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Cannabis consumption and motor vehicle collision: A systematic review and meta-analysis of observational studies

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ABSTRACT

Background: Increasing legalization of recreational cannabis and availability of cannabinoid products has resulted in expanded use, which is associated with adverse effects including concerns over increased risk of motor vehicle collision (MVC). We aimed to explore the association between cannabis consumption and MVC.
Methods: We searched MEDLINE, EMBASE, CINAHL, Cochrane library, SCOPUS, PsycInfo, Web of Science, TRID from inception to November 2024. We included studies assessing the association between cannabis consumption on MVC fatalities, any injuries, and culpability/unsafe driving actions. Pairs of reviewers independently screened search results, extracted data, and assessed risk of bias. We used a DerSimonian and Laird random-effects model for all meta-analyses and the GRADE approach to assess the certainty of evidence.
Results: We included 31 studies with 328,388 individuals. Low certainty evidence suggests that cannabis consumption may be associated with an increased risk of MVC fatality (8 studies, OR 1.55, 95% CI: 1.20 to 1.98) with an absolute risk increase (ARI) of 14 more deaths per 100,000 MVC's. Low certainty evidence from 9 case-control studies suggests cannabis consumption may be associated with an increased risk of injury due to MVC (OR 2.00, [95% CI: 1.31-3.07]; absolute risk increase of 6.8%). We are uncertain about the association of cannabis consumption with MVC culpability/unsafe driving action as the evidence was only very low certainty.
Conclusions: Low certainty evidence suggests that cannabis consumption may increase risk of MVC fatality and risk of injury from MVC. The association between cannabis use and risk of unsafe driving is uncertain.
Protocol registration: CRD42022357478

Background

Globally, cannabis is one of the most widely used illicit substances, and in Canada cannabis is the second most common recreational drug consumed after alcohol ("Canadian Cannabis Survey 2023: Summary," 2024). The legalization of cannabis for non-medical purposes in Canada and parts of United States, as well as other countries (e.g., South Africa, Thailand), and the expansion of available cannabinoid products, such as extracts, have increased the availability and potency of cannabis. (Matheson & Le Foll, 2020) The proportion of Canadians aged 16+

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reporting cannabis use in the past 12 months increased from 15% in 2017 to 27% in 2022 ("Canadian Cannabis Survey 2021: Summary," 2021; "Canadian Cannabis Survey 2022: Summary," 2022).

A 2022 Canadian survey found that, among adults endorsing cannabis use, 21% reported operating a vehicle within 2 hours of use ("Annual National Data Report to Inform Trends and Patterns in Drug-Impaired Driving 2022," 2023). Moreover, individuals who endorse cannabis use are more likely to believe cannabis does not impair or may even improve driving (Watson, Mann, Wickens, & Brands, 2019). Cannabis use is associated with adverse effects, including distortion of time, altered judgement, and loss of coordination, leading to concerns over increased risk of motor vehicle collision (MVC) (Barnes, 2006; Bolla, Brown, Eldreth, Tate, & Cadet, 2002; Degenhardt & Hall, 2008; Els, et al., 2019; Hall & Degenhardt, 2009; B. R. Martin, 2002; Moskowitz, 1985; Solowij, et al., 2002; Wang, Collet, Shapiro, & Ware, 2008).

Prior systematic reviews of cannabis use and MVC have reported inconsistent findings, concluding a doubling of the risk, much smaller associations, or no significant association.(Asbridge, Hayden, & Cartwright, 2012; Els, et al., 2019; Hostiuc, Moldoveanu, Negoi, & Drima, 2018; M.C. Li, et al., 2012; Rogeberg & Elvik, 2016; White & Burns, 2021) These reviews have important limitations, including [1] inadequate risk of bias assessment (Els, et al., 2019), [2] inclusion of studies that rely on self-report as a method of THC detection which is highly unreliable (Asbridge, et al., 2012; Els, et al., 2019) (i.e., use of self-report vs. toxological confirmed cannabis exposure) (Hostiuc, et al., 2018; Rogeberg & Elvik, 2016), [3] failure to explore sources of variability in primary studies such as the different risk of bias factors (e.g., studies that adequately versus inadequately adjust for confounding factors such as concomitant alcohol use) (M.C. Li, et al., 2012) and [4] failure to appraise the overall certainty of evidence (Asbridge, et al., 2012; Els, et al., 2019; Hostiuc, et al., 2018; M.C. Li, et al., 2012; Rogeberg & Elvik, 2016; White & Burns, 2021). We conducted a systematic review of observational studies to evaluate the association between cannabis consumption and MVC fatality, injury, and culpability that addresses these limitations. This systematic review informed a parallel guideline of cannabis for management of chronic non-cancer pain.

Methods

Registration and reporting

We reported our systematic review in accordance with the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines (Page, et al., 2021) and registered our protocol in PROSPERO (CRD42022357478) in September 2022.

Data sources

An experienced medical librarian (RJC) developed database specific search strategies from inception to June 2023, and we then updated our searches up until November 2024. We searched MEDLINE, EMBASE, CINAHL, Cochrane library, PsycInfo, Scopus, Sociological Abstracts, Web of Science, Transportation Research International Documentation (TRID) database (e-Table 1). We also screened reference lists of included studies and relevant reviews for additional potentially eligible articles. We did not restrict our search by language or publication status.

Study selection and eligibility criteria

Pairs of reviewers (AJ, AD, MZ, NL, SB, and SS) completed calibration exercises and then independently screened titles and abstracts, and subsequent full texts of potentially eligible studies using online software (DistillerSR; Evidence Partners, Ottawa, Canada). Distiller We resolved disagreements through discussion or adjudication by a third reviewer (AJ, AJD, or BS) if needed.

We included comparative observational studies (i.e., case-control, culpability designs) that assessed drivers with recent cannabis use confirmed by toxicological analysis and the association with MVCs. A culpability study design involves comparing the prevalence of the factor of interest (cannabis consumption) among drivers found “culpable” or “responsible” for their crashes or unsafe driving versus among drivers found not culpable. We excluded experimental or simulator studies due to their limited applicability in real-life situations, and studies that explored the association between cannabis consumption with other potentially impairing substances and MVCs.

Data extraction and risk of bias assessment

Using standardized, pilot tested data collection forms, reviewers conducted calibration exercises and then extracted data from eligible studies, independently and in duplicate (AJ, AD, MZ, NL, SB, and SS). Extracted information included: (1) study design, publication year, geographical area, and sample size, (2) participant characteristics (e.g., mean age, percentage of female participants, vehicle type), (3) information related to exposure and comparators such as lab/test method and cannabis type, dose and mode of administration when feasible and (4) outcome relevant information and reported raw data and associations between cannabis exposure and outcomes of interest.

The same pairs of reviewers independently assessed risk of bias across included studies using the CLARITY (Clinical Advances Through Research and Information Translation) (“Tool to Assess Risk of Bias in Case Control Studies. Contributed by the CLARITY Group at McMaster University. (2025)”) risk-of-bias instrument for case control studies considering five domains: (1) can we be confident in assessment of exposure?, (2) can we be confident that cases had developed the outcome of interest and controls had not?, (3) were the cases (those who were exposed and developed the outcome of interest) properly selected?, (4) were the controls (those who were exposed and did not develop the outcome of interest) properly selected?, and (5) were cases and controls matched according to important prognostic variables or was statistical adjustment carried out for those variables? For each domain, we classified studies as ‘low’ or ‘high’ risk of bias. Discrepancies were resolved through discussion or by third-party adjudication as needed (AJ). We considered studies had adequately adjusted for confounders if they had considered at least the following factors: age, sex, and other consumed substances such as alcohol and tobacco.

Data synthesis and analysis

For binary outcomes, we pooled adjusted odds ratios (OR’s) with unadjusted OR’s reported by study authors or those calculated using crude data. We conducted all meta-analyses using DerSimonian-Laird random-effects model (DerSimonian & Laird, 1986; Freeman & Tukey, 1950; Murad, et al., 2015). We reported results as crude or adequately adjusted effect estimates of association between the exposure and our outcomes of interest including MVC fatality, injuries, and culpability or unsafe driving action (e.g., impaired driving arrests, moving violations, culpability for MVC-related injuries or fatalities, and unsafe driving). e-Table 2 provides definitions used across studies for culpability or unsafe driving actions. All statistical analysis was performed using Stata (StataCorp., Release 17.0, College Station, TX).

Subgroup analyses

We assessed heterogeneity using the I^2 statistic and interpreted the magnitude of heterogeneity in accordance with guidelines from the Cochrane Handbook for Systematic Reviews of Interventions (0% to 40%, low; 30% to 60%, moderate; 50% to 90%, substantial; 75% to 100%, considerable.(Higgins, 2011) Also, we visually inspected forest plots for consistency, since I^2 statistics may be artificially inflated when effect estimates from primary studies are very precise (Rücker, Schwarzer, Carpenter, & Schumacher, 2008).

We performed subgroup analyses irrespective of observed statistical heterogeneity using the following a priori hypotheses, assuming a larger association between MVCs and cannabis consumption with: (1) studies using a culpability design vs. not, (2) data collected from jurisdiction where cannabis was decriminalized/legal for non-medical purposes vs. not (based on study data collection timeframe), and (3) in higher risk of bias studies on a component-by-component basis. For cannabis decriminalization/legalization subgroup, studies were categorized as "mixed" if the data collection period included time before and after decriminalization/legalization or if data were collected in multiple jurisdictions/geographical locations with different cannabis decriminalization/legalization status. We only conducted subgroup analyses if there were two or more studies in each subgroup, and evaluated credibility of significant subgroup effects using ICEMAN criteria. (Schandelmaier, et al., 2020) We performed meta-regression using Knapp-Hartung modification to the variance of the estimated coefficients for test of interaction for subgroup effects.(Knapp & Hartung, 2003)

Certainty of evidence assessments

One investigator rated, and another verified, the certainty of evidence per outcome using the Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) approach.(Guyatt, et al., 2008) The approach considers risk of bias, indirectness, inconsistency, imprecision, and small study effects, to appraise the overall certainty of evidence as high, moderate, low or very low.(Guyatt, et al., 2008) To determine an imprecision rating, we rated down if our confidence

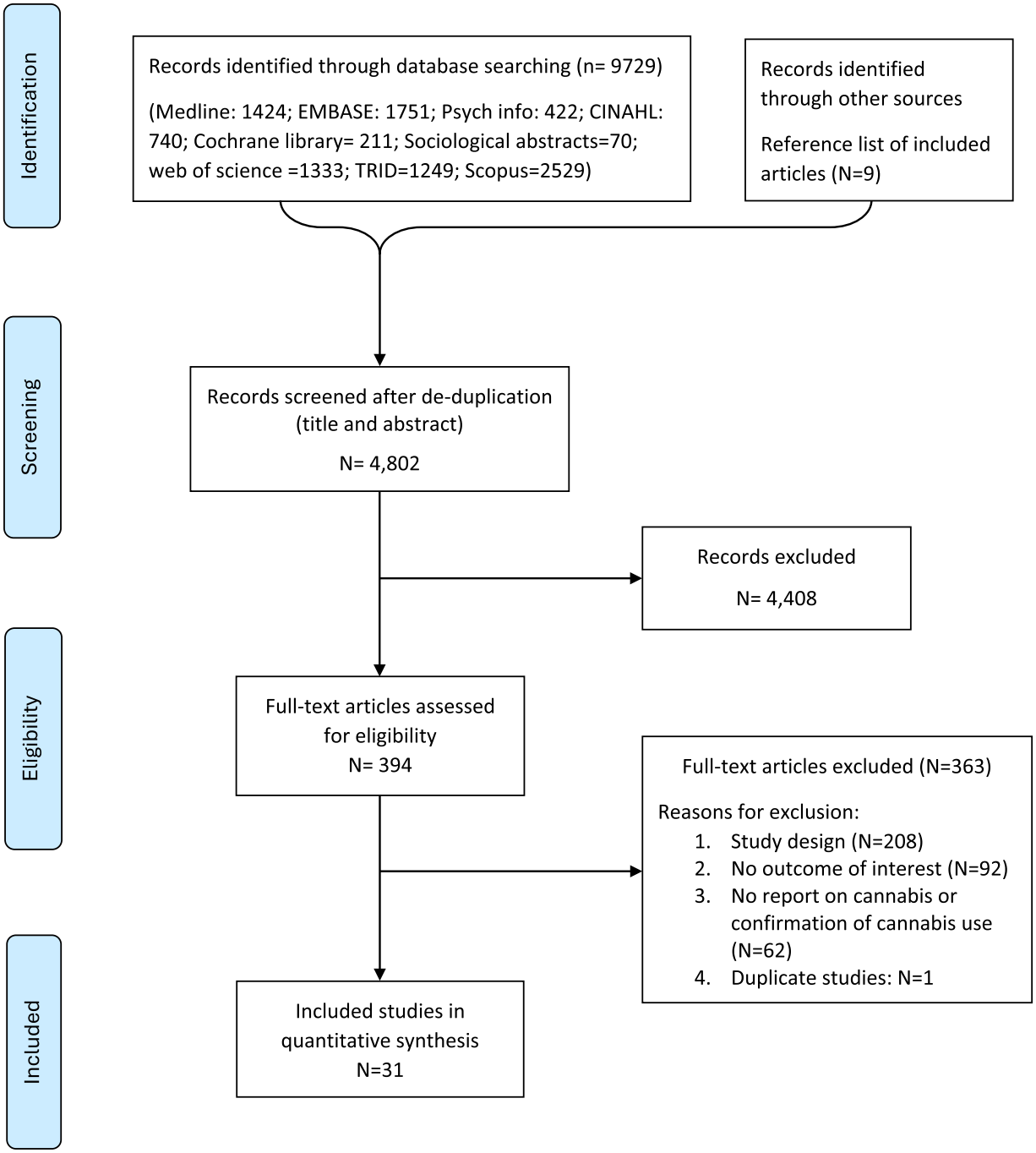

Figure 1. Flowchart of study selection.

interval crossed the line of no effect. For all outcomes with ≥10 studies contributing to meta-analysis, we assessed small-study effects using contour-enhanced funnel plots and performed Egger's test for publication bias (Sterne, et al., 2011). For evidence informed by observational studies, GRADE guidance suggests an initial certainty of evidence of low, however it allows upgrading for large effects (i.e., OR ≥ 2 or ≤ 0.5), if suspected biases work against the observed direction of effect, or a dose–response gradient (Guyatt et al., 2013a; Guyatt, et al., 2011).

To calculate absolute effects presented in summary-of-findings tables, we used population risks based on data from the 2024 National Safety Council database of MVC rates (injuryfacts.nsc.org), using a formula suggested by Guyatt et al. (2013b) From that database, we acquired a baseline risk for MVC fatality of 25 per 100,000, and 8% for MVC injuries. In terms of culpability or unsafe driving action, we considered the baseline risk from the non-exposed (control) group among included studies. We followed GRADE guidance to interpret our findings (Santesso, et al., 2020).

Results

Description of included studies

Of 4,802 unique records identified in our search, 31 studies that reported on 328,388 individuals were eligible for review (Figure 1). Of the 31 included studies, 13 used a culpability design, 18 were case-control studies (Andrews, Murphy, Nahar, & Paterson, 2015; Bédard, Dubois, & Weaver, 2007; Bernhoft, Hels, Lyckegaard, Houwing, & Verstraete, 2012; Bogstrand & Gjerde, 2014; Brubacher, et al., 2019; Chihuri, Li, & Chen, 2017; Choo, et al., 2024; Drummer, et al., 2020; Drummer, et al., 2004; Dubois, Mullen, Weaver, & Bédard, 2015; Hallvard Gjerde, Christophersen, Normann, & Mørland, 2013; H. Gjerde, Normann, Christophersen, Samuelsen, & Mørland, 2011; Hels, Lyckegaard, Simonsen, Steentoft, & Bernhoft, 2013; Jamt, Gjerde, Romeo, & Bogstrand, 2019; Johnson, Mechtler, Ali, Swedler, & Kelley-Baker, 2021; Kuypers, Legrand, Ramaekers, & Verstraete, 2012; Lacey, et al., 2016; Laumon, Gadegbeku, Martin, & Biecheler, 2005; G. Li, Brady, & Chen, 2013; G. Li, Chihuri, & Brady, 2017; Liu, Huang, & Pressley, 2016; Longo, Hunter, Lokan, White, & White, 2000; Lowenstein & Koziol-McLain, 2001; J.L. Martin, Gadegbeku, Wu, Viallon, & Laumon, 2017; Movig, et al., 2004; Mura, et al., 2003; Poulsen, Moar, & Pirie, 2014; Romano, Torres-Saavedra, Voas, & Lacey, 2014; K. Terhune, et al., 1992; K. W. Terhune, 1982; Woratanarat, et al., 2009). All studies used serum sample analysis to confirm THC and its active metabolite. In addition, 14 studies used urine samples to screen for THC. Only 16% of studies (n=5) used 1 ng/ml and one study used 0.5 ng/ml of cannabis as the cut-off for a positive test result, while the rest (n=25) used any amount greater than zero. Studies used various data sources to confirm MVCs, including hospital medical records, government administrative data (i.e., Fatal Accident Reporting System), and roadside testing stations. Of the 31 included studies, 7 (23%) used data collected after legalization or decriminalization of cannabis (Drummer, et al., 2020; Drummer, et al., 2004; Kuypers, et al., 2012; Longo, et al., 2000; Lowenstein & Koziol-McLain, 2001; Movig, et al., 2004), 42% (n=13) of studies used data collected from jurisdictions where cannabis was illegal, (Andrews, et al., 2015; Bogstrand & Gjerde, 2014; Brubacher, et al., 2019; Hallvard Gjerde, et al., 2013; H. Gjerde, et al., 2011; Jamt, et al., 2019; Johnson, et al., 2021; Lacey, et al., 2016; Laumon, et al., 2005; J.L. Martin, et al., 2017; Mura, et al., 2003; Poulsen, et al., 2014; Woratanarat, et al., 2009) and 35% (n=11) of studies compiled data from multiple jurisdictions with different cannabis policies and laws (Bédard, et al., 2007; Bernhoft, et al., 2012; Chihuri, et al., 2017; Dubois, et al., 2015; Hels, et al., 2013; G. Li, et al., 2013; G. Li, et al., 2017; Liu, et al., 2016; Romano, et al., 2014; K. Terhune, et al., 1992; K. W. Terhune, 1982). Also, there was variability in the definition of MVC injuries with one included study (3%) reporting on serious injuries alone (Hels, et al., 2013) while six studies (19%) reported on any injury ranging from minor lacerations to significant organ damage requiring hospitalizations (Jamt, et al., 2019; Johnson, et al., 2021; Kuypers, et al., 2012; Movig, et al., 2004; Mura, et al., 2003; Woratanarat, et al., 2009). Table 1 provides characteristics of included studies, and e-Table 3 presents the THC concentrations reported in the studies.

Risk of bias

We found 32% of studies (n=10) to be at low risk of bias across all domains (Table 2). Of the 31 included studies, most studies (n=23) were adequately adjusted for our minimum set of confounding factors. We found 84% of studies (n=26) to be at low risk of bias for exposure assessment, 65% (n=20) for development of outcomes in case population, 94% (n=29) for case selection, 48% (n=15) for control selection, and 74% (n=23) for case-control match and adjustment (e-Table 4).

MVC Fatality

Low certainty evidence from seven case-control and one culpability study including 92,183 participants found that cannabinoid consumption may increase the risk of fatal MVC's (OR 1.55 [95% CI: 1.20 to 1.98]) with an absolute risk increase of 14 more deaths per 100,000 MVC's (95% CI: 5 to 24 more deaths per 100,000) (e-Figure 1 and Table 2).

We found no subgroup effects for decriminalization/legalization status (data from illegal vs. decriminalized/legalized vs. mixed periods), nor for high compared to low risk of bias studies for domains 2 and 5 (e-Figures 2-4). We were unable to explore subgroups based on risk of bias domains 1, 3 and 4 due to having less than two studies in each subgroup.

MVC Injury

Low certainty evidence from 9 case-control studies with 40,046 individuals suggests cannabis consumption may be associated with an increased risk of injury due to MVC (OR 2.00, [95% CI: 1.31-3.07] corresponding to an absolute risk increase of 6.8% [95% CI: 2.2-13.1]) (e-Figure 5 and Table 2).

We found no statistically significant subgroup effects for risk of MVC injury and legal status of cannabis (data from illegal vs. decriminalized/legalized vs. mixed periods) (e-Figure 6), nor for risk of bias domains 2, 4 and 5 (e-Figures 7-9). We were unable to explore subgroups based on study design, and risk of bias domains 1 and 3 due to having less than two studies in each subgroup.

MVC culpability / unsafe driving action

We are uncertain whether cannabis consumption is associated with risk of MVC culpability/unsafe driving action as there was only very low certainty evidence from 15 culpability studies with 203,683 participants (OR 1.40 [95% CI: 1.24 to 1.58]). This association corresponds with an absolute risk increase of 44 more MVC culpability/ unsafe driving action per 1,000 MVC's (95% CI: 29 to 57 more culpability/ unsafe driving action per 1,000 MVCs) (e-Figure 10 and Table 2).

We found no statistically significant subgroup effects for MVC culpability/ unsafe driving action when assessing differences in study design (case control vs. culpability design), legal status of cannabis (data from illegal vs. decriminalized/legalized vs. mixed periods), or high versus low risk of bias (e-Figures 11-17).

Discussion

Our systemic review and meta-analysis of observational studies found low certainty evidence that cannabis consumption may be associated with an increased risk of MVC fatality and injury. The association between cannabis consumption and MVC culpability/unsafe driving action is uncertain as the evidence proved of very low certainty.

Table 1
Characteristics of included studies (n=31).

First author (publication year)	Countries	Study time period	Study design (N)	Age (mean or range)	% Male	4-wheeled passenger vehicle (%)	Outcome	Adjustment factors	THC Cut-off	THC Detection Method
(Andrews, et al., 2015)	England	2011-2013	Case control (N=187)	12-69	19.0	33.0	Mortality	None	Any THC	Blood (GCMS)
(Bédard, et al., 2007)	USA	1993-2003	Culpability (N=32,543)	32.5	71.0	100.0	UDA	Alcohol, other drug use, age, gender, driving record	Any THC	Urine, Blood (GCMS)
(Bernhoft, et al., 2012)	13 countries in Europe	2007-2010	Case control (N=41,351)	18+	-	-	Mortality	Alcohol, other drug use, age, country	THC ≥ 1ng/ml	Saliva, Blood (GCMS)
(Bogstrand & Gjerde, 2014)	Norway	2008-2009	Case control (N=9,584)	All driving ages	-	74.0	UDA	Alcohol, age, gender, season, region, time period	THC ≥ 1ng/ml	Blood (GCMS)
(Brubacher, et al., 2019)	Canada	2010-2016	Culpability (N=1,252)	44.0	63.2	100.0	UDA	Alcohol, other drug use, age, sex	Any THC	Blood (GCMS)
(Chihuri, et al., 2017)	USA	2006-2008	Case control (N=9,663)	16+	64.7	-	Mortality	Alcohol, other drug use, age, sex	Any THC	Urine, Blood (GCMS)
(Choo, et al., 2024)	USA	2017-2019	Case control (N=1,397)	42.6	53.2	66.9	UDA	Study site, gender, age, race/ethnicity, education, income	THC > 0.5 ng/ml	Blood (LCMS)
(Drummer, et al., 2004)	Australia	1990-1999	Culpability (N=1,646)	36.6	79.0	80.9	UDA	Alcohol, other drug use, age, gender, place of residence	Any THC	Blood (GCMS)
(Drummer, et al., 2020)	Australia	2013-2018	Culpability (N=1,818)	All driving ages	64.4	85.9	UDA	Alcohol, other drug use, age, gender, location, vehicle	Any THC	Blood (GCMS)
(Dubois, et al., 2015)	USA	1991-2008	Culpability (N=75,935)	46.7	64.3	100.0	UDA	Alcohol, other drug use, age, gender, driving history	Any THC	Blood (GCMS)
(H. Gjerde, et al., 2011)	Norway	2003-2008	Case control (N=10,812)	All driving ages	69.8	100.0	Mortality	Alcohol, other drug use, age, gender	Any THC	Urine, Blood (GCMS)
(Hallvard Gjerde, et al., 2013)	Norway	2003-2010	Case control (N=9,407)	-	71.7	100.0	Mortality	Alcohol, other drug use, region, season	Any THC	Blood (GCMS)
(Hels, et al., 2013)	6 countries in Europe	2007-2010	Case control (N=12,412)	18+	-	100.0	Serious Injury	Alcohol, other drug use, age, gender, country	Any THC	Saliva, Blood (GCMS)
(Jamt, et al., 2019)	Norway	2000-2015	Case control (N=3,162)	39.5	72.6	-	Any Injury	Alcohol, other drug use	Any THC	Blood (GCMS)
(Johnson, et al., 2021)	USA	2010-2012	Case control (N=9,077)	36.0	52.6	100.0	Any Injury	Alcohol, other drug use	Any THC	Blood (GCMS, LCMS)
(Kuypers, et al., 2012)	Belgium	2008-2010	Case control (N=2,653)	18+	67.0	100.0	Any Injury	Alcohol, other drug use	Any THC	Urine, Blood (GCMS)
(Lacey, et al., 2016)	USA	2014-2015	Case control (N=9,003)	16+	51.7	-	Any Injury	Alcohol, other drug use, age, race/ethnicity	THC ≥ 1ng/ml	Blood (GCMS)
(Laumon, et al., 2005)	France	2001-2003	Culpability (N=7,524)	18+	84.9	85.8	Mortality, UDA	Alcohol, other drug use, age, time of day	Any THC	Blood (GCMS)
(G. Li, et al., 2013)	USA	2007	Case control (N=8,456)	16+	62.3	-	Mortality	None	Any THC	Urine, Blood (GCMS)
(G. Li, et al., 2017)	USA	1993-2014	Culpability (N=29,484)	All driving ages	71.1	-	UDA	Alcohol, other drug use	Any THC	Urine, Blood (LCMS, EIA)
(Liu, et al., 2016)	USA	2008-2013	Case control (N=36,482)	15+	71.2	100.0	UDA	Alcohol, other drug use	Any THC	Urine, Blood (GCMS)
(Longo, et al., 2000)	Australia	1995-1996	Culpability (N=2,142)	All driving ages	-	89.03	UDA	None	Any THC	Urine, Blood (GCMS)
(Lowenstein & Koziol-McLain, 2001)	USA	1995-1996	Culpability (N=274)	18+	-	95.0	UDA	None	Any THC	Urine, Blood (GCMS, EIA)
(J.L. Martin, et al., 2017)	France	2011	Culpability (N=3,262)	All driving ages	81.9	77.6	UDA	Alcohol, other drug use, age, gender, vehicle, time of day	THC ≥ 1ng/ml	Urine, Blood (GCMS)
(Movig, et al., 2004)	Netherland	2000-2001	Case control (N=926)	38.6	73.8	100.0	Any Injury	Alcohol, other drug use, age, gender, season, time of day	Any THC	Blood (GCMS, EIA)
(Mura, et al., 2003)	France	2000-2001	Case control (N=631)	18+	74.3	100.0	Any Injury	None	THC ≥ 1ng/ml	Blood (GCMS)
(Poulsen, et al., 2014)	New Zealand	2004-2009	Culpability (N=623)	All driving ages	76.2	83.0	UDA	Alcohol, other drug use, age, gender, vehicle type	Any THC	Blood (GCMS)

(*continued on next page*)

Table 1 (*continued*)

First author (publication year)	Countries	Study time period	Study design (N)	Age (mean or range)	% Male	4-wheeled passenger vehicle (%)	Outcome	Adjustment factors	THC Cut-off	THC Detection Method
(Romano, et al., 2014)	USA	2006-2008	Case control (N=4,783)	16-97	-	-	Mortality	Alcohol, other drug use	Any THC	Urine, Blood (GCMS)
(K. W. Terhune, 1982)	USA	1975-1982	Culpability (N=290)	16+	62.4	87.0	UDA	None	Any THC	Blood (Lab analysis)
(K. Terhune, et al., 1992)	USA	1988-1992	Culpability (N=824)	16+	64.3	91.7	UDA	None	Any THC	Blood (GCMS)
(Woratanarat, et al., 2009)	Thailand	2006	Case control (N=785)	30.0	94.4	10.5	Any Injury	None	Any THC	Urine, Blood (GCMS)

Abbreviations. GCMS: Gas chromatography mass spectrometry; LCMS: Liquid chromatography mass spectrometry; EIA: Enzyme immunoassay; UDA: Unsafe driving action.

Table 2
GRADE evidence profile of cannabis consumption and motor vehicle events.

Outcome (Studies, participants)	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	Other considerations	Relative effect (95% CI)	Anticipated absolute effects		Certainty of evidence
								Risk with no THC	Risk difference with THC	
MVC Fatality (8 studies, 92,183 individuals)	Not serious	Serious[a]	Not serious	Not serious	Undetected	Large effect[b]	**OR 1.55** (1.20 to 1.98)	Moderate risk: 25 per 100,000	**14 more per 100,000** (5 more to 24 more)	Low
MVC Injury (9 studies, 40,046 individuals)	Not serious	Serious[c]	Not serious	Not serious	Undetected	Large effect[d]	**OR 2.00** (1.31 to 3.07)	Low risk: 40 per 1,000	**37 more per 1,000** (12 more to 73 more)	Low
								Moderate risk: 80 per 1,000	**68 more per 1,000** (22 more to 131 more)	
								High risk: 180 per 1,000	**125 more per 1,000** (43 more to 223 more)	
Culpability/ UDA (15 studies, 203,683 individuals)	Not serious	Serious[e]	Not serious	Not serious	Undetected	None	**OR 1.40** (1.24 to 1.58)	822 per 1,000	**44 more per 1,000** (from 29 more to 57 more)	Very low

[a] Rated down by one level due to moderate unexplained heterogeneity (I^2=48%) with not all confidence intervals overlapping [two studies Gjerde 2011 and Romano 2014 suggest THC decreases fatal MVC].
[b] Rated up by one level for large absolute effect for a very critical outcome (MVC fatality)
[c] Rated down by one level due to large unexplained heterogeneity (I^2= 84.5%) [two studies Jamt 2018 and Kuypers 2012 suggest very large effects of THC on MVC injury while other studies show some or no effect with little overlap between confidence intervals].
[d] Rated up by one level for large absolute effects across risk levels.
[e] Rated down by one level due to large unexplained heterogeneity (I^2= 77%) with some overlap of confidence intervals.

Relation to other studies

A relevant systematic review in 2018 (Hostiuc, et al., 2018), reported a slightly higher magnitude of association between cannabis consumption and MVC fatality (OR 1.73 [95% CI: 1.36 to 2.19]) compared to our review that included three additional studies (OR 1.55 [95% CI: 1.20 to 1.98]); however, the overlapping confidence intervals suggest comparable findings. As for MVC injury and cannabis consumption, our systematic review found a greater magnitude of association (OR 2.65 [95% CI: 1.40 to 5.03]) compared to the previous review (OR 2.16 [95% CI: 1.41 to 3.28]), but the overlapping confidence intervals indicate no statistically significant difference between the estimates. However, our review team excluded 5 studies that were included the previous review as they were based on self-report as a method of THC detection which was part of our exclusion criteria. In terms of MVC culpability/unsafe driving action, we identified two additional studies for a total of 15 compared to the most recently published systematic review (White & Burns, 2021), however, the magnitude of association in our review (OR 1.40 [95% CI: 1.24 to 1.58]) was comparable to that reported in the previous review (OR 1.37 [95% CI: 1.10 to 1.69]).

Despite finding similar results, previous systematic reviews either did not assess at all or assessed the certainty of the body of evidence using an untested approach and did not present their findings as absolute effects. Our review reported the magnitude of association and the associated absolute effect using GRADE language to reflect the certainty of the evidence. This approach enhances the interpretability of findings. Our review also explored additional subgroups including studies that adjusted for potential confounders versus not, decriminalization/legalization status, and for high/low risk of bias that the other reviews did not explore. Albeit we did not find any significant subgroup effects likely due to either the limited number of studies per subgroup that may have affected our ability to detect an effect or due to the variability in outcome definition such as lumping a wide range of injuries ranging from minor lacerations to organ damage under MVC injury. For decriminalization/legalization status, no difference in subgroups may be the result of stable rates of cannabis-impaired driving, more responsible

usage patterns driven by increased public awareness after decriminalization legalization, enhanced law enforcement efforts, or potential biases or changes in data quality that may obscure real differences.

Strengths and limitations

Our study has several methodological strengths including (1) restricting our eligibility criteria to studies employing validated tools to detect THC and its active metabolite in body fluid, (2) subgroup analysis and assessment consistent with current best practices (Sun, Briel, Walter, & Guyatt, 2010) (3) use of the GRADE approach to evaluate certainty of the evidence.

In terms of limitations, we were unable to evaluate the effects of serum THC concentrations or cannabis dose on driving impairment. Current standard legal limits of THC concentration in serum sample are in the range of 2-5 ng/mL, (Brands, Di Ciano, & Mann, 2021) however the studies included samples with concentration below 2 ng/ml. Other limitations included the variability in definition of MVC injuries which varied widely across included studies ranging from minor lacerations to significant organ damage requiring hospitalizations. Lastly, the included studies did not differentiate between medical and recreational cannabis use, limiting our ability to assess their potentially distinct effects on crash risk.

Implications for future research and practice

The true impact of cannabis use on MVC and driving behaviors remains unclear. One research priority is establishing a dose-response for THC exposure on MVC risk. Another research need is to identify standardized and validated roadside measures for assessment of individuals under the influence of cannabis.(Wennberg, et al., 2023) According to a recent systematic review assessing roadside screening tests for cannabis use, oral fluid tests showed the most potential for roadside screening of blood THC levels exceeding legal limits, while urine tests were not recommended.(Wennberg, et al., 2023) However, the authors noted that more development and rigorous testing is required to establish standardized and validated screening methods.(Wennberg, et al., 2023) Currently, THC levels are used with no standardized cut offs which may be problematic since the influence of cannabis can wear off within hours, although THC residuals may remain detectable in urine for 5 days, in blood for at least 7 days, and in oral fluid specimens up to 78 h after consumption.(Odell, Frei, Gerostamoulos, Chu, & Lubman, 2015) Similar to assessing blood alcohol content, there is a need to identify appropriate blood THC cut off levels that mitigate this concern.

Conclusion

Low certainty evidence suggests that cannabis consumption may increase risk of MVC fatality and injury. The association with unsafe driving is uncertain. Further high quality research is required to inform the impact of cannabis consumption on MVCs.

Data sharing

The relevant data in this study are available upon reasonable request from Dr Behnam Sadeghirad (sadeghb@mcmaster.ca)

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CRediT authorship contribution statement

Andrew Jin: Writing – review & editing, Writing – original draft, Project administration, Methodology, Formal analysis, Data curation. **Andrea J. Darzi:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Data curation, Conceptualization. **Amne Dargham:** Writing – review & editing, Validation, Methodology, Investigation, Data curation. **Navroop Liddar:** Writing – review & editing, Validation, Methodology, Investigation, Data curation. **Sepehr Bozorgi:** Writing – review & editing, Validation, Methodology, Investigation, Data curation. **Shamim Sohrevardi:** Writing – review & editing, Validation, Methodology, Investigation, Data curation. **Maurice Zhang:** Writing – review & editing, Validation, Investigation, Data curation. **Kian Torabiardakani:** Writing – review & editing, Methodology, Data curation. **Rachel J. Couban:** Writing – review & editing, Validation, Methodology, Investigation, Data curation. **Malahat Khalili:** Writing – review & editing, Visualization, Formal analysis, Data curation. **Jason W. Busse:** Writing – review & editing, Supervision, Methodology, Formal analysis, Conceptualization. **Behnam Sadeghirad:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

The JWB and BS report receiving funding from Canadian Institute of Health Research (CIHR) to develop a clinical practice guideline for cannabis for medical purposes and chronic pain.

The remaining authors declare no conflicts of interest.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.drugpo.2025.104832.

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