Update on the epidemiology of work-related traumatic brain injury: a systematic review and meta-analysis

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ABSTRACT

Background Traumatic brain injury (TBI) is a public health concern that can occur in a range of contexts. Work-related TBI (wrTBI) is particularly concerning. Despite overall work-related injury claims decreasing, the proportion of claims that are wrTBI have increased, suggesting prevention and support of wrTBI requires ongoing attention.

Objectives This review aimed to provide updated information on the burden and risk factors of wrTBI among the working adult population.

Methods Medline, Embase, PsycINFO, and Cumulative Index to Nursing and Allied Health Literature (CINAHL) were searched using a combination of TBI, work, and epidemiology text words and medical subject headings. Two reviewers independently assessed articles for inclusion. Meta-analyses were conducted to estimate prevalence and mortality of wrTBI and a narrative synthesis was conducted to provide additional context.

Results Pooled proportions meta-analyses estimate that 17.9% of TBIs were work-related and 6.3% of work-related injuries resulted in TBI, with 3.6% of wrTBI resulting in death. Populations of wrTBI were predominantly male (76.2%) and were 40.4 years of age, on average. The most commonly reported industries for wrTBI were education and training, healthcare and social assistance, construction, manufacturing, and transportation. Falls, being struck by an object or person, motor vehicle collisions, and assaults were the most commonly reported mechanisms of wrTBI.

Conclusions A better understanding of the epidemiology of wrTBI can inform prevention and management strategies. This review highlights existing gaps, including a notable lack of sex or gender stratified data, to direct future investigation.

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Key messages

What is already known about this subject?

► Work-related traumatic brain injuries (wrTBI) comprise an increasing proportion of work-related injury claims in Canada and there is an emphasis more globally on work-related injuries in the construction industry.

What are the new findings?

► wrTBI constitutes an estimated 17.9% of traumatic brain injuries and 6.3% of work-related injuries. An inability to return to work following wrTBI was reported for subsets of participants in several studies. This review identified an increase in reporting of wrTBI among service-oriented occupations, including education and healthcare. Sex and gender remain under-reported.

How might this impact on policy or clinical practice in the foreseeable future?

► This work identifies existing gaps that must be addressed to make equitable and effective changes to policy and clinical practice. Comprehensive synthesis of the knowledge in this field and sex and gender-based analyses are needed to inform policy decisions surrounding work-place safety, recommendations for injury prevention, and frameworks for supports post injury.

INTRODUCTION AND RATIONALE

Globally, an estimated 69 million individuals sustain a traumatic brain injury (TBI) each year.[1] Though some individuals recover fully with no lasting effects, an estimated 3.17 million individuals live with TBI sequelae in the United States alone.[2] Even TBIs classified as 'mild' can result in significant, long-term effects including poorer health, unemployment, and increased healthcare costs, causing a significant impact on the individual, their family, and the healthcare system.[3–5] Though TBI can occur in a range of contexts, work-related TBI (wrTBI) is of particular concern. Despite claims for work-related injuries as a whole decreasing, the proportion of TBI among work-related injury claims have increased in Canada,[6] suggesting persistent gaps in the prevention and support of wrTBI as well as a need for increased awareness of this injury. Furthermore, the loss of meaningful work that may follow a TBI can have severe consequences for an individual's identity and sense of self-worth.[7] Significant effort must be undergone, therefore, not only to better understand and prevent wrTBI, but also to understand and accommodate the needs of individuals with TBI in returning to work.

A systematic review was published in 2015 on the epidemiology of wrTBI.[8] This review, conducted on articles published until December 2013, noted a paucity of outcome data on wrTBI and a large enough variation in the data presented that a meta-analysis was not possible. Since that review was conducted, the Canadian Institutes of Health Research (CIHR), Canada's federal funding agency for health research, announced nine new research chairs in Gender, Work, and Health,[9] one of which was specifically dedicated to wrTBI, contributing to the additional work published in this area since the 2015 review. The current systematic review aimed to update our understanding of the burden, risk factors, and outcomes of wrTBI.

METHODS

This systematic review looked at the burden (ie, incidence, prevalence, mortality) and risk factors (ie, sex, age, industry/occupation, mechanism of injury, severity of injury) of wrTBI in the global adult working population, as reported in prospective and retrospective cohort studies, case-control studies, cross-sectional studies, and case series published since January 2014.

As this systematic review is an update of a previous review,[8] the search strategy and eligibility criteria will replicate those of the original study with the exception of the publication dates included in the search (original study: January 1980 to December 2013; current study: January 2014 to February 2020). We also reported outcomes (ie, sequalae, return to work) examined in studies investigating the burden or risk factors associated with wrTBI.

Search strategy

Medline, Embase, PsycINFO, and Cumulative Index to Nursing and Allied Health Literature (CINAHL) were searched for relevant articles using a search strategy including text words and subject headings (eg, medical subject headings (MeSH), Embase subject headings (Emtree)) related to work, TBI, and epidemiology (ie, risk, burden, mortality) (online supplemental file 1). Searches were limited to English-language publications published between January 2014 and February 2020 without restriction on geographical location. Records returned from this search were managed in EndNote and Covidence.[10]

Eligibility criteria: title and abstract screen

Following the removal of duplicates, two reviewers (DT, VC) independently assessed all identified titles and abstracts for eligibility. This screen focused on identifying studies addressing burden or risk of either work-related injuries or TBI. To minimise the possibility of missing relevant articles, studies were included in the full-text screen if they investigated a population or subset of work-related injuries, or if they investigated a population or subset of TBI, and if the full-text article was available through the University of Toronto Library system. This broad approach was taken based on previous experience with reviews on TBI suggesting that both relevant subgroups (in this case, work-related injuries and TBI) are not always included in the abstract though relevant data may be presented in the body of the article.

Commentaries, conference abstracts, reviews, case studies, randomised controlled trials, and reports without described methods were excluded. Studies were additionally excluded if they focused on traumatic injury without mention of head injury or a worker population, if they focused on a non-TBI work-related injury (eg, noise-related hearing loss), if they were conducted in animals or at the cellular level, if they focused on military-related or sports-related TBI, or if they were conducted in non-working paediatric or elderly populations.

To ensure the reviewers interpreted these criteria in a similar manner, a sample of articles was reviewed by both reviewers and compared to assess for agreement. Covidence software was used for screening and to monitor agreement between the two reviewers' assessments.[10] Any differences were resolved through discussion and consensus. If consensus could not be reached, articles were moved to the full-text screen for further review.

Eligibility criteria: full-text screen

All articles included in the full-text screen were reviewed independently by two reviewers (DT, VC). For inclusion in the review, studies needed to provide quantitative information on the burden or risk factors of wrTBI specifically. Exclusion criteria used for the abstract and title screen continued to apply. Additionally, articles were excluded if wrTBI data could not be separated from more general data (eg, TBI not examined separately from neck, spinal cord, facial, or superficial head injuries).

As with the title and abstract screen, a sample of full-text articles were reviewed to calibrate interpretation of the inclusion criteria. Covidence software was used to conduct the screening and monitor agreement between the reviewers' assessments.[10] All differences in screening were resolved through discussion and consensus. The reference lists of articles meeting the criteria for full-text review were manually searched for additional articles relevant to the review.

Data extraction

Study details (ie, location, duration, design, population, sample size, data source, TBI and work case definitions), epidemiological findings (ie, prevalence, mortality, demographic information, industry or occupation, mechanism of injury), and TBI-related outcomes (ie, psychological and physical sequelae, return to work) were extracted from included studies as reported. One reviewer (DT) completed the data extraction, which was then peer reviewed by a second reviewer (VC).

Quality assessment

A 17-item checklist, developed by Chang *et al* for their 2015 review (online supplemental file 2), was used to assess the quality of included studies.[8] It is an amalgamation of tools developed for evaluating primary research[11] and occupational injuries and illnesses.[12] Notably, this tool assesses the robustness of studies' definitions of work, TBI, and TBI severity (case definition). Items were rated from 0 (not reported or defined) to 2 (clearly reported/well defined) or 'N/A' if not applicable. As maximum possible scores varied between studies, both a fraction (total/maximum) and a percentage score were calculated. No studies were excluded based on these scores. One reviewer (DT) completed the quality assessment, which was then peer reviewed by a second reviewer (VC).

Narrative synthesis

A narrative synthesis was conducted to provide context for the meta-analysis and report on aspects of the studies where meta-analysis was not feasible. Specifically, this synthesis looked at case definitions for work and TBI across studies, reported industries, mechanism of injury, and outcomes. Due to a limited number of studies reporting on incidence of wrTBI, this was also explored in the narrative synthesis.

Data synthesis

Pooled estimates of sex (proportion male) and mean age of individuals with wrTBI were calculated to provide context for the wrTBI population represented. Studies needed to report sex and age, respectively, for wrTBI separately from other injuries to be included in analyses. Studies purposely recruiting for equal representation of males and females or with samples of less than 10 were excluded. Only studies reporting age as a mean and standard deviation (SD) could be included in the age estimate.

To provide estimates of prevalence and mortality, we conducted pooled proportions, random-effect model meta-analyses.[13] Specifically, the prevalence of wrTBI among work-related injuries, the prevalence of wrTBI among TBI, and the mortality rate of wrTBI were assessed. To be included in these

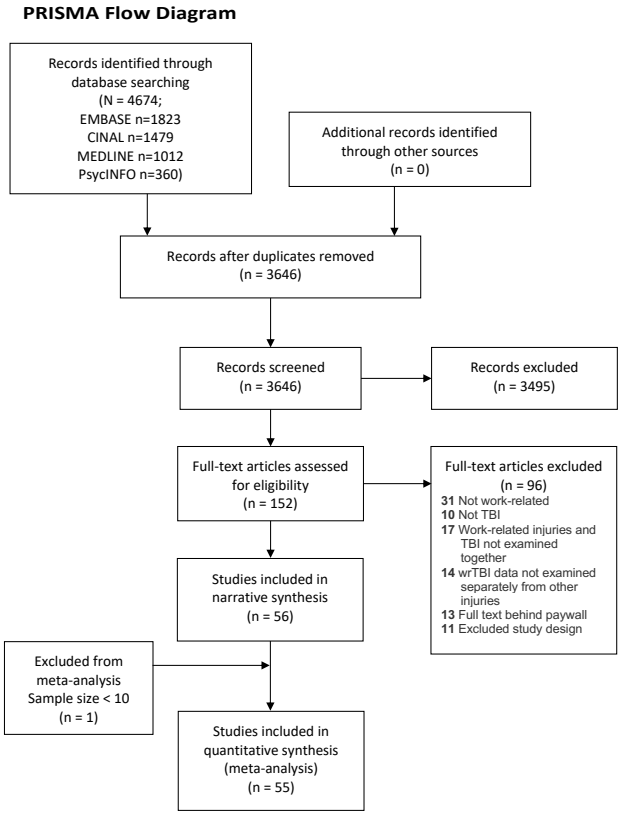

Figure 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram.

analyses, studies needed to include the number or proportion of wrTBI within the relevant population (work-related injuries or TBI, respectively) or report on the number or proportion of fatal injuries within a wrTBI population. All meta-analyses used random-effects models[13] and excluded studies with samples less than 10. Analyses were conducted using R.[14]

RESULTS

Search & screening

Our search strategy returned 4674 records across the four searched databases. After removing duplicates, 3646 titles and abstracts were reviewed, and 152 full-text articles were assessed to identify 56 articles for inclusion (figure 1). No additional articles were identified from reference lists. The reviewers had 97% agreement for the review of titles and abstracts and 84% agreement for the review of full-text articles for inclusion. All discrepancies were resolved in discussion between the two reviewers.

Included studies

Of the included studies, 18 (32%) report on wrTBI (online supplemental table 1), 33 (59%) report on work-related injuries (online supplemental table 2), and 9 (16%) report on TBIs (online supplemental table 3). Two studies explored traumatic injuries more broadly and had both TBI and work-related subsets; [15 16] they are presented in both online supplemental tables 2 and 3. Additionally, one study conducted a comparison between wrTBI and non-wrTBI with detailed wrTBI reporting; [17] it has been included in both online supplemental tables 1 and 3. Finally, one study explored wrTBI specifically, but reported on wrTBI in relation to overall work-related injuries during the study period; [18] it has been included in both online supplemental

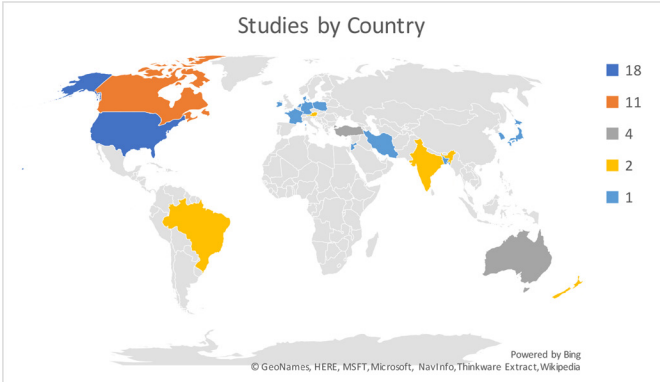

Figure 2 Included studies by country.

tables 1 and 2. Studies represented in multiple tables are denoted with a § with additional information on the relevant sample.

Age and sex are presented for all groups when provided. Industry/occupation and mechanism of injury are reported for the wrTBI group only due to inconsistent reporting among work-related injury and TBI focused studies and an inability to extract wrTBI-specific information in these domains.

Included studies spanned a variety of contexts, with the majority situated in specific employment environments (24%) or healthcare settings (39%). Almost all included studies were cohort studies (34%), cross-sectional studies(23%), or descriptive secondary analyses of surveilance or claims data (21%). The majority originated from the United States (32%) or Canada (20%) (figure 2) and study periods spanned 1980–2018, with durations ranging from months to decades (figure 3). Of the 18 studies reporting on wrTBI, over half were conducted in Canada (55%) with the remainder conducted in the United States (22%), Australia (17%), and Brazil (6%).

Quality assessment

Quality assessment scores for included studies ranged from 43% to 97%. Maximum possible scores ranged from 28 to 34, with total scores ranging from 13 to 33. Many studies failed to report TBI case or severity definitions, resulting in the lowest average scores and highest SD in these categories (case definitions of TBI: 0.82±0.88; TBI severity 0.59±0.85).

The 2015 review only assessed quality of wrTBI articles (53%–94%).[8] When looking at just the wrTBI subset included here, scores ranged from 69% to 94%, suggesting the quality of wrTBI articles may have increased since the 2015 review was completed.

No articles were excluded from the review or analyses due to their score. A summary of scores is presented in online supplemental file 2.

Narrative synthesis

The studies included in this review were highly heterogeneous in study population, data sources, and study design; as such, significant variability was seen in the case definitions, reported industry/occupation, mechanism of injury, and outcomes.

Severity and case fatality

Of the 56 articles included in this review, 11 (20%) included fatal injuries, 5 (9%) of which investigated fatal injuries exclusively. In the five studies with a sample size greater than 10 reporting on fatal injuries as a subset of all wrTBI, the percentage of fatal cases ranged from 1% to 8%.[19–23] Studies reporting on fatal

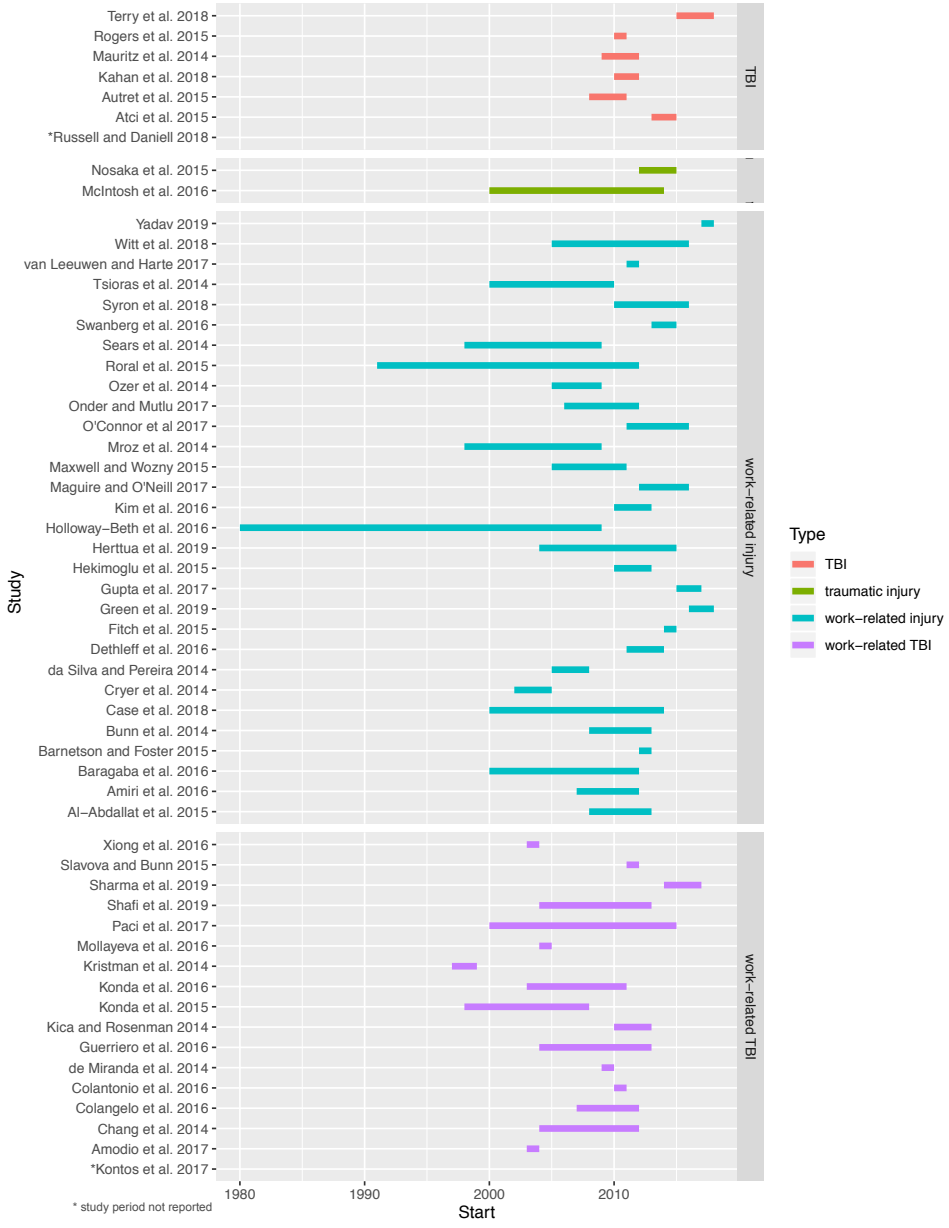

Figure 3 Study periods of included studies

work-related accidents reported wrTBI as the cause of 14-26% of work-related fatalities. [15 24–26 27]

Case definition: TBI and work

Fewer than half of the included studies (n=22, 39%) identified TBI using specific codes or frameworks (eg, International Classification of Diseases, workers' compensation database codes), seven (13%) used a TBI diagnosis, and the remainder (n=27, 48%) did not specify how TBI was identified. The majority of both the wrTBI-specific articles (89%) and TBI-specific articles (78%) used codes or diagnosis to identify TBI.

Similarly, methods of identifying work-related injuries were highly variable, with 24 (44%) studies using worker's compensation data or specific employment settings, 12 (22%) using other defined datasets that included reporting on occupation, 4 (7%) relying on self-report, and the remainder (27%) lacking information on how work-related cases were identified. All wrTBI-specific articles reported case definitions for work; however, eight articles focusing on work-related injuries (26%) failed to specify how work was identified.

Industries/occupations

Among studies looking at work-related injuries (n=33), 15 (46%) looked at specific industries, predominantly in manual labour (ie, mining, construction, farming).[25 26 28–40] Only one of the work-related injury studies reported the industry for workers experiencing wrTBIs (24.7% construction related),[20] and one study that examined TBI reported that all but one of the wrTBIs were farm related.[15]

Among studies looking specifically at wrTBI (n=18) almost all (n=15, 82%) included some information about the industries or occupations of the affected workers, with the most commonly reported industries being construction, education and training, healthcare and social assistance, and transportation. Only one study looked at a specific industry, reporting on fatal wrTBI in construction.[24] Construction was cited as the cause of

8.3%–33.6% of wrTBI in seven studies.[19 21 23 41–44] Interestingly, eight studies reported on wrTBI occurring in both the education and training sector (4.7%–16.0% of wrTBIs reported) and the healthcare and social assistance sector (9.2%–40.9% or wrTBIs reported),[18 19 23 42–46] both of which receive relatively little research attention. Finally, transportation accounted for a range of 2.2%–12.0% of wrTBI across eight studies.[17–19 21 23 41 42 44 47] Further analysis of industries or occupations is complicated by inconsistent grouping across studies and difficulty mapping occupations to industries and vice versa.

Mechanism of injury

Five studies specifically investigated falls as a mechanism of interest among the broader work-related injury (online supplemental table 2) or TBI populations (online supplemental table 3).[16 20 38 48 49] Additionally, one study on work-related injury specifically noted that 63.5% of wrTBI were attributable to falls.[28] The remainder of articles looking at work-related injury or TBI did not report on the mechanism of injury for the wrTBI subset.

Among studies specifically investigating wrTBI (online supplemental table 1), 12 reported mechanism of injury (67%) with the most commonly reported mechanisms being falls, being struck by an object or person, motor vehicle collisions, and assaults. Falls, slips or trips caused 23.7%–58.2% of injuries across 11 studies.[17 19 21 23 24 42 43 45–47 50] Being struck by an object or person accounted for 14.4%–53.1% of all injuries across eight studies.[17 19 21 23 43 45–47] All but one of these studies reported assaults separately, indicating injuries coded as being struck by an object or person were likely accidental. Motor vehicle collisions were reported in eight studies, representing 6.5%–29.8% of wrTBI.[17 19 21 23 43 45 47 50] Finally, eight studies reported assault as being the cause of 1.1% to 14% of wrTBI,[17 19 21 23 43 45 46 50] with one additional study looking specifically at wrTBI due to assault.[18]

Outcomes

Very few studies that reported on the burden of and risk factors for wrTBI also reported on outcomes post-wrTBI (excluding death). Return-to-work outcome information was reported in eight wrTBI studies; six of which reported some portion of their study population (17.1%–87%) did not return to work at various stages of recovery.[17 18 43 50–52] Additionally, two studies reported that time off from work was required post injury.[23 46] One study focused on mental health outcomes, identifying 82.1% of the wrTBI subset as having probable PTSD.[53]

Incidence of wrTBI

Only five studies reported on the incidence of wrTBI among the working population. Two studies estimated the incidence based on full-time worker equivalents (2.6/100 000 and 4.3/10 000).[24 42] The remaining three used 'workers',[23] 'employed civilians',[47] and 'worker contracts'[41] as the denominator (estimated at 19.8, 31.6, and 6.14 per 10 000, respectively).

Reporting on sex/gender

Of the 56 studies included in this review, 22 (39%) reported on the sex or gender of individuals with wrTBI. However, only five of the studies (9%) stratified the reporting of other variables by sex or gender,[23 44 52 54 46] all of which reported significant differences between the two reported groups (male/female or man/woman).

Data synthesis

Pooled estimates of sex and age were calculated to characterise individuals with wrTBI. All studies reporting sex used a male/female binary; therefore, we calculated the pooled proportion of males among individuals with wrTBI. This was done using a random effects model pooled proportions meta-analysis of the 19 studies reporting sex data for wrTBI. One study purposely recruited to have equal representation of men and women and was excluded from this analysis.[45] Based on the available data, 76.2% of wrTBI occurred in males (table 1 and online supplemental figure 1). Though age was reported in 20 studies, only 8 reported a mean and SD; therefore, the pooled means meta-analysis was limited to these studies. Based on this subset, the average age of workers was 40.44 years (table 1 and online supplemental figure 2).

A pooled proportion of wrTBI among work-related injuries was calculated based on data from 32 studies reporting on this subset, resulting in an estimate of 6.3% of work-related injuries being wrTBI (table 1 and online supplemental figure 3) Using the same methodology, wrTBIs were estimated to comprise 17.9% of TBIs based on eight TBI studies (table 1 and online supplemental figure 4). Finally, based on a pooled proportion meta-analysis of five studies including a fatal wrTBI subset, 3.6% of all wrTBIs were estimated to result in death (table 1 and online supplemental figure 5). One study[16] had a sample size of less than 10 and was excluded from all meta-analyses.

DISCUSSION

As with the previous review,[8] the studies included here were highly heterogeneous in the target populations, definitions of TBI, and data sources used. However, several of our findings aligned with those from the initial review. In both reviews, the majority of studies investigated mild injury with studies focusing on severe and fatal cases having a higher proportion of males. Falls, motor vehicle collisions, and being struck by or against an object or person were the top three mechanisms of injury in both reviews; however, this review found higher rates of assault as a cause of injury.

Similar to the previous review, the majority of studies were based in Canada and the USA.[8] However, the current review identified more studies outside of these two countries, with a

Table 1 Results from pooled proportions and pooled mean meta-analyses

Variable of interest	# of Studies	Pooled estimate	95% CIs	tau^2	I^2
Average age of workers with wrTBI	8	40.44 years	39.62 to 41.26	0.83	85.1%
Proportion of wrTBI that occur in males	19	0.762	0.657 to 0.843	1.27	99.7%
Proportion of TBI that are work-related	8	0.179	0.073 to 0.376	2.12	99.6%
Proportion of work-related injuries that are TBI	32	0.063	0.045 to 0.089	1.01	99.9%
Proportion of wrTBI that are fatal	5	0.036	0.016 to 0.077	0.77	93.6%

TBI, traumatic brain injury; wrTBI, work-related TBI.

total of 19 countries represented. The majority of wrTBI specific publications were based in Canada, which is likely due, in part, to initiatives such as CIHR research chairs in Gender, Work and Health.[9]

Only one study reported on the rates of wrTBI among various industries stratified by sex,[23] which supported similar industry-specific trends by sex to those reported in the previous review.[8] Specifically, females had lower rates of injury across industries with the exception of the health and social service sectors.[23] Though sex and gender are acknowledged as distinct but related concepts, neither of which is binary,[55] the majority of studies included did not distinguish between sex and gender and none of the included studies included sexes or genders beyond the binary distinction of males/females or men/women, respectively. Future work should clearly distinguish between sex and gender in their methodologies and conduct sex and gender-based analyses to guide policy and social services. It is important to note, however, that many of the sources of data used in these studies (eg, worker's compensation claims) do not differentiate between sex and gender, nor do they provide reporting beyond the binary of male/female in most cases. To be able to report on sex and gender differences at regional or national levels using surveillance data, data on both sex and gender must be collected at that level.

This review was able to make significant additions to the findings of the 2015 review it intended to update.[8] Specifically, we were able to formally estimate the prevalence of wrTBI among work-related injury (6.3%) and TBI (17.9%) as well as the prevalence of a fatal outcome (3.6%) using meta-analyses, which was not conducted in the previous review. Additionally, we were able to report on outcomes following wrTBI based on studies that examined the burden of and risk factors for wrTBI (ie, studies that met the inclusion/exclusion criteria). While these studies examined return to work, an important outcome, it is recognised that it is far from the only one. Cognitive, physical, and psychological sequelae are well documented post-TBI and may impact an individual's ability to return to work,[3–5 56] yet were largely not explored by the studies in this review. We acknowledge that there is a body of literature examining return-to-work and other outcomes following wrTBI that was not included in this review as it does not examine burden or risk factors of wrTBI. We would encourage future studies investigating wrTBI burden and risk factors to investigate return to work further.

The studies included in this review represent a variety of methodologies, data sources and definitions of work and TBI. Population-level data was used in half of the included studies and two thirds of studies focused on wrTBI. However, in most cases, these data were not leveraged to compare wrTBI with other work-related injuries or non-work-related TBI, making drawing comparisons and broader conclusions about the wrTBI population difficult.

The ways in which studies identified wrTBI were also highly heterogenous. Standardised codes for area of injury were used more often in studies focusing on TBI or wrTBI; however, much of the literature is on work-related injuries. As with sex and gender, comparisons using worker's compensation data, or the equivalent, are limited by the data collected. Claims data are not collected for research purposes, and using it for such comes with limitations both in what data are collected and for whom.[57] Many of the worker's compensation data sources only report on successful claims, thereby excluding injured workers whose claims are unsuccessful or who do not make a claim. Additionally, the data collected are likely to be highly variable between countries or even regions within countries, which can impact the ability to compare between jurisdictions. Our review found this specifically with injury definitions. For example, Australian workers compensation datasets often use the Type of Occurrence Classification System codes that include TBI-specific codes,[23 46] whereas Canadian datasets often use a diagnosis of concussion or brain injury,[18 58] and others use combinations of codes to approximate a TBI.[42] Many studies included here used worker's compensation data collected at a provincial or state level (eg, Victoria, Australia[23]; Ontario, Canada[58]; Michigan, USA.[19] Only three of the articles looking at wrTBI explored datasets at the national level, one using Ministry of Work and Employment datasets in Brasil,[41] and the other two based out of the USA using the National Electronic Injury Surveillance System and the Bureau of Labour Statistics Census, respectively.[24 42] The paucity of studies investigating wrTBI in juxtaposition to other forms of work-related injury highlights an important area for future research.

Falls and being struck by objects accounted for a large proportion of the reported injuries, suggesting opportunities for prevention. Falls can be addressed with proper footwear, protective rigging, and appropriate maintenance of facilities; being accidentally struck by objects or people can be addressed through appropriate procedures and training, which are already documented in the literature.[59 60] As most of the studies included here examined non-fatal injuries, it is possible that these prevention efforts have been implemented to the extent that they prevent fatal injuries but not those that are less severe. Future work on wrTBI would benefit from discussions on the policy and preventative measures in place that might safeguard against fatal or severe TBI. This context will also facilitate more robust comparisons across jurisdictions where protective measures may differ.

Strengths and limitations

The purposefully broad search strategy and two-stage, systematic screening process was a considerable strength of this review, maximising the relevant literature captured. Furthermore, this review is the first, to our knowledge, to perform meta-analyses of the burden and risk of wrTBI and to provide a narrative synthesis of outcomes from studies that examined the burden of and risk factors for wrTBI, the lack of which was a noted limitation in the 2015 review.[8]

The decision to exclude non-English language articles is a major limitation of this study but was made to ensure consistency with the 2015 review.[8] To determine the impact of excluding non-English abstracts, we ran a comparison search without language restrictions. This search showed approximately 1% of abstracts were missed by excluding non-English language articles published between 2014 and 2020; future reviews may wish to expand on both reviews by looking at non-English articles addressing wrTBI. Additionally, any primary research presented in grey literature was not captured in our search strategy. It is possible the high representation of American and Canadian studies in the sample is due to wrTBI reporting in other countries occurring predominantly in grey literature or publications in languages other than English. This should be explored in further reviews.

This review used the inclusion/exclusion criteria described by Chang *et al* in 2015.[8] Based on those criteria, articles focusing on outcomes without mention of wrTBI risk factors or burden were excluded. Therefore, the data presented in this review discussing outcomes following wrTBI are not a comprehensive picture of the literature on outcomes. Indeed, we are aware of several studies not included in this review that focus on wrTBI

outcomes.[61–63] The wrTBI literature would benefit from a review focusing more specifically on outcomes following wrTBI.

The articles included in this review were highly heterogeneous, limiting the possible analyses and necessitating caution with the interpretation of results. Due to the heterogeneity in the method of reporting ages, mean age for study populations need to be calculated or estimated in many cases, which may impact the robustness of analyses.

CONCLUSIONS

This review summarises the literature on wrTBI published since 2013, providing much needed updates to our knowledge in this area. Comprehensive synthesis of the knowledge in this field and sex and gender-based analyses are needed to inform policy decisions surrounding workplace safety, provide recommendations for injury prevention, and to guide frameworks for supports post injury. Though more work must be done, this review is a step towards that goal. To that end, this review elucidates current gaps in our understanding of wrTBI, providing guidance on the research still needed in this field.

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Contributors DT and AC conceptualised the study as an update to a previous review conceptualised by AC and colleagues (Chang et al. 2015). DT updated the search strategy and conducted the search. DT and VC screened titles/abstracts and full-text articles for inclusion. DT extracted data from included articles and conducted quality appraisals of included studies; extracted data and quality appraisals were peer reviewed by VC. DT conducted meta-analyses and drafted the manuscript. VC and AC critically reviewed the manuscript, and all authors read and approved the final manuscript.

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Supplemental File 1: Search Strategies

MEDLINE

1. exp Work/
2. exp Occupational Injuries/ or exp Occupational Health/ or exp Accidents, Occupational/ or exp Occupational Diseases/
3. (worker* or workplace* or "work place*" or work-related or "work related" or occupation* or job* or industr*).mp.
4. (work* adj3 (injur* or accident* or incident* or trauma* or wound* or fatal* or death* or compensat*)).mp.
5. 1 or 2 or 3 or 4 [****Combined Work-related terms****]
6. exp Craniocerebral Trauma/
7. ((head* or brain* or cerebr* or crani* or hemispher* or intercrani* or inter-crani* or intracrani* or intra-crani* or skull*) adj3 (injur* or trauma* or wound* or contusion* or laceration* or damag* or fractur* or haematoma* or hematoma* or haemorrhag* or hemorrhag* or bleed*)).mp.
8. (tbi* or mtbi*).mp.
9. concuss*.mp.
10. "axonal injur*".mp.
11. 6 or 7 or 8 or 9 or 10 [****Combined TBI-related terms****]
12. exp Epidemiology/
13. exp risk/
14. exp Epidemiologic Factors/
15. exp epidemiologic methods/
16. (epidemiolog* or incidence or prevalence or mortality or rate* or burden* or risk* or factor* or etiolog* or aetiolog* or caus*).mp.
17. 12 or 13 or 14 or 15 or 16 [****Combined Epi terms****]
18. 5 and 11 and 17 [****epi of wr-TBI****]
19. limit 18 to (english language and yr="2014 - 2020")

EMBASE

1. exp Work/
2. exp occupational health/ or exp occupational accident/ or exp occupational disease/
3. (worker* or workplace* or "work place*" or "work related" or work-related or occupation* or job* or industr*).mp.
4. (work* adj3 (injur* or accident* or incident* or trauma* or wound* or fatal* or death* or compensat*)).mp.
5. 1 or 2 or 3 or 4 [****Combined Work-related terms****]
6. exp head injury/
7. ((head* or brain* or cerebr* or crani* or hemispher* or intercrani* or inter-crani* or intracrani* or intra-crani* or skull*) adj3 (injur* or trauma* or wound* or contusion* or laceration* or damag* or fractur* or haematoma* or hematoma* or haemorrhag* or hemorrhag* or bleed*)).mp.
8. (tbi* or mtbi*).mp.
9. concuss*.mp.
10. "axonal injur*".mp.
11. 6 or 7 or 8 or 9 or 10 [****Combined TBI-related terms****]
12. exp epidemiology/
13. exp risk/
14. exp epidemiological data/
15. (epidemiolog* or incidence or prevalence or mortality or rate* or burden* or risk* or factor* or etiolog* or aetiolog* or caus*).mp.
16. 12 or 13 or 14 or 15
17. 5 and 11 and 16
18. limit 17 to (english language and yr="2014 - 2020")
19. limit 18 to (conference abstract or conference proceeding or "conference review")
20. 18 not 19
21. limit 20 to embase

PsycINFO

1. exp working conditions/ or exp industrial accidents/ or exp occupational health/ or exp work related illnesses/
2. (worker* or workplace* or "work place*" or work-related or "work related" or occupation* or job* or industr*).mp.
3. (work* adj3 (injur* or accident* or incident* or trauma* or wound* or fatal* or death* or compensat*)).mp.
4. 1 or 2 or 3
5. exp traumatic brain injury/ or exp brain damage/ or exp head injuries/

6. ((head* or brain* or cerebr* or crani* or hemispher* or intercrani* or inter-crani* or intracrani* or intra-crani* or skull*) adj3 (injur* or trauma* or wound* or contusion* or laceration* or damag* or fractur* or haematoma* or hematoma* or haemorrhag* or hemorrhag* or bleed*)).mp.
7. (tbi* or mtbi*).mp.
8. concuss*.mp.
9. "axonal injur*".mp.
10. 5 or 6 or 7 or 8 or 9
11. exp epidemiology/
12. exp causality/ or exp etiology/ or exp risk factors/
13. (epidemiolog* or incidence or prevalence or mortality or rate* or burden* or risk* or factor* or etiolog* or aetiolog* or caus*).mp.
14. 11 or 12 or 13
15. 4 and 10 and 14
16. limit 15 to (english language and yr="2014 - 2020")

CINAL

S1. (MH "Work")
S2. (MH "Occupational Diseases+") OR (MH "Occupational-Related Injuries")
S3. (MH "Accidents, Occupational+")
S4. (AB (work* or occupation* or job* or industr*) OR TI (work* or occupation* or job* or industr*))
S5. S1 OR S2 OR S3 OR S4
S6. (MH "Head Injuries+")
S7. TX (head* or brain* or cerebr* or crani* or hemispher* or intercrani* or inter-crani* or intracrani* or intra-crani* or skull*) n3 (injur* or trauma* or wound* or contusion* or laceration* or damag* or fractur* or haematoma* or hematoma* or haemorrhag* or hemorrhag* or bleed*)
S8. TX tbi* or mtbi*
S9. TX concuss*
S10. TX "axonal injur*"
S11. S6 OR S7 OR S8 OR S9 OR S10
S12. (MH "Epidemiology+") OR (MH "Risk Factors+")
S13. (MH "Risk for Injury (NANDA)+")
S14. (MH "Epidemiological Research+")
S15. TX (epidemiolog* or incidence or prevalence or mortality or rate* or burden* or risk* or factor* or etiolog* or aetiolog* or caus*)
S16. S12 OR S13 OR S14 OR S15
S17. S5 AND S11 AND S16 (Limiters - Published Date: 20140101-20200131; English Language

Summary of Quality Assessment Scores

	Objectives/Study Design	***Average***	***SD***
1	Was the research question/study objective sufficiently described?	1.85	0.36
2	Study design appropriate to address the study question/objective?	1.87	0.34
	Study Population/Participant Selection		
3	Data source and method of participant selection sufficiently described?	1.87	0.34
4	Study sample is an unbiased representation of the target population?	1.48	0.54
5	Coverage of the population in the data source reported and adequate?	1.07	0.54
6	Inclusion/exclusion criteria sufficiently described?	1.78	0.46
	Case Definitions		
7	"Work-related" clearly defined?	1.35	0.83
8a	"TBI" clearly defined?	0.83	0.86
8b	Severity of TBI measured?	0.61	0.86
8c	Definition of fatal cases clearly described?	1.25	0.79
	Measurements		
9	Injury rates reported and denominator clearly defined?	1.85	0.36
10	Variables defined and robust to measurement/ misclassification bias?	0.87	0.58
11	Missing data reported for main variables analyzed?	1.67	0.67
	Analysis		
12	Analysis sufficiently described/justified and appropriate?	1.81	0.39
	Results/Discussion		
13	Results reported and discussed in sufficient detail and interpreted appropriately/accurately?	1.96	0.19
14	Were study limitations stated?	1.57	0.74
15	Do the results support the conclusions?	1.96	0.19
	Overall		
	Total Score:	23.39	4.56
	Maximum Score:	30.59	2.32
	Percentage:	76%	13%

Supplemental Table 1: Studies specifically exploring wrTBI (n=18)

(Sample sizes are for entire study population unless otherwise specified)

Author & Year, Location [Period]	**Design [sample size]**	**Study population**	**Data source**	**Case definition: TBI**	**Case definition: work**	**% wrTBI, Severity**	**Sex**	**Age (mean)**	**Industry/ Occupation** **collapsed small groups*	**Mechanism of Injury**	**Return to Work Outcomes**	**Quality Asses.**
Amodio et al. 2017 Toronto, Canada [2003]	Retrospective medical record review [N=98]	WSIB referrals to neurology rehabilitation centre	Chart review of medical records	Diagnosed with TBI	Insured workers (WSIB)	100%	74.5% male	41.46 ± 11.09 Male: 41.52 ± 11.39 Female: 41.28 ± 10.36	Managers/ professionals/ technicians & associate professionals: 21.4% (12.3% of males, 52% of females) Skilled agricultural, forestry & fishery workers/ plant machine operators and assemblers: 37.8% (45.2% of males, female percentage not reported) Remainder not reported due to small cell size.	-	-	23/28 (82%)
Chang et al. 2014 Victoria, Australia [2004-2011]	Cross-sectional study [N=4,186]	Insured workers in Victoria	Victorian WorkCover Authority; Australian Bureau of Statistics	TOOCS: "(1) 'intracranial injuries' and bodily location 'cranium' or 'brain'; or (2) 'fractures' and bodily location 'head' (not tooth/ teeth), 'head and neck', or 'head and other'"	Compensation Research Database WC claims	100%, 1.8% of which were fatal	63.6% male	38.9 ± 13.2 Male: 38.5 ± 13.2 Female: 39.5 ± 13.2	Manufacturing: 13.2% (17.1% of males, 6.4% of females) Construction: 8.3% (12.7% of males, 0.7% of females) Wholesale trade: 5.7% (6.9% of males, 3.6% of females) Retail trade: 5.9% (5.3% of males, 7.0% of females) Transport, postal & warehousing: 9.4% (13.1% of males, 3.0% of females) Public admin. & safety: 8.1% (9.8% of males, 5.3% of females) Education & training: 13.9% (5.7% of males, 28.1% of females) Healthcare & social assistance: 9.3% (2.9% of males, 20.3% of females) Arts & recreation services: 5.4% (4.9% of males, 6.4% of females) *Other (< 5% each): 20.9% (21.8% of males, 18.8% of females)	Struck by/against: 53.1% (51.4% of males, 56.1% of females) Falls/trips/slips: 23.7% (21.0% of males, 28.4% of females) Assaults & violence: 12.5% (14.8% of males, 8.5% of females) MVC: 7.2% (9.1% of males, 3.9% of females) Other/unspecified: 3.5% (3.7% of males, 3.1% of females)	74.5% lost time from work (75.2% of males, 73.3% of females), 24.2% lost more than 10 days (27.7% of males, 18.2% of females)	30/34 (88%)
Colangelo et al. 2016 Edmonton, Canada [2007-2011]	Retrospective cohort study [N=218]	WC Board of Alberta rehabilitation facility	Workers' Compensation Board	Brain injury diagnosis referred for neuropsychologist assessment Severity: Loss of consciousness	WC Board rehabilitation facility patients receiving time-loss benefits	100%, 60.1% had LOC at time of injury	86.2% male	42.8 ± 12.6	-	MVC: 29.8% Blunt force head trauma: 29.4% Slip & fall: 13.8% Fall: 18.3% Assault: 4.6% Explosion: 3.2% Other: 0.9%	59.2% in brain injury program (110.0 ± 105.7 days); 17.1% not fit to work post-injury	23/28 (82%)
Colantonio et al. 2016 Ontario, Canada [2010]	Descriptive retrospective cohort study [N=50]	Participants discharged from a neurology services program	Medical records, self-report surveys	"Mild to moderate TBI"	WSIB reported injuries	100%, classified as mild-to-moderate TBI	Gender reported as 64% male	44.5 ± 11.9	-	-	50% able to return to work	26/28 (93%)

de Miranda et al. 2014 Brazil [2009]	Epidemiological cross-sectional study [N=2,006]	Employees who are hired according to Consolidation of Labor Laws	Ministry of Work and Employment datasets	ICD-10 (S06 to S06.9)	"employees receiving social security benefit due to work typical accidents"	100%	88% male in subset of 1074 (Table 2)	Occupation subgroups ranged from 32.7 ± 11.5 to 38.9 ± 14.6	Transport, Storage & Mail: 12.27% Water, Sewage & Waste Management: 1.63% Construction: 9.99% Commerce, Automobile & Motorcycle Repair: 26.11% Public Administration, Defense & Social Security: 2.62% Others: 46.59% Not located: 0.79%	-	-	27/32 (84%)
Guerriero et al. 2016 Victoria, Australia [2004-2012]	Retrospective cohort study [N=1,786]	Workers insured by WorkSafe Victoria	Compensation Research Database	Australian Standard Type of Occurrence Classification System: injury coded as "intracranial injury"	"A claim may be lodged once a worker is off work for more than ten days or medical expenses have surpassed a certain threshold amount"	100%	63.1% male	40.6 ± 13.5	Manufacturing: 11.1% (14.5% of men, 5.5% of women) Electricity, gas, water & waste services: 10.9% (not stratified) Construction: 9.8% (not stratified) Wholesale trade: 6.1% (7.0% of men, 4.4% of women) Retail trade: 6.4% (5.7% of men, 7.7% of women) Transport, postal & warehousing: 10.0% (14.4% of men, 2.6% of women) Public administration & safety: 7.5% (8.4% of men, 5.8% of women) Education and training: 12.4% (5.4% of men, 24.3% of women) Health care & social assistance: 9.2% (2.9% of men, 19.8% of women) Arts & recreation services: 6.6% (5.6% of men, 8.4% of women) *Other (< 5% each): 20% (not all stratified) *Study reported data stratified by sex, characterized as men and women*	-	-	30/32 (94%)
Kica and Rosenman 2014 Michigan, United States [2010-2012]	Descriptive secondary analysis of surveillance data [N=318]	Michigan's 134 hospitals	Hospital records, Michigan's Workers' Compensation Agency and death certificates	ICD-9 codes for skull fracture (800.0-.9, 801.0-.9, 802.0-.9, 803.0-.9, 804.0-.9); ICD-10 codes for skull fracture Severity: Loss of consciousness (y/n)	Workers' Compensation Agency records of wage replacement	100%, 4.72% of which were fatal (n=15); 44.97% had LOC, 22.44% missing LOC data	Gender reported as 84.6% male	Average age: 43, Range: 17-75	Construction: 13.3% Primary metal manufacturing: 11.5% Public administration: 8.2% Transportation & warehousing: 7.9% Health care & social assistance: 6.1% Wholesale trade: 6.1% Retail trade: 5.7% Administration & support & waste management and remediation services: 5.4% Educational services: 5.4% Agriculture, forestry, fishing & hunting: 5.0% *Other (<5% each): 24.0% *Only reported for a subset of 279 cases*	Fall: 48.2% Struck by: 34.3% MVA: 7.5% Assault: 5.0% Medical condition: 5.0% *Only reported for a subset of 280 cases*	-	30/34 (88%)

Konda et al. 2015 United States [1998-2007]	Descriptive secondary analysis of surveillance data [N=586,600 (weighted)]	67 US hospitals with 24 hour EDs	National Electronic Injury Surveillance System (NEISS)	NEISS-Work: 'concussion' (code 52), 'internal organ injury' (code 62) or 'fracture' (code 57) & 'head' (body part code 75) Severity: non-fatal injuries	National Electronic Injury Surveillance System - Occupational supplement	100%	68% male (weighted)	15–24: 21% 25–34: 26% 35–44: 23% 45–54: 18% 55+: 12% (weighted)	Agriculture, forestry, fishing & hunting: 5% Transportation & warehousing: 8% Construction: 12% Accommodation & food services: 8% Public administration: 5% Retail trade: 11% Healthcare & social assistance: 11% Manufacturing: 8% Educational services: 5% Professional & business services: %5 Unknown: 9% *Other (<5% each): 12% (weighted)	Contact with objects and equipment: 43% Falls: 36% All others (including assaults/violence, transportation, etc.): 21% (weighted)	-	22/32 (69%)
Konda et al. 2016 United States [2003-2010]	Descriptive secondary analysis of surveillance data [N=2,210]	Construction workers in the US	Bureau of Labor Statistics Census of Fatal Occupational Injuries	OIICS: TBIs: 060, 061, 062, 068, and 069. TBIs due to all firearm-related incidents Severity: Fatal	Bureau of Labor Statistics Census of Fatal Occupational Injuries	100%, all fatal	99% male	16-19: 3% 20-24: 9% 25-34: 21% 35-44: 23% 45-54: 24% 55-64: 13% 65+: 6%	Construction	Contact with objects and equipment: 16% Falls: 57% Transportation incidents: 21% All others (including assaults/violence, fires and explosions, etc.): 5%	-	27/32 (84%)
Kontos et al. 2017 Ontario, Canada [Not Reported] **excluded from meta analysis*	Qualitative thematic analysis [N=32]	Neurology clinic funded by the WSIB	In-depth semi-structured qualitative interviews	Diagnosis of wrTBI: "sustained a head injury and/or had a formal diagnosis of a work-related traumatic brain injury"	"workers who have been injured at work" referred to clinic	100%	47% male	35-44: 23.0% 45-54: 34.6% 55-64: 42.3% *Reported for a subset of 26 participants (6 participants without age information)*	Education: 17.9% Business & Administration, Sales & Service: 21.4% Healthcare: 17.9% Manufacturing, Primary Industry: 25.0% Security, Trades & Transportation: 17.9% *Reported for a subset of 28 participants (4 participants without industry/sector information)*	Assault: 14.3% Fall/slip: 32.1% MVC: 14.3% Struck by/against object: 39.3% *Reported for a subset of 28 participants (4 participants without mechanism of injury information)*		20/28 (71%)
Kristman et al. 2014 Ontario, Canada [1997-1998]	Retrospective cohort study [N=728]	Worker's compensation system	Administrative data from the WSIB, Ontario Health Insurance Plan	WSIB lost-claims data: brain part of body code (1100) and the concussion nature of injury code (6200). Severity: mild (method not specified)	Workplace Safety and Insurance Board lost-time claims	100%, all mTBI	65.8% male *Reported as sex (male/female), discussed as man/woman*	18-24: 13.6% 25-34: 28.2% 35-44: 24.5% 45-54: 21.0% 55≤: 12.6%	-	-	-	30/32 (94%)
§ Mollayeva et al. 2016 Ontario, Canada [2004]	Cross-sectional study [N=66]	WSIB insured workers with lost time claims	Workplace Safety and Insurance Board	Diagnosis of 'concussion', 'closed head injury', 'contusion', or 'head injury with sequalae consistent with brain injury'	WSIB lost-time claims due to TBI caused by physical assaults	100%, 76% classified as [mTBI] or concussion	40.9% male	37 (median) 20-64 range	Health care/social service aids: 40.9% Law enforcement/public administration sector: 33.3% Education: 15.2% Transportation: 7.6% Other: 3.0% *Calculated from number of claims reported per sector*	Assault: 100%	22.7% (n=15) returned to work by the end of 2004 (ten females and five males)	23/32 (72%)

Paci et al. 2017 Quebec, Canada [2000-2014]	Cross-sectional study [N=285]	Montreal General Hospital	Traumatic Brain Injury Database and the Trauma Registry Database	World Health Organization Task Force: mild TBI diagnosis Severity: GCS	"Occurred at the workplace… or performing work duties" as identified in the Trauma Registry Database	100%; 8.1% were fatal. GCS: 76.8% 13-15, 7.7% 9-12, 15.4% 3-8	94.7% male	43.62 16-76 range	Construction/trades: 42.5% Vehicle driver/operator: 14.2% Retail/sales: 11.5% Manufacturing: 7.1% City worker (including maintenance, police, & firefighters): 6.2% Mechanic: 4.0% *Others (<5% each): 14.6% *Reported for a subset of 226*	Falls: 64.1% MVC: 17.8% Falling object/ projectile: 15.8% Electrocution: 1.2% Assault: 1.2% *Reported for a subset of 259*	-	28/34 (82%)
Shafi et al. 2019 Victoria, Australia [2004-2012]	Population-based, retrospective cohort study [N=3,129]	WorkSafe Victoria claimants	Compensation Research Database	TOOCS: 'affliction nature group' was coded as 'intracranial injuries' Severity: post-injury hospitalization	Workers' compensation claims	100%, all mTBI	58.0% male	15-24: 15.0% 25-34: 25.0% 35-44: 21.5% 45-54: 23.2% 55<: 15.2%	Healthcare & social assistance: 11.00% (3.14% of males, 21.75% of females) Education & training: 16.0% (7.28% of males, 27.98% of females) Public administration & safety: 6.5% (7.66% of males, 4.87% of females) Others: 66.7% (81.92% of males, 45.40% of females) *Sex stratified reporting calculated from table 2*	Hit by moving objects: 32.1% Falls, trips & slips: 26.1% Hitting objects with body: 24.9% Assault: 8.8% MVA & other: 8.1%	18.40% took time off work (within a 3-month time frame) (21.00% of males, 14.75% of females)	30/32 (94%)
Sharma et al. 2019 Ontario, Canada [2014-2016]	Prospective cohort study [N=102]	neurology services clinic	Self-report questionnaires	"head and/or brain injury"	WSIB assessment referral	100%	53.9% male	54% aged 45–64	Education: 21.6% Healthcare: 11.4% Construction & landscaping: 11.4% Other: 55.6%	Struck by/against an object or person: 55% [14% were assaults] Falls: 30.3% MVC: 11% Other: 3.7%	63.3% returned to work, 42.1% on modified duties	21/28 (75%)
Slavova and Bunn 2015 Kentucky, United States [2011]	Descriptive secondary analysis of surveillance data [N=596]	Kentucky EDs or hospital facilities	ED visits, hospital discharge data, and workers' compensation first report of injury data)	ICD-9-CM diagnosis code of 850 (ED and hospital); WC data: (i) nature of injury "concussion" (code 07) or (ii) a case narrative text search for "concussion."	Workers' compensation designated payer	100%	Gender reported as 63.6% male	Median: 39 16-24: 18.3% 25-34: 22.1% 35-44: 23.3% 45-54: 19.6% 55-64: 13.3% 65≤: 3.4%	Only available for 339 cases linked with WC data, % of that total: Services industry (n=104; 30.7%) Transportation/public utilities (n= 50; 14.7%) Whole sale and retail (n= 50; 14.7%) Manufacturing (n= 32; 9.4%)	MVC: 10.7% Fall: 36.2% Struck by/against: 43.8% Other: 9.2% *Reported for a subset of 552, 44 cases missing information*	-	26/32 (81%)
§ Terry et al. 2018 Vancouver, Canada [2015-2017]	Case-control study [wrTBI subset N=46]	Four outpatient rehabilitation clinics for TBI	Standardized questionnaires during initial assessment (2-26 weeks post injury) and follow up (21-47 weeks post injury)	World Health Organization Neurotrauma Task Force definition of mild TBI	Workers' compensation claims	45.10%	60.9% male	39.0 ± 11.8	Manual Labor: 28.3% Skilled craft or trade: 19.6% Transport: 2.2% Sales and service: 15.2% Management or professional: 8.7% Other: 26.1%	Struck by object: 43.5% MVC: 6.5% Fall: 30.4% Assault:10.9% Other: 8.7%	Initial Assessment: 2.2% full return to work, 8.7% had partial return, 87.0% on leave. Follow up (n=38): 44.7% full return to work, 18.4% partial return to work, 36.8% no return to work. *8 wrTBI participants lost to follow up*	27/28 (96%)

Xiong et al. 2016 Ontario, Canada [2003]	Retrospective medical record review [N=209]	Toronto Rehabilitation Institute	Medical records	TBI diagnosis Severity: mild, ≤ 30 min LOC, GCS score of 13-15, and PTA ≤ 24 h	WSIB referral to the neurology service at a hospital	100%, all mild	Sex reported as 71.3% men	40.2 ± 11.1	Managers/ professionals/ technicians or associate professionals: 12.9% (5.4% of men, 31.7% of women) Clerical support workers/service and sales workers: 13.9% (7.4% of men, 30% of women) Skilled agricultural, forestry and fishery workers/ plant and machine operators and assemblers: 35.9% (46.3% of men, 10% of women) Elementary occupations (laborers): 26.8% (32.2% of men, 13.3% of women) Missing: 10.5% *Study reported data stratified by sex, characterized as men and women*	-	22% working, full- or part-time (18.1% of men, 31.7% of women), 78% not working (disability benefit) (81.2% of men, 68.3% of women)	25/28 (89%)

Acronyms: AIS - Abbreviated Injury Score, ED - Emergency Department, GCS - Glasgow Coma Scale, ICD - International Classification of Diseases (versions 9 or 10), ISS - Injury Severity Scale, LOC - loss of consciousness, mTBI - mild traumatic brain injury, MVA/C - motor vehicle accident/collision, OIICS - Occupational Injury and Illness Classification System, PTA - posttraumatic amnesia, TOOCS - Type of Occurrence Classification System, WC - Workers' Compensation, WSIB - Workplace Safety and Insurance Board (Ontario)

§ indicates studies in multiple summary tables

Supplemental Table 2: Studies exploring work-related injuries with a wrTBI subset (n=33)

(Sample sizes are for entire study population unless otherwise specified)

Author & Year, Location [Period]	**Design [sample size]** (work-related injury)	**Study Population**	**Data source**	**Case definition: TBI**	**Case definition: work**	**% TBI** [Severity]	**Quality Assess.**
Al-Abdallat et al. 2015 Amman, Jordan [2008-2012]	Descriptive cross-sectional study [N=88]	Fatal occupational accidents in three Jordanian hospitals	Hospital records of deaths	"Head Injury" Severity: Fatal	"Occupational deaths resulting from accidents"	21.6% [all fatal]	17/28 (61%)
Amiri et al. 2016 Iran [2007-2011]	Descriptive, retrospective cohort study [N=21,864]	Work-related injuries in Insured construction workers	Iranian Social Security Organization	"Body part affected: Cranium and brain"	"Insured workers"	3.65% **Calculated from table 3 based on sample size and 799 crainium and brain injuries reported*	23/34 (68%)
Baragaba et al. 2016 Unites States [2000-2011]	Longitudinal cohort study [N=1,638,856 (weighted)]	Individuals reporting work-related injury on national survey	Medical Expenditure Panel Survey	"Type of injury: Head"	Self-reported: whether or not the injury occurred at work	9.4% (weighted)	20/32 (63%)
Barnetson and Foster 2015 Canada [2012]	Descriptive secondary analysis of claims data [N=246,342]	Media reports vs Worker's compensation claims	Association of Workers' Compensation Boards of Canada	"Intracranial Injury"	Workers' compensation time-loss injuries and fatalities claims data	2.1% (as reported by worker's compensation claims)	23/34 (68%)
Bunn et al. 2014 Kentucky, United States [2008-2012]	Descriptive secondary analysis of surveillance data [N=1,827]	Kentucky trauma centres	Kentucky Trauma Registry database	GCS: "Coma/severe brain injury"	Primary payer: Worker's compensation	7%	24/28 (86%)
Case et al. 2018 Alaska, United States [2000-2003]	Descriptive secondary analysis of surveillance data [N=117]	Alaska's aviation industry	Alaska Trauma Registry	ICD-9-CM Severity: non-fatal injuries	"worker in the aviation industry" as recognized in the Alaskan Trauma Registry	29% (n=8) of crash related injuries (n=28) Not reported for non-crash injuries	27/32 (84%)
Cryer et al. 2014 New Zealand [2002-2004]	Descriptive secondary analysis of claims data [N=1,104]	Accident Compensation Corporate compensated claims data	Hospital discharge records and workers' compensation	ICD-10 "traumatic brain injury with or without skull fracture" Severity: ICD based ISS	Primary payer: Accident Compensation Corporation of New Zealand	24%	28/32 (88%)
da Silva and Pereira 2014 Bahia, Brazil [2005-2007]	Descriptive cross-sectional study [n=83, work typical accidents]	Private hospitals in the southwestern region of Bahia, Brazil	Unified Health System Hospital Information System	ICD-10 codes for intracranial injury, designated as "Traumatic Brain Injury"	"Work typical accidents"	3.6% **Reported as 3 cases, 4.9% of fall-related traumas*	23/34 (68%)
Dethleff et al. 2016 Germany [2011-2013]	Descriptive cross-sectional study [n=19, traumatic injuries]	Medical evacuations from offshore wind farm	Wind farm documents, Emergency protocols	"Cerebral concussion" Severity: GCS	Employed on the wind farm	10.53% **2 cerebral concussions out of 19 traumatic injuries*	16/28 (57%)

Fitch et al. 2015 Savar, Bangladesh [2014]	Retrospective cohort study [N=181]	Center of Rehabilitation of the Paralyzed	Survey	"Concussion, internal injury"	"Injured garment workers"	21.6%	17/28 (61%)
Green et al. 2019 Twin Cities, United States [2016-2017]	Retrospective cohort study [N=111]	Janitors who were members of the Service Employees International Union	Survey	"Concussion"	"Work-related injury was based on the National Center for Health Statistics and Bureau of Labor Statistics"	3.60%	20/28 (71%)
Gupta et al. 2017 Jhansi, India [2015-2016]	Cross-sectional study [N=309]	Railway wagon repair workshop urban area	Semi-structured questionnaire administered by an interviewer	"Crushing head injury"	Self-reported: Injuries occurring inside the working environment of the workshop	0.97%	17/28 (61%)
Hekimoglu et al. 2015 Van, Turkey [2010-2012]	Retrospective hospital document review [N=245]	Occupational accidents reported to 2 hospitals in Van both before and after an earthquake	Hospital documents	"Head trauma"	"Injuries due to occupational accidents"	Pre-earthquake period: 2.4% Post-earthquake period: 4.9%	16/30 (53%)
Herttua et al. 2019 Denmark [2004-2014]	Retrospective cohort study [N=1,401]	Merchant ships	Contacts from ships to Telemedical Assistance Service	ICD-10 diagnoses: injuries to the head (S00-S09)	Employed on merchant ships	13%	24/28 (86%)
Holloway-Beth et al. 2016 Illinois, United States [1980-2008]	Descriptive secondary analysis of claims data [N=18,892]	Law enforcement personnel injured on the job	Illinois Workers' Compensation Commission	"Body part affected: Head"	Workers' Compensation Commission claims, when disputes re: compensation are not resolved directly with employer	5.62% **Calculated from table 3*	26/32 (81%)
Kim et al. 2016 Korea [2010-2012]	Case-control study [N=1,298]	10 emergency departments	ED-based Occupational Injury Surveillance	ICD-10 codes: "Head injury (S06.0–S06.9); Intracranial injury (S06.1–S06.9)"	Emergency Department-based Occupational Injury Surveillance database reports of injuries from falls related to paid work	13.4% head injury, 6.9% intracranial injury [10.1% of intracranial injuries fatal]	26/30 (87%)
Maguire and O'Neill 2017 United States [2012-2015]	Retrospective cohort study [N=1,630]	Emergency medical services workers	Bureau of Labor Statistics	"Body part injured: Head"	Bureau of Labor Statistics	11.66% **Reported in text as 190 head injuries*	22/32 (69%)
Maxwell and Wozny 2015 United States [2005-2010]	Exploratory secondary analysis of surveillance data [N=800,791]	Work-related injuries in federal employees	Federal Employees' Compensation Act and FedScope	"Area of injury: Head, internal"	Federal Employees' Compensation Act workplace injury and illness claims	6.17%	26/32 (81%)
§ McIntosh et al. 2016 Australia [2000-2013]	Retrospective case series [n=53, work-related subset of study population]	Quad bike fatalities	National Coronial Information System	AIS: 'Specific injury pathology: Traumatic brain injury'	"Work activity"	20.80% [all fatal] **Reported in supplemental table A9*	22/32 (69%)

§ Mollayeva et al. 2016 Ontario, Canada [2004]	Cross-sectional study [Total work-related injuries N=74,332]	WSIB insured workers with lost time claims	Workplace Safety and Insurance Board	Diagnosis of 'concussion', 'closed head injury', 'contusion', or 'head injury with sequalae consistent with brain injury'	WSIB lost-time claims	1.35%	23/32 (72%)
Mroz et al. 2014 Maryland, United States [1998-2008]	Descriptive secondary analysis of claims data [N=232,072]	Workers insured by IWIF	Injured Workers' Insurance Fund (IWIF) claims database	"Injury type: head"	Workers' compensation claims	2.75% **Calculated from 6,386 reported head injuries*	25/32 (78%)
§ Nosaka et al. 2015 Okayama, Japan [2012-2014] **excluded from meta analysis*	Retrospective cohort study [n=3, work-related subset of study population]	Okayama University Hospital	Clinical records related to hospitalizations due to falls	AIS: H= head Severity: ISS	"Working settings: Occupational"	66.67%, [50% fatal] **Calculated from table 1 based on 2 reported fatalities*	27/30 (90%)
O'Connor et al 2017 Ireland [2011-2015]	Descriptive epidemiology study [N=944]	Horse race meetings	Race meeting injury report forms related to falls	"Concussion", "Structural brain injury"	Licensed professional jockeys	6.78% **Calculated from table 3 based on sample size and 64 concussions and structural brain injuries reported*	26/32 (81%)
Onder and Mutlu 2017 Soma, Turkey [2006-2011]	Retrospective cohort study [N=231]	Opencast coal mines of the Aegean Lignite Enterprise of Turkish Coal Enterprises	ELI lignite coal mine accident records	"Part of body: Head"	"All accidents at work in which the person is unfit for work for more than 3 full days"	16.45%	18/28 (64%)
Ozer et al. 2014 Zonguldak, Turkey [2005-2008]	Retrospective autopsy report review [N=42]	Coal mines	Autopsy reports	"Cerebral damage secondary to blunt head trauma" Severity: Fatal	Employed in Zonguldak coal mines	26.2% [all fatal]	19/32 (59%)
Rorat et al. 2015 Wroclaw, Poland [1991–2011]	Retrospective autopsy report review [N=120]	Farm-related fatalities	Medico-legal autopsy reports by the Department of Forensic Medicine	"Isolated lethal cranio-cerebral injuries"	"Activity related to (work on the farm) agriculture."	14.17% [all fatal] **Reported as 17 lethal cranio-cerebral injuries*	16/28 (57%)
Sears et al. 2014 Washington, United States [1998-2008]	Retrospective cohort study [N=4,700]	Insured workers in Washington state	Washington State Trauma Registry & worker's compensation claims	ICD-9-CM code of 800.0–801.9, 803.0–804.9, 850.0–854.1, 950.1–950.3, or 959.01. Severity: ISS	Workers' compensation claims	19.83% [1% fatal] **Reported as 932 TBI, 9 fatal*	33/34 (97%)

Swanberg et al. 2016 United States [2013-2014]	Cross-sectional study [n=97, participants reporting an injury in the past year]	Workers currently employed at a thoroughbred farm	Questionnaire	"Injury site: head"	Self-reported: "Thinking about your current job on the horse farm, in the past 12 months have you had a work-related injury?"	7.22% **Calculated based on sample size and 7 reported head injuries*	20/28 (71%)
Syron et al. 2018 Alaska, United States [2010-2015]	Cross-sectional study [N=304]	Commercial fishing industry vessels	Commercial Fishing Safety Research and Design Program surveillance data, Coast Guard reports	OIICS: "Nature of injury: intracranial injury"	Traumatic injuries among seafood processors that were reported to the US Coast Guard	5.26%	30/34 (88%)
Tsioras et al. 2014 Austria, [2000-2009]	Cross-sectional study [N=1,077]	ÖBf wood-cutting activities	ÖBf registries	"Type of injury: Concussion"	ÖBf employed fulltime forest workers	1.2%	13/30 (43%)
van Leeuwen and Harte 2017 Netherlands [2011]	Retrospective cohort study [N=1,294]	Dutch mental health professionals working in inpatient psychiatric facilities	Online questionnaire	"Concussion"	Working in inpatient psychiatric facilities	1.62% **Calculated from table 3 based on sample size and 21 reported concussions*	20/28 (71%)
Witt et al. 2018 Kentucky, United States [2005–2015]	Descriptive secondary analysis of claims data [N=4,377]	Kentucky Department of Workers' Claims	WC first reports of injury data	"Nature of injury: Concussion"	Workers' compensation claims	1%	25/32 (78%)
Yadav 2019 Dadra and Nagar Haveli, India [2017]	Capture-recapture epidemiological study [N=113]	Dadra and Nagar Haveli territory	Police First Information Reports, government health facility records	ICD-10 (otherwise unspecified) "Body part: Head"	"Accident in industrial unit"	7.08%	20/32 (63%)

Acronyms: AIS - Abbreviated Injury Score, ED - Emergency Department, GCS - Glasgow Coma Scale, ICD - International Classification of Diseases (versions 9 or 10), ISS - Injury Severity Scale, mTBI - mild traumatic brain injury, OIICS - Occupational Injury and Illness Classification System, TOOCS - Type of Occurrence Classification System, WC - Workers' Compensation, WSIB - Workplace Safety and Insurance Board (Ontario)

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Supplemental Table 3: Studies exploring traumatic brain injury with a wrTBI subset (n=9)

(Sample sizes are for entire study population unless otherwise specified)

Author & Year, Location [Period]	Design [sample size]	Study population	Data source	Case definition: TBI	Case definition: work	% wrTBI	Quality Asses.
Atci et al. 2015 Elazig, Turkey [2014-2014]	Retrospective medical record review [N=3,524]	TBI at Elazig Training and Research Hospital	Medical records (patients and hospital registration)	"All traumatic head injuries that resulted from any physical injury, falls and suicide attempt." Severity: GCS 14-15 mild, 9-13 moderate, 3-8 severe	"Occupational accidents"	10.73% **Reported as 18.4% of falls or 378 cases*	20/30 (67%)
Autret et al. 2015 Rennes, France [2008-2010]	Retrospective cohort study [TBI subset n=34]	Brain injuries at a rehabilitation centre	Medical charts, professional reintegration unit files, phone interviews	"Traumatic brain injury" Severity: GCS	"Work-related injury"	35.29% **Reported as 12/34 or 36.4%, the authors miscalculated the reported percentage*	18/28 (64%)
Kahan et al. 2018 New Zealand [2010-2011]	Longitudinal cohort study [N=205]	TBI in the Hamilton and Waikato regions	Brain Injury Incidence and Outcomes New Zealand In the Community (BIONIC) study	World Health Organization criteria for TBI diagnosis Severity: GCS; 13–15 score = mild and post-traumatic amnesia (<24 hours)	"place of injury: work place"	19.5%	23/28 (82%)
Mauritz et al. 2014 Austria [2009-2011]	Retrospective cohort study [N=81,112; Residents n=73,662; Visitors n=7,450]	Hospital admissions for TBI	Hospital admissions as presented by Statistik Austria	ICD-10 codes S06.0–S06.9	"Cause of injury: work-related"	2.57% **Reported as 91 (1.2%) visitors from table I and 1989 (2.7%) residents from table II*	29/34 (85%)
§ McIntosh et al. 2016 Australia [2000-2013]	Retrospective case series [TBI Subset, n=58]	Quad bike fatalities	National Coronial Information System	AIS: 'Specific injury pathology: Traumatic brain injury'	"work activity"	18.97%, all fatal **Reported as 11/58 in supplemental table A9*	22/32 (69%)
§ Nosaka et al. 2015 Okayama, Japan [2012-2014] **excluded from meta analysis*	Retrospective cohort study [TBI Subset, n=8]	Traumatic injuries at Okayama University Hospital	Clinical records related to hospitalizations due to falls	AIS: H= head Severity: Injury Severity Score	"Working settings: Occupational"	25%, 50% fatal **Calculated from table 1*	27/30 (90%)
Rogers et al. 2015 United States [2010]	Retrospective, cross-sectional, descriptive study [N=2,087]	TBI in Levels I and II trauma centres	National Sample Program	ICD-9-CM codes (800-801.9, 803.0-804.9, 850.0-854.1, 959.01) Severity: GCS score of 9 to 12 or a head AIS of 3 or 4	Primary payer: Worker's compensation (half of wrTBIs)	3% [2.4% weighted]	22/28 (79%)
Russell and Daniell 2018 United States [Not Reported]	Cross-sectional study [TBI subset n=199] **Conducted survey to determine TBI history in 246 individuals*	TBI among theatre workers	Survey	Positive response to the prompt: "Can you think of any instance in your life in which you have hit your head?"	Self-reported: working in theater environments	70.35% **Reported as n=140 wrTBI, percentage calculated based on 199 with history of head impact*	20/28 (71%)
§ Terry et al. 2018 Vancouver, Canada [2015-2017]	Case-control study [N=102]	Four outpatient rehabilitation clinics for TBI	Standardized semi structured interview questionnaires	World Health Organization Neurotrauma Task Force definition of mild TBI	Workers' compensation claims	45.1%	27/28 (96%)

Acronyms: AIS - Abbreviated Injury Score, GCS - Glasgow Coma Scale, ICD - International Classification of Diseases (versions 9 or 10), mTBI - mild traumatic brain injury

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Supplemental file 3: Forest plots of meta analyses

Figure 1 – Pooled proportion wrTBI population that is male

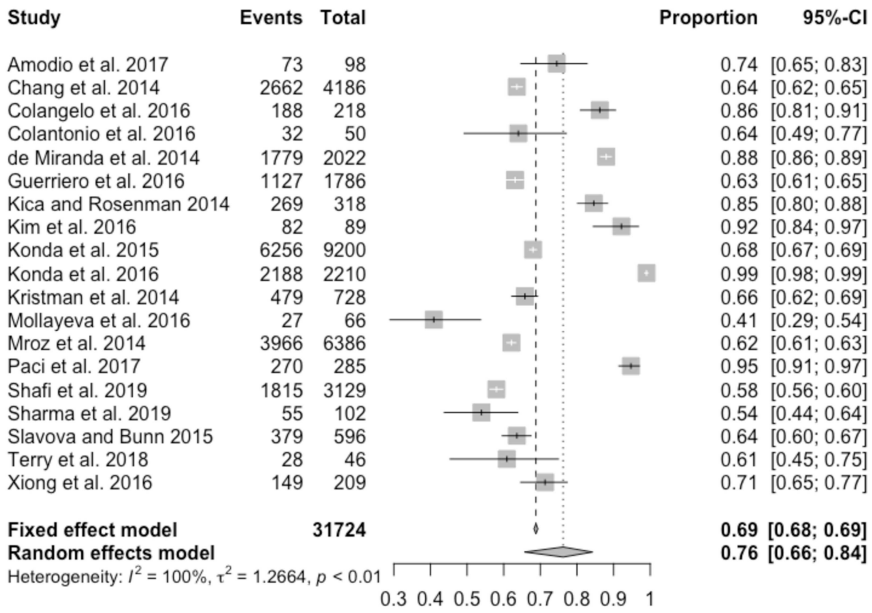

Figure 2 – Pooled mean age in wrTBI population

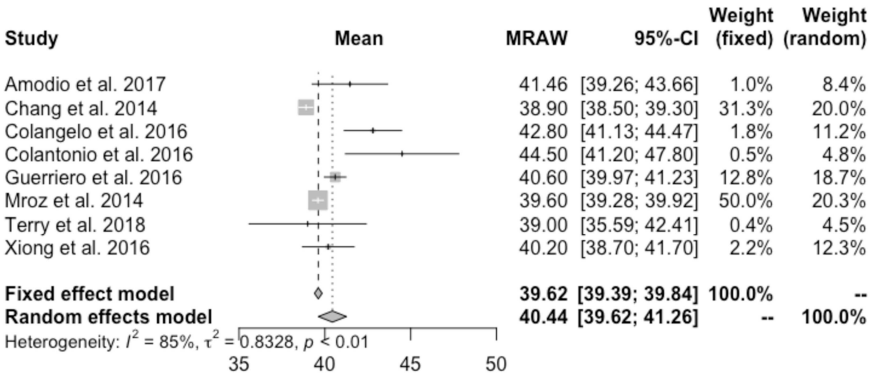

Figure 3 – Pooled proportion of wrTBI among work-related injuries

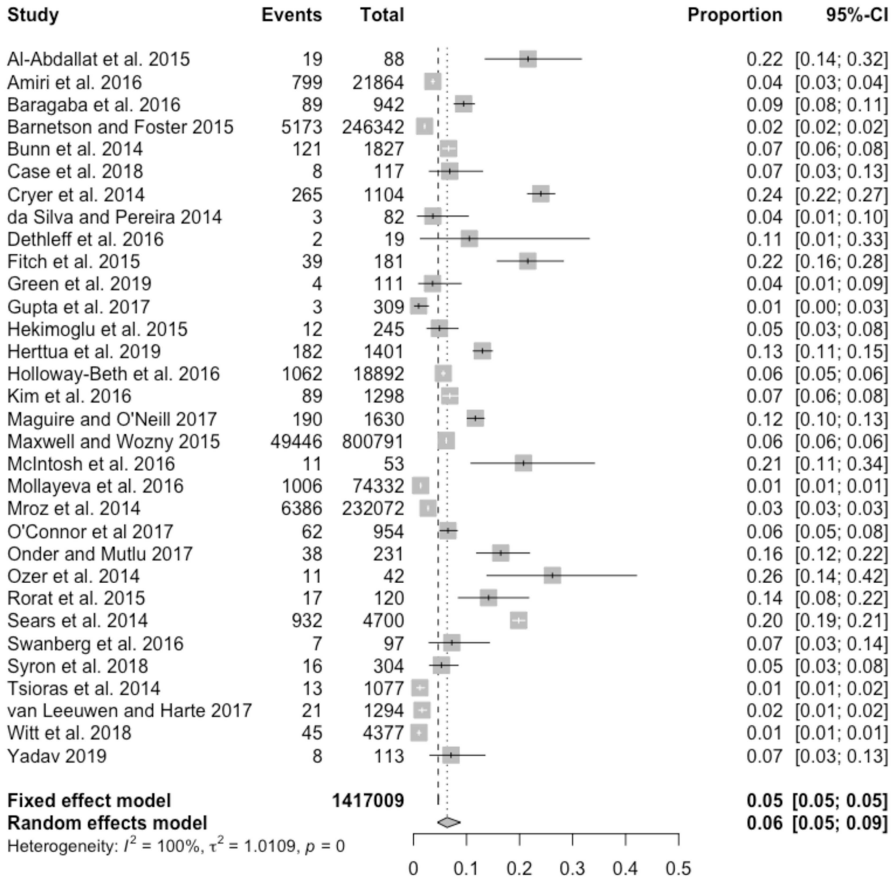

Figure 4 – Pooled proportion of wrTBI among TBI

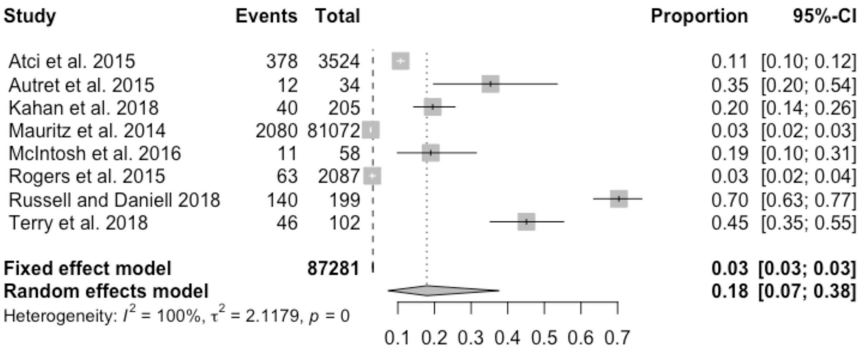

Figure 5 – Pooled proportion of wrTBI resulting in death