell et al., 2018). However, more research is needed on the short- and long-term public health effects of non-smoked cannabis (Fischer et al., 2017). Indeed, products such as vape oils and solid concentrates are not without harms, largely due to higher THC concentrations (Russell et al., 2018). Dried flower tends to have a biological THC limit of 30%, whereas non-flower products can exceed 70% (Caulkins et al., 2018; Cavazos-Rehg et al., 2018; Hammond, 2021; Raber et al., 2015). Inhalation of vaporized high potency concentrates ('dabbing') is of concern (Stogner & Miller, 2015). In the current review, dabbing was only reported by three studies, one at the national level (U.S.), and two at the state level (Colorado); however, in all three, nearly one third of youth who had recently consumed cannabis reported recently dabbing (Patrick et al., 2020; Tormohlen et al., 2019a; 2019b). Estimates of oral cannabis consumption among youth and young adults who had consumed cannabis were also approximately a third (Hammond et al., 2021; Kolar et al., 2019; Krauss et al., 2017a; 2017b; Patrick et al., 2020; Schauer et al., 2016; Tormohlen et al., 2019a; 2019b). As cannabis policies liberalize, it is important that public health messages highlight differences between cannabis products, devices, and routes of administration including risks from consuming high potency THC products. This is important for youth, where open discussion may still be stigmatized as products remain illegal for minors.

4.1. Limitations of review

There are several limitations to this systematic review. First, due to the of the heterogeneity of cannabis products, devices, routes of administration, and time frames used across studies, a *meta*-analysis was not appropriate. Second, the review excluded grey literature and non-peer reviewed articles, potentially excluding relevant data. Whereas data from US national monitoring surveys, such as Monitoring the Future, are often published in the peer-review literature, the review did not include data from Canada's national monitoring survey (Canadian Student Tobacco Alcohol and Drugs Survey) as they were not published in peer-review journals (Government of Canada, 2020b). It is possible that subgroups of populations were missed from the review because it only included samples reported to be representative or weighted to be representative to at least a city level. Smaller studies with targeted samples can identify differences among smaller groups and marginalized populations that are important to consider, but beyond the scope of this review (Montgomery & Mantey, 2018; Montgomery & Oluwoye, 2016; Greaves & Hemsing, 2020).

4.2. Limitations of included studies

The current review focused on population-based studies, which have limitations including non-response, self-reported outcomes, and samples that exclude sub-groups including military personnel and prisoners. Similarly, studies among youth from schools can exclude home-schooled people or some private schooled people. Finally, the current review included young adults without a defined age limit: we used the age range the individual studies provided. Therefore, there are limitations to the conclusions that can be drawn due to the wide range of ages that young adults could apply to, especially for a population which according to national surveys in the US and Canada, have the highest prevalence rates of cannabis consumption (Government of Canada, 2020a; SAMHSA, 2019). Future research should examine young adult cannabis consumption across the wide range of routes of administration, devices, and products to fully capture the cannabis market among those who have the highest rates of use in the population, while mirroring age ranges used by national government surveys.

4.3. Conclusions

The heterogeneity of cannabis products, devices, and their routes of administration restricted our ability to collate average prevalence estimates. It appears that smoking cannabis is decreasing and vaping cannabis is increasing among youth and young adults. Fewer studies focused on oral, dabbed, or topical cannabis; but broadly, prevalence estimates of cannabis consumed orally or by dabbing were approximately a third among recent cannabis consumers. Studies of cannabis consumption should specify what cannabis products, devices, and routes of administration are used by respondents to capture the variety of these products. In jurisdictions where non-medical cannabis is legal, policymakers should seek to provide guidance and education to youth on types of product and routes of administration. The implications of this work are increasingly important as more jurisdictions legalize cannabis. Youth and young adults consume cannabis in a wide range of products, devices, and routes of administration, with each product having its own public health benefit and concerns.

Declaration of Competing Interest

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.addbeh.2022.107258.

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