Traumatic brain injury in homeless and marginally housed individuals: a systematic review and meta-analysis

Jacob L Stubbs, Allen E Thornton, Jessica M Sevick, Noah D Silverberg, Alasdair M Barr, William G Honer, William J Panenka

Summary

Background Homelessness is a global public health concern, and traumatic brain injury (TBI) could represent an underappreciated factor in the health trajectories of homeless and marginally housed individuals. We aimed to evaluate the lifetime prevalence of TBI in this population, and to summarise findings on TBI incidence and the association between TBI and health-related or functioning-related outcomes.

Methods For this systematic review and meta-analysis, we searched without date restrictions for original research studies in English that reported data on the prevalence or incidence of TBI, or the association between TBI and one or more health-related or function-related outcome measures. Studies were included if they had a group or clearly identifiable subgroup of individuals who were homeless, marginally housed, or seeking services for homeless people. With use of random-effects models, we calculated pooled estimates of the lifetime prevalence of any severity of TBI and the lifetime prevalence of moderate or severe TBI. We used meta-regression and subgroup analysis to evaluate potential moderators of prevalence estimates and the leave-one-out method for sensitivity analyses. We then summarised findings from all studies that evaluated TBI incidence and the association between TBI and health-related or functioning-related outcomes. All statistical analyses were done using R version 3.5.1. The study is registered with PROSPERO, number CRD42019119678.

Findings Of 463 potentially eligible studies identified by the search, 38 studies were included in the systematic review and 22 studies were included in the meta-analysis. The lifetime prevalence of any severity of TBI in homeless and marginally housed individuals (18 studies, n=9702 individuals) was 53·1% (95% CI 46·4–59·7; I^2=97%) and the lifetime prevalence of moderate or severe TBI (nine studies, n=5787) was 22·5% (13·5–35·0; I^2=99%). The method used to ascertain TBI history, the age of the sample, and the sample size significantly moderated estimated lifetime prevalence of any severity of TBI. TBI was consistently associated with poorer self-reported physical and mental health, higher suicidality and suicide risk, memory concerns, and increased health service use and criminal justice system involvement.

Interpretation The lifetime prevalence of TBI is high among homeless and marginally housed individuals, and a history of TBI is associated with poorer health and general functioning. Health-care providers and public health officials should have an increased awareness of the burden of TBI in this population. Prospective and longitudinal studies are needed to better understand how the health of this population is affected by TBI.

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Department of Psychiatry (J L Stubbs BKin, J M Sevick BEng, Prof W G Honer MD, W J Panenka MD), **Division of Physical Medicine and Rehabilitation** (N D Silverberg PhD), **and Department of Anesthesiology, Pharmacology & Therapeutics** (A M Barr PhD), **University of British Columbia, Vancouver, BC, Canada; British Columbia Mental Health and Substance Use Services Research Institute, Vancouver, BC, Canada** (J L Stubbs, Prof A E Thornton PhD, J M Sevick, A M Barr, Prof W G Honer, W J Panenka); **Department of Psychology, Simon Fraser University, Burnaby, BC, Canada** (Prof A E Thornton); **Rehabilitation Research Program, Vancouver Coastal Health Research Institute, BC, Canada** (N D Silverberg); **and British Columbia Provincial Neuropsychiatry Program, Vancouver, BC, Canada** (W J Panenka)

Correspondence to: Mr Jacob L Stubbs, British Columbia Mental Health and Substance Use Services Research Institute, Vancouver, BC V5Z 4H4, Canada **j.stubbs@alumni.ubc.ca**

Introduction

More than 6 million people experience homelessness annually in the USA and the EU.[1] Homeless individuals experience markedly poorer mental and physical health than the general population, including a high prevalence of psychotic disorders, major depression, and drug and alcohol dependence,[2] and a high prevalence of infectious diseases, including HIV, hepatitis C, and tuberculosis.[3] Homeless and similarly marginalised individuals also have substantially higher all-cause mortality than the general population.[4] Traumatic brain injury (TBI) is a pervasive and under-recognised public health problem.[5] TBI is associated with a number of deleterious outcomes, with meta-analytic evidence providing a link for the subsequent development of neurological and psychiatric disorders.[6] TBI is often preventable, and thus might represent a modifiable risk factor for serious psychiatric illness and neurodegenerative disease.

Obtaining reliable estimates of TBI incidence and lifetime prevalence in the homeless and marginally housed population, as well as in the general population, has been challenging. Reported incidence of TBI varies widely across counties,[5] and the methods of sampling participants and defining TBI cases differ between reports. Considerably higher rates of TBI have been reported in population-based studies that capture injuries for which medical attention is not sought,[7,8] as compared with studies that gather data from medical records or emergency departments.[9,10] Additional sources of bias also exist, including in the common definitions of TBI,[5]

Research in context

Evidence before this study

Previous studies and a previous systematic review have suggested that the lifetime prevalence and incidence of TBI might be considerably higher in homeless and marginally housed individuals than in the general population. Moreover, many of these studies report that TBI is associated with poorer health or functioning in these individuals. Marked methodological variation exists among previous studies, including in the tools used to ascertain a history of TBI, in the study-specific definitions of TBI, and in the outcome measures assessed. This variation limits our understanding of the prevalence, incidence, and impact of TBI in this population. To date, no meta-analyses have been done to evaluate the prevalence of TBI in homeless and marginally housed individuals, nor have any quantitative analyses of heterogeneity among previous studies been done. In preparation for this review, we did systematic searches in MEDLINE, Embase, PsycINFO, CINAHL, and Web of Science for studies that evaluated TBI in homeless or marginally housed study samples. Specific database search terms are outlined in the appendix. Studies were eligible for inclusion if they evaluated the prevalence or incidence of TBI, or the association between TBI and health-related or functioning-related outcome measures, and they were original peer-reviewed studies in the English language. No date restrictions were applied.

Added value of this study

To our knowledge, this is the first meta-analysis to evaluate the prevalence of TBI in homeless and marginally housed individuals and the first quantitative assessment of heterogeneity among studies that assess TBI in this population. We show that homeless and marginally housed individuals experience a high lifetime prevalence of TBI, and notably, a lifetime prevalence of moderate or severe TBI that is approximately ten-times higher than estimates in the general population. We found high heterogeneity among studies and our meta-regression analyses identified several factors that moderated individual study findings. Our review also found that TBI is associated with poorer self-reported health, higher suicidality and suicide risk, increased health service use, and increased criminal justice system involvement.

Implications of all the available evidence

TBI is a pervasive and largely under-recognised factor associated with the poorer health and functioning experienced by homeless and marginally housed populations. Our findings suggest that health-care providers who work with these individuals should be aware of the high prevalence of TBI and associated effects on health and functioning. Additionally, given the high prevalence of moderate or severe TBI, and the considerable number of individuals with evidence of traumatically-induced lesions visible with MRI, the threshold for referral to neuroimaging specialists after head injury should be reduced in this population. Further research is urgently needed to address limitations to our understanding of the burden of TBI in at-risk and multimorbid populations. However, in light of the significant moderating factors that we identified, future studies should carefully consider and clearly describe all aspects of study design to maximise validity and clinical relevance.

and sampling or referral biases. Similarly, the method for ascertaining history of TBI has not been unanimously agreed upon and estimates of the lifetime prevalence of TBI vary considerably. Meta-analytic work has found that 12% of the general population reported at least one TBI over the lifespan.[11] A 2018 state-wide study in Ohio, USA, which used a modified version of the comprehensive Ohio State University TBI ascertainment method (a short, structured interview based on the Centers for Disease Control definition of TBI and endorsed by the National Institute of Neurological Disorders and Stroke),[12] found an estimated lifetime prevalence of TBI of 21·7% in the general population, and a lifetime prevalence of moderate or severe TBI of 2·6%.[8] Although several tools designed to ascertain TBI history are available (eg, the Ohio State University TBI ascertainment method[13] and the Brain Injury Screening Questionnaire),[14] these methods have been inconsistently used in studies of homeless and marginally housed individuals.

A previous systematic review that summarised eight studies published between 1996 and 2012 found that estimates of the lifetime prevalence of TBI in homeless populations ranged from 8% to 53%.[15] The most commonly identified methodological limitations included poor external validity and reporting of power calculations. The authors also noted that TBI was not a primary aim for the majority of studies, and that important factors, such as symptom burden and injury severity, were rarely evaluated. Only three studies identified by the previous review evaluated severity of TBI, precluding systematic evaluation of the effects of more clinically significant brain injuries. The authors concluded that there were considerable methodological limitations and heterogeneity across available studies, and that a strong need existed for larger studies with validated and comprehensive measures, and longitudinal designs.[15] In subsequent years, as the potential importance of TBI in these vulnerable individuals has become increasingly recognised, a number of larger and more comprehensive studies have been published. Several of these more recent studies have specifically examined the impact of moderate or severe TBI in this population, and several have addressed other limitations highlighted by the previous review. However, to the best of our knowledge, no meta-analytic estimates of TBI prevalence in homeless or marginally housed individuals have been reported, nor has there been a comprehensive review of the association between TBI and health or functioning (eg, neurocognitive

function or day-to-day functioning, such as employment) in these individuals.

Evaluating the prevalence and burden of TBI in individuals who are homeless or marginally housed is critical to understanding the unique challenges and health-care needs of this population. Furthermore, identifying factors that contribute to heterogeneity across studies is integral to establishing standardised approaches for future research and in finding targets for the prevention of TBI and treatment of its sequelae in this population. In this study, we aimed to estimate the lifetime prevalence of TBI in homeless and marginally housed individuals, to quantitatively evaluate factors that moderate estimates of prevalence, and to systematically review the association between TBI and health and functioning-related outcome measures in this population.

Methods

Search strategy and selection criteria

We did a systematic review and meta-analysis following the PRISMA and MOOSE guidelines.[16,17] Studies were included in the review if they had a sample that exclusively comprised individuals of any age who were homeless, marginally housed, or seeking services for homeless people at the time of assessment (or if there was a clearly identifiable subgroup of individuals who were homeless, marginally housed, or seeking services for homeless people at the time of assessment and data was able to be extracted for this subgroup), and if they examined the prevalence of TBI, the incidence of TBI, or the association between TBI and one or more health-related or functioning-related outcome measures. Our definition of functioning was deliberately broad to evaluate the full scope of the effects of TBI in this population, and was considered to be any non-health-related outcome measure or any outcome related to day-to-day functioning in society (eg, neurocognition or involvement in the criminal justice system). Studies were excluded from the review if they were not published in English, were not peer-reviewed, or were not original research studies with unique observational data (ie, reviews or meta-analyses).

The decision to conduct a meta-analysis was made after doing the literature search to ensure that a sufficient number of studies were available that had recorded lifetime prevalence of TBI. Studies were excluded from the meta-analysis if they did not have prevalence data that could be extracted or obtained through corresponding authors, had a sample size smaller than 25, or if they were judged to be from the same study sample as another study included in the analysis by consensus of two study authors (JLS and WJP). For studies that were identifiably from the same study sample, we included the study with the largest sample size in the meta-analysis.

We did a systematic search without date restrictions in MEDLINE, Embase, PsycINFO, CINAHL, and Web of Science using a search strategy developed in conjunction with a librarian specialising in systematic review searches. The search strategy was piloted in MEDLINE by iteratively adding and refining relevant search terms and by ensuring that the included search terms returned studies we knew to exist on this topic. Our search strategy was consistent across all databases, and the strategy used in MEDLINE (Ovid interface) is reported in the appendix (p 1). Manual forward and backward reference searching was done on studies of particular importance in the opinion of JLS and WJP and on the previous review on this topic.[15] Searches of all databases and retrieval of results from each database were done on Dec 14, 2018, with no date restrictions.

See **Online** for appendix

Screening of titles and abstracts of all records returned by the search strategy, screening of full texts eligible for inclusion, and the risk of bias assessment for included studies were independently conducted by two study authors (JLS and JMS). Inter-rater reliability for both the title and abstract and full text screening was calculated using Cohen's κ. Risk of bias for individual studies was assessed using the US National Heart, Lung, and Blood Institute's Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies.[18] Discrepancies were resolved through discussion between study authors to reach a consensus, or with a third study author (WJP) if necessary.

The protocol for our systematic review was registered in the PROSPERO database (CRD42019119678).

For the **study protocol** see https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=119678

Data analysis

All variables of interest were independently extracted by two study authors (JLS and JMS) using a customised form. The form was piloted and refined on ten of the studies selected for inclusion. All extracted variables are described in the appendix (p 2).

For studies included in the meta-analysis, we quantitatively evaluated several potential moderators of estimated prevalence of TBI using meta-regression and subgroup analysis. First, we evaluated whether the measure of central tendency of age of the sample (subsequently referred to as age of the sample) or the total sample size was associated with estimated prevalence. Second, we assessed whether the method of ascertaining TBI history moderated estimated prevalence by stratifying TBI ascertainment methods into five categories: (1) a non-specific self-report question or series of questions to ascertain TBI; (2) medical record; (3) questionnaire or screening tool specifically designed to ascertain TBI; (4) the Ohio State University TBI Identification (OSU TBI-ID) structured interview; and (5) other ascertainment method. Third, we evaluated whether studies that used self-reported loss of consciousness as a minimum criterion for defining TBI, as opposed to a more liberal definition (eg, self-report of a period of being dazed or confused), were associated with lower estimated prevalence. Finally, we evaluated whether the site of participant recruitment—stratified into studies that recruited participants from a shelter or hostel

versus studies that recruited participants from a service or clinic for homeless individuals—was associated with different estimates of prevalence.

We did two separate analyses to evaluate the lifetime prevalence of TBI. The first aimed to measure the overall lifetime prevalence of TBI, encompassing all levels of severity, and including studies that did not stratify by severity. The second aimed to measure the lifetime prevalence of moderate or severe TBI, encompassing studies that stratified participants into moderate or severe TBI categories, studies that examined only moderate or severe TBI, or studies that assessed TBI without explicitly defining severity but which we deemed were predominantly focused on more significant brain injury. We deemed that two studies that did not explicitly evaluate TBI severity focused predominantly on moderate or severe TBI; one study assessed "definite TBI" on the basis of MRI evidence and persistent sequelae attributable to the TBI,[19] and the other study defined TBI as brain injury resulting in lasting impairment or contributing to disability.[20] Therefore, we evaluated these two studies alongside others that explicitly examined moderate or severe TBI. We used random-effects models for each analysis to calculate a pooled estimate of prevalence, with the Clopper-Pearson method used to generate 95% CIs for individual studies and the inverse variance method to weight each study. We also calculated 95% prediction intervals (PIs) for our summary estimates to provide a range for the predicted estimate of prevalence for new studies.[21]

Heterogeneity between studies was quantified with the I^2 statistic.[22] For studies that did not report age of the sample, and for which these data could not be obtained from the corresponding author (n=2), we imputed the weighted mean age of participants from all other studies that were included in the analysis. We conducted sensitivity analyses using the leave-one-out method. We evaluated small-study effects visually with a funnel plot and statistically with Egger's test.[23]

Finally, we used subgroup analysis and meta-regression to evaluate moderators of individual study estimates of the lifetime prevalence of TBI. We used univariable meta-regression to evaluate unadjusted effects in the analyses of lifetime prevalence and the lifetime prevalence of moderate or severe TBI, and we included all potential moderators, for which appropriate data were available, in a multivariable meta-regression to evaluate adjusted effects in the analysis of lifetime prevalence. We used mixed effects models for all meta-regression analyses.

All statistical analyses were performed in R (version 3.5.1) with the packages meta (version 4.9-4) and metafor (version 2.0-0).[24–26]

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

Our database searches identified 463 potentially eligible studies. After removal of duplicates, 260 study titles and abstracts were screened (figure 1). We assessed 51 full text articles for eligibility, of which 13 were excluded from the systematic review (appendix p 1) and an additional 16 were excluded from the meta-analysis. There was a high inter-rater reliability for screening titles and abstracts (κ=0·95) and full texts (κ=0·96).

38 studies were included in the systematic review (table 1).[19,20,27–62] The included studies were published between 1995 and 2018, and recruited participants from Australia, Canada, Japan, South Korea, the UK, and the USA. The predominant recruitment settings were through homeless shelters or hostels (18 studies) and services or clinics that serve homeless populations (16 studies). Six (16%) of 38 studies were conducted in populations of military service members who were homeless or seeking services for homeless people, and the remainder of studies recruited participants from civilian populations. Of the 38 studies included in the systematic review, we included 22 in the meta-analysis (figure 1). 18 (82%) of 22 studies (n=9702) assessed the lifetime prevalence of TBI, and nine (41%, n=5787) assessed the lifetime prevalence of moderate or severe TBI.

The risk of bias assessment for all studies included in the systematic review is shown in the appendix (pp 2, 3). In general, studies had a clear research objective, recruited participants from similar populations, and clearly described dependent variables. However, 17 (45%) of 38 studies did not provide a clear definition of homelessness or marginal housing, and 23 (61%) did not report whether the participation rate of eligible persons was more than 50%. Of note, 20 (53%) of 38 studies did not clearly describe the specific definition used to categorise participants as having TBI. Studies were generally comprised of predominantly male samples, and eight studies were comprised of exclusively male samples.

The overall pooled estimate of the lifetime prevalence of TBI was 53·1% (95% CI 46·4–59·7, 95% PI 25·9–78·6; figure 2). There was a significant amount of heterogeneity between studies (I^2=97%, p<0·0001). The funnel plot is reported in the appendix (p 4) and did not show evidence of small-study effects, which was supported by Egger's test (p=0·96). The results of the leave-one-out sensitivity analyses are reported in the appendix (p 5), and show that no single study, nor the studies for which we imputed mean age, had a disproportionate effect on the pooled estimate of prevalence of TBI.

The results from our univariable and multivariable meta-regression analyses are reported in table 2, with raw coefficients reported in the appendix (p 6). The overall

multivariable meta-regression model was significant and accounted for 30·0% of the heterogeneity (Q_s=27·20, p<0·0001, R^2=0·300). The age of the study sample (p=0·045), total sample size (p=0·047), and using the OSU TBI-ID structured interview (*vs* a single question or series of questions) to ascertain history of TBI (p=0·0035) were significantly associated with higher estimated prevalence. Studies that used other screening tools (HELPS or BISQ) to ascertain history of TBI (p=0·11) and the site of study recruitment (p=0·85) were not significantly associated with estimated prevalence in the meta-regression, although the sample size for each predictor was relatively small. Three studies reported both an overall estimate of prevalence and a subgroup of individuals who reported loss of consciousness after injury.[33,35,53] On average, 43·4% reported loss of consciousness (range 32·2–58·0), compared with the total 56·0% (range 35·3–76·4) who reported TBI across those three studies with a more inclusive definition (ie, self-reporting a period of being dazed, confused, or experiencing memory loss). Individual study and pooled estimates of lifetime TBI prevalence stratified by TBI ascertainment method are shown in the appendix (p 7). Heterogeneity among studies that ascertained history of TBI using OSU TBI-ID structured interviews (I^2=95%) and other screening tools (I^2=94%) was high, although it was lower than the heterogeneity observed across all studies (I^2=97%).

The pooled estimate of the lifetime prevalence of moderate or severe TBI was 22·5% (95% CI 13·5–35·0, 95% PI 3·1–72·3; figure 2). There was high heterogeneity between studies (I^2=99%, p<0·0001). The funnel plot is reported in the appendix (p 8) and did not show evidence of small-study effects upon visual inspection; Egger's test showed no asymmetry (p=0·56). The leave-one-out sensitivity analyses are reported in the appendix (p 9), and show that no single study, nor the studies that did not explicitly evaluate severity but which we deemed to be focused predominantly on moderate or severe TBI, had a disproportionate effect on the pooled estimate of lifetime prevalence of moderate or severe TBI. None of the moderators (as previously described for overall lifetime prevalence of TBI) were statistically significantly associated with estimated prevalence of moderate or severe TBI in univariable meta-regression analyses.

In this review, 28 (74%) of 38 studies assessed the association between a history of TBI and health-related or functioning-related outcomes. A summary of results is reported in the panel, and a study-level breakdown of results is presented in the appendix (pp 9–12). The association between TBI and many outcome measures was equivocal, whereby findings were either mixed or the outcome was evaluated by only a small number of studies. However, despite the heterogeneity in study methodology and outcomes assessed, history of TBI was consistently associated with poorer self-reported physical[39,53,58] and mental health,[39,53,58] increased health service use[43,58,60] and criminal justice involvement,[43,53,58–60] and younger age at first experience of homelessness[39,43,58] in all studies that evaluated TBI and these outcomes. Furthermore, history of TBI was associated with suicidal ideation and higher suicide risk[31,43,51,60] in four of five studies[53] that evaluated suicidality, and self-reported memory concerns[35,38,43,53,61] in five of six studies[34] that evaluated memory concerns. The most common mechanism of injury was assault across all five studies that evaluated mechanism of injury.[29,33,35,53,59] Age at first TBI ranged from 15 years to 19·9 years, and we calculated a weighted mean age of first TBI of 15·8 years. In one large marginally housed cohort who underwent MRI scans, 28·0% of participants had incidental neuroimaging findings (eg, aneurysms or infarcts), with 6·9% in a largely overlapping sample showing evidence of previous brain trauma.[19,53]

Only five studies included in this review assessed incident TBI, precluding a methodologically robust

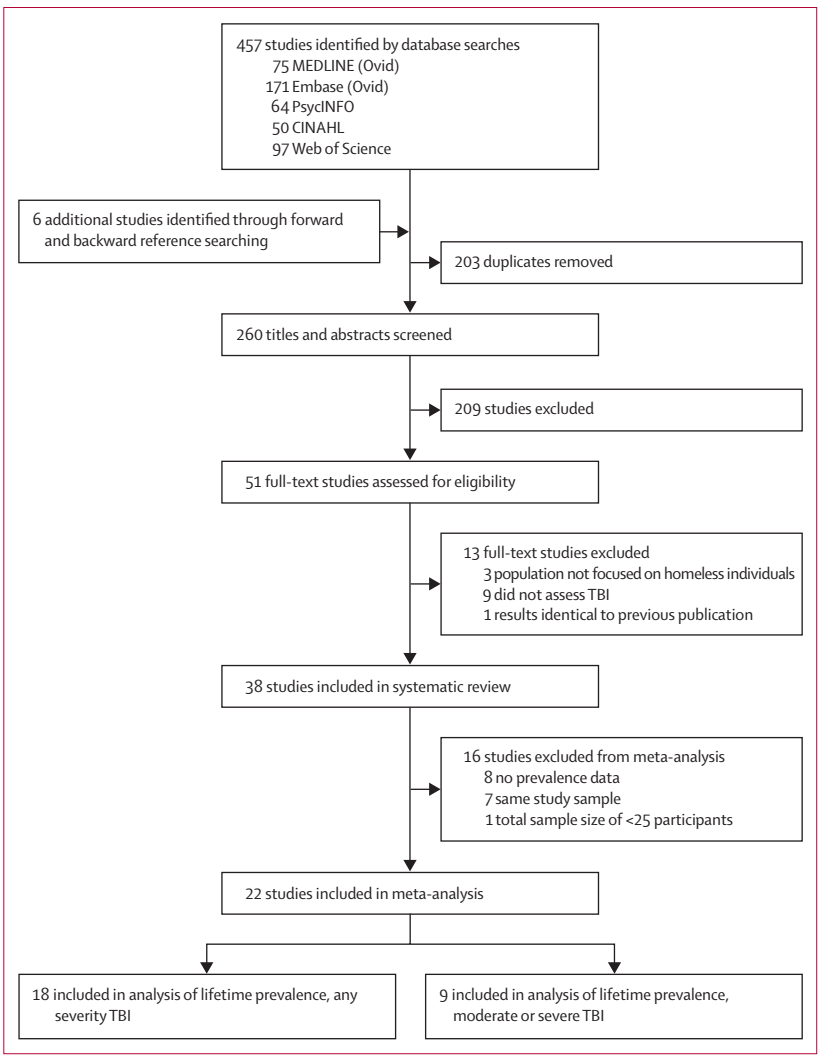

Figure 1: **Study selection**
TBI=traumatic brain injury.

	Country	Study design	Population description				Lifetime prevalence of TBI		Incidence of TBI	TBI ascertainment method
			Setting	Sample size	Age, years*	Female, n/N (%)	Any severity, n/N (%)	Moderate or severe, n/N (%)		
Andersen et al (2014)[27]	Canada	Cross-sectional	Shelter for homeless men	34	58·8	0/34	12/34 (35·3%)	11/34 (32·4%)	..	Questionnaire or screening tool: Brain Injury Screening Questionnaire
Bacciardi et al (2017)[28]	Canada	Cross-sectional	Community agencies that serve homeless individuals (shelters, drop-in centres, outreach teams, inpatient programmes, and criminal justice programmes)	416	39·9	117/416 (28·1%)	277/416 (66·6%)	108/198 (54·5%)§	..	Single question or series of questions: "Have you ever had an injury to the head which knocked you out or at least left you dazed, confused, or disoriented?"
Barnes et al (2015)[29]	USA	Cross-sectional	VA service clinics for veterans seeking homeless services	229	51·8	9/229 (3·9%)	207/229 (90·4%)	63/229 (27·5%)	..	Structured interview: OSU TBI-ID
Bremner et al (1996)[30]†	UK	Cross-sectional	Hostel for homeless men	62	NR	0/62	29/62 (46·8%)	..	..	Single question or series of questions: specific questions NR
Brenner et al (2017)[31]‡	USA	Cross-sectional	VA service clinics for veterans seeking homeless services	309	52·3	11/309 (3·6%)	282/309 (91·3%)	90/309 (29·1%)	..	Structured interview: OSU TBI-ID
Brown et al (2013)[32]†	USA	Cross-sectional	Emergency, transitional, and day shelters	250	56·2	48/250 (19·2%)	147/250 (58·8%)	..	..	Single question or series of questions: "Have you ever had an injury to the head which knocked you out or at least left you dazed, confused, or disoriented?"
Bymaster et al (2017)[33]†‡	USA	Cross-sectional	Health care clinic sites for a US county homeless programme	127	48	40/127 (31·5%)	97/127 (76·4%)	38/127 (29·9%)	..	Structured interview: OSU TBI-ID
Cotman et al (1997)[34]	USA	Pre-test/post-test	Residential programme to assist recovery from homelessness	24	30·6	11/24 (45·8%)	2/24 (8·3%)	..	..	Other: NR
Gargaro et al (2016)[35]†	Canada	Cross-sectional	Clients seeking support from an Assertive Community Treatment Team in a downtown urban setting	48	43·4	15/48 (31·3%)	27/48 (56·3%)	..	..	Structured interview: OSU TBI-ID
Gonzalez et al (2001)[36]†	USA	Cross-sectional	Health care clinic associated with community shelter and outreach programme for homeless individuals	60	39·8	24/60 (40·0%)	23/60 (38·3%)	..	..	Single question or series of questions: documented instance of LOC or patient self-report of serious blow to the head or LOC; specific questions NR
Hurstak et al (2017)[37]†	USA	Cross-sectional	Overnight shelters, homeless encampments, meal programmes, and recycling centres	343	58	79/343 (23·0%)	149/343 (43·4%)	..	..	Single question or series of questions: participants asked to report the number of lifetime head traumas they had experienced, and detailed information was collected for up to three instances that resulted in LOC or hospitalisation; specific questions NR
Hux et al (2009)[38]†	USA	Cross-sectional	Homeless shelters and domestic violence facility	282	34·8	248/282 (87·9%)	69/282 (24·5%)	..	..	Questionnaire or screening tool: HELPS screening tool
Hwang et al (2008)[39]†‡	Canada	Cross-sectional	Shelters and meal programmes	904	37·4	303/904 (33·5%)	475/904 (52·5%)	109/904 (12·1%)	..	Single question or series of questions: "Have you ever had an injury to the head which knocked you out or at least left you dazed, confused, or disoriented?"; additional injury details for up to three injuries were collected
Kim et al (2007)[40]	South Korea	Retrospective case-control	Hospital neurosurgical department	76	53% were >50	5/76 (6·6%)	..	..	..	Medical record

(Table 1 continues on next page)

	Country	Study design	Population description				Lifetime prevalence of TBI		Incidence of TBI	TBI ascertainment method
			Setting	Sample size	Age, years*	Female, n/N (%)	Any severity, n/N (%)	Moderate or severe, n/N (%)		
(Continued from previous page)										
Kozloff et al (2016)[41]†	Canada	Cross-sectional	Community agencies that serve homeless individuals (shelters, drop-in centres, outreach teams, inpatient programmes, and criminal justice programmes) in five Canadian cities	2255	40·9	730/2255 (32·4%)	1475/2255 (65·4%)	..	..	Single question or series of questions: "Have you ever had an injury to the head which knocked you out or at least left you dazed, confused, or disoriented?"
LePage et al (2014)[42]	USA	Retrospective case-control	VA North Texas Health Care System	2205	53·6	121/2205 (5·5%)	..	..	0·5% over 1 year	Medical record: ICD-9 codes
Mackelprang et al (2014)[43]†	USA	Cross-sectional	Homeless shelters, drop-in centres, domestic violence shelters, streets	2732	21·8	1730/2732 (63·3%)	1175/2732 (43·0%)	..	..	Single question or series of questions: "Have you ever been hit in the head so hard that you saw stars or were knocked unconscious—for example, from a blow, a fall, or a motor vehicle accident?" and "After your head injury, did you start having problems with headaches, concentration or memory, understanding, excessive worry, sleeping, or getting along with people?"
McCormick and White (2016)[44]	UK	Retrospective case-control	Hospital admissions records	7830 hospital admissions in 2010–11	38·7 over the study period	20% over study period	..	..	2·1% of hospital admissions (2010–11) in the homeless group were for head injury	Medical record: National Health Service hospital episode statistics in England
McMillan et al (2015)[45]	UK	Retrospective case-control	Hostels and other designated accommodations for homeless individuals	1590	40·5	347/1590 (21·8%)	..	..	13·5% over 30 years	Medical record: ICD-9 and ICD-10 codes
Montgomery et al (2015)[46]	USA	Retrospective case-control	Veterans Health Administration clinical and administrative systems	11 909	NR	NR	..	..	..	Medical record
Nielssen et al (2018)[20]‡	Australia	Retrospective chart review	Mental health clinics in three hostels for homeless individuals	2388	42·3	156/2388 (6·5%)	..	345/2388 (14·4%)	..	Medical record
Nikoo et al (2015)[47]	Canada	Cross-sectional	Emergency shelters and streets	500	37·9	200/500 (40·0%)	318/500 (63·6%)	..	..	Single question or series of questions: specific questions NR
Nikoo et al (2017)[48]†	Canada	Prospective longitudinal	Shelters, meal programmes, community health centre, and drop-in centres in three Canadian cities	1190	42·2	385/1190 (32·4%)	718/1190 (60·3%)	..	19·4% at 1-year follow-up; 17·1% at 2-year follow-up; 17·9% at 3-year follow-up	Single question or series of questions: "Have you ever had an injury to the head which knocked you out or at least left you dazed, confused, or disoriented?"
Noël et al (2016)[49]	Canada	Prospective longitudinal	Community agencies that serve homeless individuals (shelters, drop-in centers, outreach teams, inpatient programmes, and criminal justice programmes) in five Canadian cities	497	40·8	138/497 (27·8%)	..	..	..	Single question or series of questions: "Have you ever had an injury to the head which knocked you out or at least left you dazed, confused, or disoriented?"
Oddy et al (2012)[50]†‡	UK	Cross-sectional	Dry hostels, wet hostels, and day centres for homeless individuals	100	32·7	25/100 (25·0%)	48/100 (48·0%)	12/65 (18·5%)	..	Single question or series of questions: "Have you ever had an injury to the head which knocked you out or at least left you dazed, confused, or disoriented?", with additional questions regarding the number of injuries, LOC and whether participants went to the hospital for the first three injuries

(Table 1 continues on next page)

	Country	Study design	Population description				Lifetime prevalence of TBI		Incidence of TBI	TBI ascertainment method
			Setting	Sample size	Age, years*	Female, n/N (%)	Any severity, n/N (%)	Moderate or severe, n/N (%)		
(Continued from previous page)										
Palladino et al (2017)[51]	USA	Cross-sectional	Homeless outreach services, including a VA medical centre and drop-in centre for veterans experiencing homelessness	103	53·7	0/103	..	..	..	Structured interview and questionnaire or screening tool: OSU TBI-ID and TBI-4 tools
Russell et al (2013)[52]†	USA	Cross-sectional	Metropolitan VA hospital	678	51·9	36/678 (5·3%)	285/313 (91·1%)	..	..	Structured interview and questionnaire or screening tool: OSU TBI-ID and TBI-4¶
Schmitt et al (2017)[53]†	Canada	Cross-sectional	Single-room occupancy hotel rooms and downtown community court	283	43·5	47/205 (22·9%)	100/283 (35·3%)	49/283 (17·3%)	..	Single question or series of questions: "Have you ever had a serious head/face injury?", with additional questions regarding LOC, confusion, or memory loss post injury
Solliday-McRoy et al (2004)[54]†‡	USA	Cross-sectional	Homeless shelter	90	41	0/90	43/90 (47·8%)	16/90 (17·8%)	..	Single or series of questions: specific questions NR
Song et al (2018)[55]†	Canada	Cross-sectional	Shelters, homeless outreach services, and streets in three Canadian cities	500	38	200/500 (40·0%)	318/500 (63·6%)	..	..	Single question or series of questions: "Have you ever had an injury to the head which knocked you out or at least left you dazed, confused, or disoriented?"
Stergiopoulos et al (2015)[56]‡	Canada	Cross-sectional	Community agencies that serve homeless individuals (shelters, drop-in centres, outreach teams, inpatient programmes, and criminal justice programmes) in five Canadian cities	1500	41·1	477/1500 (31·8%)	..	688/1500 (45·9%)	..	Single question or series of questions: specific questions NR
Svoboda and Ramsay (2014)[57]	Canada	Retrospective cohort	Wet shelter programme, hostel for homeless individuals, and three low-income housing sites	170	43·7	0/170	..	..	28·8% (participants in wet shelters); 3·3% (participants in hostels); and 5·1% (participants in low-income housing) over 1 year	Medical record: broad criteria to capture "head injury"
To et al (2015)[58]	Canada	Prospective longitudinal	Shelters and meal programmes for homeless individuals	1181	43	382/1181 (32·3%)	718/1181 (60·8%)	..	..	Single question or series of questions: "Have you ever had an injury to the head which knocked you out or at least left you dazed, confused, or disoriented?"
Topolovec-Vranic et al (2014)[59]†‡	Canada	Cross-sectional	Shelter for homeless men	111	54·2	0/111	50/111 (45·0%)	46/111 (41·4%)	..	Questionnaire or screening tool: Brain Injury Screening Questionnaire
Topolovec-Vranic et al (2017)[60]	Canada	Cross-sectional	Community agencies that serve homeless individuals (shelters, drop-in centers, outreach teams, inpatient programmes, criminal justice programmes) in five Canadian cities	2088	40·9	657/2088 (31·5%)	1098/2088 (52·6%)	..	..	Single question or series of questions: "Have you ever had an injury to the head which knocked you out or at least left you dazed, confused, or disoriented?", "Were you, in fact, knocked out or unconscious after this (or any of these if more than 1 head injury(ies)?", and "About how long were you unconscious or knocked out after this head injury (if 1)/these head injuries (if >1)?", with additional questions regarding the length of LOC for up to five injuries

(Table 1 continues on next page)

	Country	Study design	Population description				Lifetime prevalence of TBI		Incidence of TBI	TBI ascertainment method
			Setting	Sample size	Age, years*	Female, n/N (%)	Any severity, n/N (%)	Moderate or severe, n/N (%)		
(Continued from previous page)										
Vila-Rodriguez et al (2013)[19]‡	Canada	Prospective longitudinal	Single-room occupancy hotel rooms	293	44·1	68/293 (23·2%)	..	31/293 (10·6%)	..	Other: evidence of previous TBI on MRI or history of TBI (LOC for ≥5 min or confusion for ≥1 day) and persistent symptoms referable to TBI, including seizures or organic personality disorder
Zieman et al (2017)[61]	USA	Retrospective chart review	Central neurology clinic cohort of referred patients from homeless shelters with TBI as a result of domestic violence	115	37·9	109/115 (94·8%)	..	..	..	Questionnaire or screening tool: HELPS screening tool
Zlotnick et al (1995)[62]†	USA	Cross-sectional	Rehabilitation programme for homeless individuals recovering from alcohol misuse	52	60% were >35	0/52	21/52 (40·4%)	..	..	Single question or series of questions: specific questions NR

TBI=traumatic brain injury. VA=US Department of Veterans Affairs. OSU TBI-ID=Ohio State TBI Identification method. NR=not reported. LOC=loss of consciousness. ICD=International Classification of Diseases. *Measure of central tendency (mean or median), unless otherwise stated. †Included in meta-analysis of lifetime prevalence. ‡Included in meta-analysis of lifetime prevalence of moderate or severe TBI. §218 (52·4%) of 416 participants were missing data on severe TBI. ¶Prevalence estimate from the OSU TBI-ID (n=313) used in meta-analysis.

Table 1: **Summary of included studies**

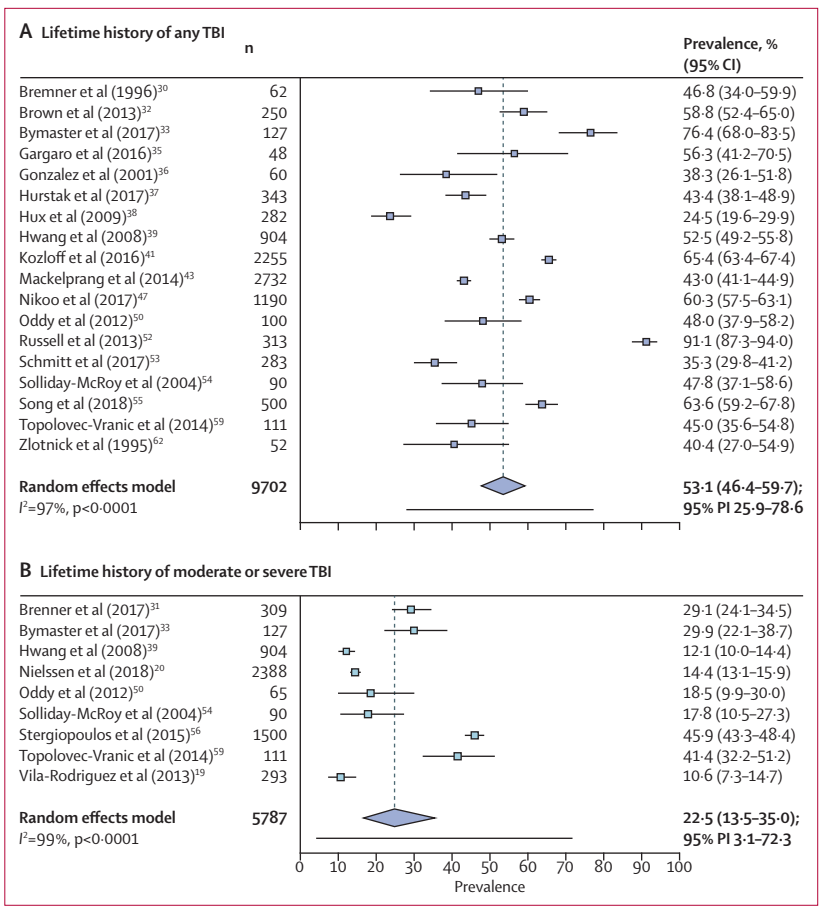

Figure 2: **Forest plots of prevalence estimates for any severity of TBI and for moderate or severe TBI**
Box size for each study is based on the weight for random-effects analysis, calculated using the inverse of the variance. Prevalence estimate from Oddy et al (2012)[50] derived from first injury only. TBI=traumatic brain injury. PI=prediction interval.

meta-analysis of the incidence of TBI in this population. Estimated incidence of TBI in homeless and marginally housed individuals varied considerably between studies and ranged from 0·5% over 1 year[42] to 28% over 1 year.[57] Although we did not quantitatively assess moderators of these estimates, TBI ascertainment method appeared to be associated with estimated incidence. For example, Nikoo and colleagues[48] did a comprehensive baseline interview with each participant and assessed incident TBI at yearly follow-up interviews, and found that 17·1–19·4% of participants sustained TBI per year.[48] By contrast, LePage and colleagues[42] and McMillan and colleagues[45] used ICD-9 codes, ICD-10 codes, or both to ascertain TBI.[42,45] LePage and colleagues found that 0·5% of participants sustained TBI over 1 year, and McMillan and colleagues found that 13·5% of participants sustained TBI over the 30-year study period (approximately 0·5% per year). A study-level summary of results from studies evaluating incidence of TBI is presented in the appendix (p 13). Homelessness was associated with a higher incidence of TBI in comparison with non-homeless control groups.[42,44,45,57] Similarly, residential instability was

	Studies	Participants	Estimated prevalence, % (95% CI)	Heterogeneity		Change in estimated prevalence from univariable meta-regression analyses*		Change in estimated prevalence from multivariable meta-regression analysis*	
				I^2	p value	Change, % (95% CI)	p value	Change, % (95% CI)	p value
Measure of central tendency of age for the study sample	18	9702	52·1% (46·4–59·7)	97%	<0·0001	1·5% ($-4·7\times10^{-2}$ to 3·1)	0·058	1·6% ($2·7\times10^{-2}$ to 3·2)	0·045
Sample size	18	9702	52·1% (46·4–59·7)	97%	<0·0001	$5·3\times10^{-3}$% ($-1·6\times10^{-2}$ to $2·6\times10^{-2}$)	0·49	$1·8\times10^{-2}$% ($3·6\times10^{-4}$ to $3·6\times10^{-2}$)	0·047
Site of study recruitment									
Service or clinic	6	2855	64·7% (48·2–78·3)	95%	<0·0001	Reference	..	Reference	..
Shelter or hostel	12	6847	47·4% (41·1–53·7)	95%	<0·0001	–39·4% (–66·7 to –12·1)	0·0047	3·6% (–31·4 to 38·1)	0·85
TBI ascertainment method									
Single question or series of questions	13	8821	50·1% (43·7–56·5)	97%	<0·0001	–25·0% (–57·6 to 7·7)	0·13	Reference	..
Other screening tool (HELPS or BISQ)	2	393	33·8% (17·1–55·9)	94%	<0·0001	–47·8% (–90·8 to –4·8)	0·029	–32·7% (–73·1 to 7·6)	0·11
OSU TBI-ID structured interview	3	488	78·0% (53·4–91·6)	95%	<0·0001	73·6% (37·4 to 100·0)	<0·0001	67·9% (22·3 to 100·0)	0·0035

LOC=loss of consciousness. TBI=traumatic brain injury. OSU TBI-ID=Ohio State TBI Identification method. *For a one-unit change in the predictor variable.

Table 2: **Meta-regression results evaluating potential moderators of estimated lifetime TBI prevalence**

associated with a higher incidence of TBI.[48] Lifetime history of TBI, receiving a TBI in the previous year, mental health diagnoses and poorer mental health, drug and alcohol misuse, and younger age were also associated with incident TBI over a 1-year period.[48,57]

Discussion

The results of our systematic review and meta-analysis suggest that more than half of homeless and marginally housed individuals have a lifetime history of TBI, and that almost a quarter have a history of moderate or severe TBI. Thus, the lifetime prevalence of TBI in homeless and marginally housed individuals is between 2·5-times and 4·0-times higher than estimates in the general population.[8,11] Moreover, the lifetime prevalence of moderate or severe TBI in this population is nearly ten-times higher than estimates in the general population.[8] We also found that TBI was associated with increased suicidal ideation and suicide risk, poorer self-reported physical and mental health, and increased health service and criminal justice system involvement. However, heterogeneity across estimates limits our ability to establish the true prevalence of TBI in this population.

We identified high statistical heterogeneity and considerable methodological limitations across many of the included studies, which hinders a clear understanding of the magnitude of the impact of TBI in this population. This heterogeneity can be attributed in part to the age of the study sample, because study samples with a higher proportion of older individuals evaluate individuals with a longer time at risk of TBI. This heterogeneity is also explained in part by study design factors, such as the tool used to ascertain TBI history, which reflects that standardised and reproducible research methods were not always used in previous studies on this topic. Three studies in our review had identifiable subgroups defined only by loss of consciousness. These studies suggest that using only loss of consciousness as a screening criterion might result in lower estimated prevalence than the standard WHO criteria, which also include confusion and memory loss. In the general population, excluding individuals with a head injury and alteration (but not loss) of consciousness would miss approximately 80% of all injuries considered to be TBIs by commonly used definitions.[5,63,64] Notably, the use of OSU TBI-ID to ascertain TBI history was associated with an estimated prevalence that was nearly 30% higher than in studies that used a single question. Although they have inherent limitations, clinical interviews such as the OSU TBI-ID are considered to be the preferred method for ascertaining TBI history.[65] Clinical interviews also allow a trained researcher to use an approach tailored to the study population to obtain the level of detail required for an expert assessment of the evidence. Thus, ascertainment method might represent one of the most important design considerations in studies evaluating history of TBI. Consequently, our summary estimate of prevalence in this population is limited by inadequate ascertainment methods that appear to underestimate the prevalence of TBI in this population. If prevalence estimates ascertained through structured interviews represent the most accurate estimate of prevalence, our pooled estimate of prevalence

Panel: **Associations between history of TBI and health-related or functioning-related outcomes**

Physical health (12 studies)

- Associated with having seizures in three studies[19,39,60] and not associated with seizures in two studies[53,59]
- Associated with poorer self-reported physical health in three studies[39,53,58] and more chronic health conditions in one study[58]
- Associated with dizziness in two studies[38,53]
- Associated with headaches or migraine headaches in three studies[38,53,60]
- Associated with memory problems in five studies[35,38,43,53,61] and not associated with memory problems in one study[34]
- Associated with evidence of traumatically induced lesions visible on structural MRI, lower fractional anisotropy, and lower total cortical grey matter in one study[53]
- Not associated with geriatric syndromes in one study,[32] Charlson comorbidity score in one study,[53] or active HIV or hepatitis C infection in one study[53]

Mental health (11 studies)

- Associated with a diagnosis of schizophrenia in one study,[43] bipolar disorder in two studies,[28,43] manic or hypomanic episodes in one study,[60] and panic disorder in one study[60]
- Associated with a higher number of psychiatric diagnoses in three studies[31,43,58]
- Associated with poorer self-reported mental health in three studies[39,53,58] and a history of mental illness in one study[59]
- Associated with lower odds of psychotic disorder in one study[60] and not associated with psychotic disorder in one study[53]
- Associated with polysubstance use in one study[35]
- Associated with drug misuse in four studies[39,43,58,60] and not associated with drug misuse in four studies[35,53,55,59]
- Associated with alcohol misuse in five studies,[39,43,53,58,60] and not associated with alcohol misuse in two studies[35,55]
- Associated with mood disorders in one study[53] and mood disorder with psychotic features in one study[60]
- Associated with lower odds of self-reported depression in two studies[35,38] and diagnosed depressive disorder in two studies[43,60]
- Associated with self-reported anxiety in two studies[35,38] and not associated with diagnosed anxiety disorder in one study[53]
- Associated with post-traumatic stress disorder in two studies[43,60] and not associated with post-traumatic stress disorder in one study[53]
- Associated with trouble controlling violent behaviour in one study[35]
- Associated with self-reported emotional problems in one study[35]

Suicidality (six studies)

- TBI-related symptoms or a history of TBI were associated with higher risk for suicide or suicidal ideation in four studies,[31,43,51,60] and not associated with suicidal ideation in one study[53]
- Associated with suicide attempts in two studies[43,60] and not associated with suicide attempts in one study[35]

Mortality (two studies)

- The standardised mortality ratio was significantly higher in homeless participants admitted to hospital with head injury than in non-homeless participants in one study[45]
- In another study, 30-day mortality for homeless participants recruited from a neurosurgical unit was not significantly different to that of non-homeless participants[40]

Neurocognition (nine studies)

- Associated with poorer neurocognition in two studies[27,53] and clinical cognitive impairment in one study[19]
- Not associated with neurocognition in six studies[34,36,37,54,56,62]
- Lower neurocognitive scores were found to be associated with lower grey matter volume and poorer white matter integrity of the corpus callosum as assessed with neuroimaging[53]

Temporal relationship to homelessness (six studies)

- Between 51% and 92% of participants experienced their first TBI before their first experience of homelessness or marginal housing[29,39,43,50,53,59]

Other outcomes (seven studies)

- Associated with a higher likelihood of reporting victimisation in one study[43]
- Associated with difficulties with activities of daily living in one study[43]
- Associated with a history of childhood trauma, physical abuse, and emotional abuse in one study,[55] and associated with a history of childhood physical abuse, sexual abuse, and neglect in one study[43]
- Associated with a history of intimate partner violence[43,53]
- Associated with lower than expected educational attainment in one study[43] and a history of special education in one study;[43] not associated with education in two studies[53,59]
- Associated with employment and a higher monthly income in one study[58] and not associated with employment in one study[43]
- Associated with higher frequency of emergency room visits and hospital admissions in three studies[43,58,60] and not associated with outpatient days in the previous 6 months in one study[60]
- Associated with having access to a physician in two studies[58,60]
- Associated with arrest, incarcerations, or criminal justice system involvement in five studies[43,53,58–60]

(Continues on next page)

(Panel continued from previous page)

- Associated with being a victim of physical or sexual assault in two studies[43,58]
- Associated with a parental history of substance abuse in one study[59]
- Associated with so-called survival sex during homelessness in one study[43]
- Associated with a history of foster care in one study[43]
- Associated with a higher number of homeless episodes or a longer lifetime duration of homelessness in two studies,[43,58] and not associated with lifetime duration of homelessness or marginal housing in two studies[53,59]
- Associated with military service in one study[43]
- Not associated with having a place to go when sick or in need of health advice in one study[60]
- Not associated with marital status in one study[43]
- Not associated with screening positive for homelessness in veterans in one study[46]

might be a considerable underestimate of the true prevalence of TBI in this population.

Despite considerable statistical and methodological heterogeneity between studies, we found that a history of TBI is associated with various aspects of poor health and functioning. Additionally, several characteristics of homeless and marginally housed populations (eg, residential instability or substance use) were associated with sustaining TBI. Some relationships might be bidirectional: for example, TBI could increase the risk for homelessness, and homelessness could increase the risk for incident TBI. Establishing whether TBI is a risk factor for poor outcomes (eg, homelessness or serious health conditions) will be important to understand and address the impact of TBI in this population.

Our results suggest that physicians and care providers working with homeless and marginally housed populations should have an increased awareness of TBI. Previous studies have shown that homeless and marginally housed individuals have a frequency of actionable incidental findings on brain MRI that substantially exceed that expected of the general population.[19] For example, Vila-Rodriguez and colleagues[19] reported that the prevalence of aneurysms was 8·6% and of brain infarcts was 11% in homeless and marginally housed individuals. By contrast, the expected rates in similarly aged samples from the general population are less than 1% for aneurysms and less than 3% for brain infarcts.[66] In an overlapping sample, Schmitt and colleagues[53] reported visible encephalomalacia on neuroimaging that was deemed likely to be caused by traumatic injury in 6·9% of the cohort, and found that evidence of trauma on neuroimaging was associated with poorer cognition and executive functioning in this population.[53] Clinicians might therefore consider lowering the threshold for referral to neuroimaging specialists after head injury in homeless and marginally housed patients, because depending on the resources available, an assessment that complements self-reporting might be indicated. Confirmation of structural brain damage caused by TBI might facilitate triage and referral to specialised services, such as cognitive rehabilitation, which could improve functional outcomes.[67,68] Furthermore, imaging findings might positively inform the patient–caregiver relationship (eg, by increasing understanding of challenging behaviours that might be attributable to damage visible on neuroimaging).

To our knowledge, this is the first study to quantitatively evaluate the lifetime prevalence of TBI and to comprehensively summarise the associations between TBI and health-related or functioning-related outcomes in homeless and marginally housed individuals. However, our study has some limitations. Firstly, the included studies were almost exclusively retrospective in design, which precludes interpretation about the directionality of the relationships. Future prospective studies are needed in order to adequately evaluate, for example, whether TBI leads to substance use or homelessness, or whether factors such as substance use or homelessness lead to TBI. Secondly, we limited our search to peer-reviewed publications and elected not to search the so-called grey literature. In the screening process for this study, we encountered several theses and book chapters; however, we elected to exclude these in order to limit our results to only peer-reviewed studies.

TBI is prevalent among homeless and marginally housed individuals and might be a common factor that contributes to poorer health and functioning than in the general population. Primary care providers and those working with this group should be aware of the prevalence and associated consequences of TBI. Evaluating history of TBI might be relevant to a comprehensive assessment of homeless and marginally housed patients, who often have complex comorbidities. In addition, public health research and practice should focus on TBI prevention and more accurately characterising the scope and effects of TBI in this vulnerable population. Although to our knowledge no studies have been done to evaluate whether incident TBI is reduced with housing interventions, randomised trial evidence shows that rent supplements in combination with intensive case management substantially improve living situation, safety, and community functioning.[69] These findings suggest that the provision of stable housing might also lower the risk for TBI. High-quality studies are urgently needed to elucidate the true prevalence and incidence of TBI, and the directionality of the relationship between TBI and outcomes in the homeless and marginally housed population.

Contributors
JLS led the title and abstract screening, full-text screening, risk of bias assessment, data extraction, statistical analysis, and drafting of the manuscript. JMS participated in the title and abstract screening, full-text screening, risk of bias assessment, and data extraction. JLS, AET, NDS, AMB, WGH, and WJP interpreted the results and participated in the drafting of the manuscript. All authors approved the final manuscript.

Declaration of interests
NDS has sat on the paid advisory board of Highmark Interactive, received consulting or speaking fees from WorkSafeBC and Yukon WCB, the National Hockey League, and Major League Soccer, and has received fees for expert testimony in neuropsychology. WGH has received consulting fees or sat on paid advisory boards for the Canadian Agency for Drugs and Technology in Health, AlphaSights, Guidepoint, In Silico, Translational Life Sciences, Otsuka, Lundbeck, and Newron. WJP is the founder and chief executive officer of Translational Life Sciences, an early stage biotechnology company. He is also on the scientific advisory board of Medipure Pharmaceuticals and Vitality Biopharma, and in the past has been on the board of directors for Abattis Bioceuticals and on the advisory board for Vinergy Resources; these companies are early stage biotechnology enterprises with no relation to brain injury. All other authors declare no competing interests.

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