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Cause of Death After Traumatic Brain Injury: A Population-Based Health Record Review Analysis Referenced for Nonhead Trauma

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Abstract

Introduction: Traumatic brain injury (TBI) is a leading cause of disability and is associated with decreased survival. Although it is generally accepted that TBI increases risk of death in acute and postacute periods after injury, causes of premature death after TBI in the long term are less clear.

Methods: A cohort sample of Olmsted County, Minnesota, residents with confirmed TBI from January 1987 through December 1999 was identified. Each case was assigned an age- and sex-matched non-TBI referent case, called *regular referent*. Confirmed TBI cases with simultaneous nonhead injuries were identified, labeled *special cases*. These were assigned 2 age- and sex-matched *special referents* with nonhead injuries of similar severity. Underlying causes of death in each case were categorized using death certificates, *International Classification of Diseases*, *Ninth Revision*, *International Statistical Classification of Diseases*, *Tenth Revision*, and manual health record review. Comparisons were made over the study period and among 6-month survivors.

Results: Case–regular referent pairs (n=1,257) were identified over the study period, and 221 were special cases. In total, 237 deaths occurred among these pairs. A statistically significant

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Conflict of Interest Statement
The authors have no conflicts of interest to declare.

difference was observed between total number of deaths among all cases (n=139, 11%) and regular referents (n=98, 8%) (*P*=.006) over the entire period. This outcome was not true for special cases (32/221, 14%) and special referents (61/441, 14%) (*P*=.81). A greater proportion of deaths by external cause than all other causes was observed in all cases (52/139, 37%) vs regular referents (3/98, 3%) and in special cases (13/32, 41%) vs special referents (5/61, 8%) (*P*<.001 for both). Among all case-referent pairs surviving 6 months, no difference was found between total number of deaths (*P*=.82). The underlying cause of death between these 2 groups was significantly different for external causes only (*P*<.01). For special cases surviving 6 months vs special referents, no difference was observed in total number of deaths (*P*=.24) or underlying causes of death (*P*=1.00) between groups.

Discussion/Conclusion: This population-based case-matched referent study showed that increased risk of death after TBI existed only during the first 6 months after injury, and the difference was due to external causes.

Keywords

cause of death; life expectancy; long-term survival; mortality; traumatic brain injury

Introduction

Traumatic brain injury (TBI) is a leading cause of death and disability [1]. It is accepted that moderate to severe TBI increases risk of death acutely after injury [2–6]. Yet, an association between TBI and premature cause of death in the long term is not well understood. Investigators have reported specific causes of death after TBI in the long term. However, TBI cases were most commonly identified through use of hospital-based *International Classification of Diseases* (*ICD*) coding [7–13], and death rates were compared with the general population through use of standardized mortality ratios (SMRs) [9–12, 14–21]. These methods have well-recognized limitations, including underestimating TBI cases and not controlling for other traumatic injuries associated with the event that can affect mortality rate [18–23].

Understanding the relationships between TBI, death, and the underlying cause of death in the acute, postacute, and chronic phases after injury is essential for the development of preventive and clinical surveillance strategies to reduce TBI-associated death. The goals of the present analysis had 3 tiers. The study aimed to identify underlying causes of death in a population-based sample of patients with health-record–confirmed TBI and compare the underlying cause of death in the cases with their corresponding population-based referents. It studied the effect of nonhead trauma on causes of death by matching TBI patients experiencing nonhead trauma with referents experiencing nonhead trauma of the same severity. Further, the study aimed to determine whether cause of death differs between the postacute and chronic phases after injury; these categories were compared between study groups over the entire study period and among 6-month survivors.

Methods

This study was approved by Mayo Clinic and Olmsted Medical Center institutional review boards.

Rochester, Minnesota, county seat of Olmsted County (2018 census population, 156,277), is home to Mayo Clinic, a large private medical center. Comprehensive data about each patient at Mayo Clinic have been linked to a unique identification number since 1907. This linkage was developed into the Rochester Epidemiology Project (REP) in 1966 [24]. This health records linkage system is widely recognized as a powerful tool for population-based epidemiologic studies [25, 26], allowing for unique assessment of the natural history of TBI [27–31].

REP has data from more than 500,000 persons and includes all demographic information, surgical procedure codes, drug prescription, and diagnostic codes assigned at every medical contact for each person in this geographically defined region [32]. These data can be screened electronically with a coding system developed at Mayo Clinic for clinical purposes specifically, using 3 different systems and a modification of *ICD*, *Eighth Revision*, and *ICD, Ninth Revision* (*ICD-9*) [33], shown to have high sensitivity and specificity [25] (eAppendix).

TBI was defined as a "traumatically induced injury that contributed to the physiological disruption of brain function" [30, 31, 34, 35]. Each TBI event severity was categorized using the Mayo Classification System (Box) [36]. This classification system uses all health record data available, which creates an inclusive classification system superior to single clinical indicators of TBI severity (eg, loss of consciousness, initial Glasgow Coma Scale [GCS] score, length of posttraumatic amnesia) when applied to an epidemiologic cohort [35, 36]. TBI severity classification categories included *definite* (consistent with moderate-severe TBI), *probable* (consistent with mild TBI), or *possible* (consistent with concussive TBI) (Box).

Case Identification

Methods for sample identification have been described previously [31, 34, 35]. A search of Olmsted County residents in the REP from January 1, 1985, through December 31, 1999, identified 46,114 cases with a TBI-related diagnostic code. Because of the labor-intensive effort involved in manually reviewing each case, a 20% random sample was initially selected. Time and budgetary constraints subsequently limited the cases to a 16% random sample, identifying 7,175 records. Trained nurse abstractors manually reviewed these records under the direction of a board-certified physiatrist (A.W.B.). Confirmed cases were defined as individuals without a documented history of prior TBI who had their first TBI event between January 1, 1985, and December 31, 1999. This abstraction confirmed 1,429 TBI cases. Information required to identify cases and their referents was available from January 1, 1987, limiting the sample to 1,257.

Selection of Referents

As described previously [31, 34, 35], TBI cases were matched to an individual of same sex and birth year (±1 year) seen by a REP clinician while an Olmsted County resident in the year (±1 year) of the case's TBI. These were referred to as *regular referents*.

TBI cases associated with additional nonhead injuries were then identified among all cases, and the severity of those nonhead injuries was quantified with a Trauma Mortality Prediction Model [37]. These cases were referred to as *special cases*. Each of these cases was matched to 2 individuals of the same sex and birth year (±2 years) seen by a REP clinician while an Olmsted County resident in the year (±1 year) of the case's TBI and had a traumatic injury of the same severity as their case's, unassociated with head trauma, within a year of their case's TBI. These referents were referred to as *special referents*. Of 1,257 TBI cases, 221 cases had TBI with ***other*** nonhead injuries and were categorized as special cases.

Underlying Cause of Death

The *underlying* cause of death was identified and was defined as the diagnosis of longest duration in the sequence of events leading to death. This compares with the *immediate* cause of death, or the final diagnosis that caused death. Underlying causes of death were categorized through extensive chart review using death certificates, *ICD-9* and *International Statistical Classification of Diseases*, *Tenth Revision* (*ICD-10*), and manual review of specific factors of external causes of death (D.E. and A.W.B.).[38] All *ICD-9* codes were converted to *ICD-10* equivalents under the direction of a board-certified physiatrist (A.W.B.). Similarly, related *ICD-10* categories were collapsed (Table 1).

Statistical Analysis

Underlying cause of death categories were compared between 2 case and referent groups: all cases (regular and special) matched with all regular referents (not considering nonhead trauma), and special cases each matched with 2 special referents. This strategy enhanced the analytical power for the smaller special case sample.

To determine any difference between cause of death in the postacute and chronic phases after injury, the categories were compared between case and referent groups during the entire study period and among 6-month survivors.

Descriptive summaries were reported as mean (SD) for continuous variables and as frequency (percentage) for categorical variables. Comparisons of proportions between cases and referents were performed with Fisher exact test. All tests were 2 sided, and $P<.05$ was considered statistically significant. Analysis was performed with statistical software (SAS version 9.4; SAS Institute Inc).

Results

Case characteristics and the mechanism of TBI were tabulated for the sample (n=1,257 cases) and by age group (Table 2). The mean time to follow-up for cases was 10.5 years. In total, 237 deaths occurred over the study period for the 1,257 case-referent pairs when all cases were matched to all regular referents—139 among cases and 98 among referents

(*P*=.006) (Table 3). Death occurred in 48% of cases after definite TBI, 10% after probable TBI, and 6% after possible TBI (Table 3). The underlying cause of death among cases was proportionally largest for external causes (52/139,37%) compared with 3 among matched referents (3/98, 3%) (*P*<.001) (Table 4). The number of deaths in the other collapsed categories for cases and referents were not significantly different.

Over the entire study period, a total of 93 deaths occurred among the 221 special cases (32/221, 14%) and the 441 matched special referents (61/441, 14%) (Table 5). (For 1 special case, only 1 referent could be identified.) No significant difference was observed in the proportion of total deaths in each sample (*P*=.81). However, the proportion of deaths due to external causes in the special cases (13/32, 41%) was significantly greater than for special referents (5/61, 8%) (*P*<.001). No significant difference was observed in the proportion of deaths for other causes.

Within all case–regular referent pairs surviving 6 months, 185 deaths occurred, and no significant difference was observed between the numbers of death among cases and referents (*P*=.82) (Table 4). The proportion of underlying cause of death due to external causes among cases was significantly different than among referents (*P*<.01). Seventy-five deaths of 6-month survivors occurred among the 221 special cases and the 441 matched special referents (Table 5). No difference was detected in total deaths (*P*=.24) or in proportion of deaths due to external causes between special cases and referents (*P*=1.00) among 6-month survivors (Table 5).

Discussion

This population-based case-matched referent analysis of underlying cause of death after TBI showed that death due to external causes accounted for the greatest proportion of case deaths and was significantly greater than for matched referents. Further, when TBI cases whose injury included nonhead trauma were compared with referents having a similar severity of traumatic nonhead injury, the proportion of deaths due to external causes was significantly different from the referents only during the first 6 months after injury. Previous findings in this cohort have shown that the increased risk of death after TBI exists only in the first 6 months after injury [34].

In the context of the present analysis, it is reasonable to conclude that the external causes of death during the first 6 months after injury relate predominantly to the injuries associated with the traumatic event. The term *external cause of death* refers to the effect that comes from outside the body (eg, injury, poison, assault, exposure). Of all deaths from external causes across the case and referent groups, manual record review of death certificates and *ICD* coding of external cause of death found only 3 of the deaths attributable to factors not related to injury (eg, poison, overdose).

The population-based results reported herein are consistent with those reported by Selassie et al [10], that unintentional injury was the leading cause of death during the 15 months following discharge among patients hospitalized for TBI in South Carolina. A large national Swedish study also showed a preponderance of deaths due to external causes among 6-

month survivors of TBI, particularly due to suicide, compared with both a population-based sample and sibling referents [8]. In a separate Swedish study of individuals hospitalized with severe TBI (GCS <8), a strong cause of death rate from external causes early after injury was found, but the rate did not differ from the general population after 1 year [39].

Among studies reporting cause of death in subgroups of individuals hospitalized for TBI and monitored over the longer term—with cases identified through hospital-determined *ICD* codes and deaths reported using SMRs—a large-scale nationally representative sample showed that external causes of death (18%) predominated after natural causes [11]. SMRs for suicide were 2.7 to 4.0, depending on the diagnosis group, and a suicide SMR for concussive injury was 3.02.

Ventura et al [12] analyzed a state-based trauma registry sample of patients hospitalized after TBI. Cases were identified with hospital-based *ICD* codes and death reported using SMR. They found that deaths within the first month after injury were caused by circulatory conditions and unknown causes, with TBI a contributing cause. Death due to mental health or behavioral disorders and nervous system diseases dominated this sample. Deaths due to external causes were the fifth highest SMR overall.

Studies showing statistically significant associations between TBI and cause of death differing from the findings reported herein likely relate to methodologic differences in case identification (manual review and abstraction vs administrative *ICD* coding by hospitals) and reference samples (population-based referents vs the general population). We have shown that only 40% of TBI cases in a population-based cohort confirmed by health record review were identified when only using *ICD-9* coding recommended by the Centers for Disease Control and Prevention for identifying TBI [22]. Use of SMRs to compare the number of TBI-related deaths in a given sample may limit the accuracy of attributing deaths to TBI because the comparison group is not controlled for other contributors of death, such as other traumatic injuries associated with the event [23].

The strengths of this study include confirmation of TBI cases in a defined population through manual health record review, stratification of injury severity across its spectrum, comparison of cause of death in cases to population-based referents considering nonhead trauma, and determination of underlying cause of death through detailed manual review of death certificates and diagnostic coding. Consistent with other studies in this population, the incidence of TBI in the present cohort was dominated by *probable* and *possible* TBI, with *definite* injury occurring in 8% (105 cases) of the sample. This population-based cohort also confirmed the association between injury severity and death (Table 3). However, other studies using samples exclusive to moderate-severe TBI cases have found cause of death to be significantly higher not only for external causes but also for respiratory, circulatory, and nervous system disorders [40–43]. These differences in findings may relate to the small proportion of definite cases in our sample.

Limitations

This study has several limitations. The lack of statistical significance in the number of deaths, particularly among 6-month survivors in special cases and special referents, may be due to too few deaths, particularly of persons with *definite* TBI. Although the present analysis considered simultaneous nonhead injuries using 2 matched referents, other preexisting comorbidities of cases were not considered when selecting referents, potentially affecting results. In addition, the use of 2 regular referents for all cases would have strengthened the power of the study, considering the relatively few *definite* TBI cases.

The population of Olmsted County is predominantly White, with age and sex distribution similar to that for Minnesota, the Upper Midwest, and the US White population [24]. The applicability of this study's findings to other community settings is limited because of the underrepresentation of persons of color and the distinctive medical care system of the region (ie, entire population served by primarily 2 group practices).

Finally, advances in the development of models of trauma care in the period since these data were acquired may potentially limit the relevance of these findings for current practice. However, there has been no consistent indication that mortality rate specifically after TBI has improved in recent decades, supporting the pertinence of these results [17, 44, 45].

Conclusion

Using the REP diagnostic record linkage resource to confirm cases and population-based matched referents, this study provides a distinctive report of the underlying cause of death after TBI over the full spectrum of age and injury severity, considering the influence of nonhead trauma for matched referents. Results show that in a population-based sample, TBI is associated with higher mortality rates during only the first 6 months after injury, and this increased risk of death is due to external causes. This in turn has implications for the long-term medical and rehabilitation treatment of individuals who survive the postacute phase after TBI as their health needs change with recovery and aging.

Acknowledgments

Statement of Ethics

This study was approved by Mayo Clinic and Olmsted Medical Center institutional review boards. All study participants provided authorization for their health data to be used for research purposes.

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Appendix

APPENDIX 1.

Mayo Adapted HICD-A codes

Mayo Adapted HICD-A	CODE DESCRIPTION
02985000	PSYCHOSIS, ACUTE, WITH TRAUMA, BRAIN
02985110	PSYCHOSIS, ACUTE, WITH BRAIN TRAUMA
02985120	SYNDROME, AMNESTIC, TRAUMATIC (ACUTE)
02995000	PSYCHOSIS, CHRONIC, WITH BRAIN TRAUMA
02995110	PSYCHOSIS, CHRONIC, WITH TRAUMA, BRAIN
03042000	SYNDROME, ACUTE, BRAIN, WITH TRAUMA
03042120	SYNDROME, POST-CONTUSION, BRAIN NOS
03042130	SYNDROME, FRONTAL LOBE, POST-TRAUMA
03052000	SYNDROME, CHRONIC, BRAIN, WITH TRAUMA
03052110	SYNDROME, BRAIN, ORGANIC, CHRONIC, C BRAIN TRAUMA
03052130	SYNDROME, POST-CONTUSION, BRAIN CHRONIC
04310000	HEMORRHAGE, SUBDURAL, NOS
04310110	HEMORRHAGE, SUBDURAL, NOS
04310111	HEMATOMA, SUBDURAL, NOS
04310120	HEMATOMA, EPIDURAL, ACUTE
04310130	HEMATOMA, EPIDURAL, NOS
04310131	HEMATOMA, EXTRADURAL, NOS, SEE ALSO EPIDURAL
04310140	HEMATOMA, SUBDURAL, ACUTE
04310150	HEMATOMA, SUBDURAL, CHRONIC
04311000	HEMORRHAGE, SUBDURAL, WITH PARALYSIS
04311110	HEMORRHAGE, SUBDURAL, WITH PARALYSIS
07610810	DAMAGE, BRAIN, DUE TO BIRTH INJURY
07610811	INJURY, BIRTH, BRAIN
07619510	TRAUMA, BIRTH, NEC
07700000	COMA
07700110	COMATOSE
07700111	COMA, NOS
07700112	UNCONSCIOUS-SEE ALSO DISORDER
07700120	COMA, NOS, CAUSE SPECIFIED
07700130	COMA, SPINDLE
07700140	VEGETATIVE STATE (CNS)
07707110	AMNESIA, POST-TRAUMATIC
07755110	DISORDER, CONSCIOUSNESS, CAUSE SPECIFIED
07920120	HEADACHE, POST TRAUMA
08000000	FRACTURE, SKULL VAULT, CLOSED
08000010	FRACTURE, SKULL, VAULT
08000020	FRACTURE, SKULL, FRONTAL
08000030	FRACTURE, SKULL, VERTEX

Mayo Adapted HICD-A	CODE DESCRIPTION
08000040	FRACTURE, SKULL, PARIETAL
08001000	FRACTURE, SKULL VAULT, OPEN
08001010	FRACTURE, SKULL VAULT, OPEN
08001020	FRACTURE, SKULL, FRONTAL, OPEN
08001030	FRACTURE, SKULL, VERTEX, OPEN
08001040	FRACTURE, SKULL, PARIETAL, OPEN
08009000	FRACTURE, SKULL VAULT, LATE EFFECT
08009010	FRACTURE, SKULL VAULT, LATE EFFECT
08009020	FRACTURE, SKULL, FRONTAL, LATE EFFECT
08009030	FRACTURE, SKULL, VERTEX, LATE EFFECT
08009040	FRACTURE, SKULL, PARIETAL, LATE EFFECT
08010000	FRACTURE, SKULL BASE, CLOSED
08010110	FRACTURE, SKULL, ANTERIOR FOSSA
08010120	FRACTURE, SKULL, BASE
08010130	FRACTURE, SKULL, MIDDLE FOSSA
08010140	FRACTURE, SKULL, POSTERIOR FOSSA
08010150	FRACTURE, SKULL, OCCIPITAL
08010160	FRACTURE, SKULL, ANTRUM
08010170	FRACTURE, SKULL, ETHMOID
08010180	FRACTURE, SKULL, SPHENOID
08010190	FRACTURE, SKULL, TEMPORAL
08010200	FRACTURE, SINUS, CODE ALSO FRACTURE SKULL, PART SPECIFIED
08010210	FRACTURE, MALLEUS (EAR)
08011000	FRACTURE, SKULL BASE, OPEN
08011110	FRACTURE, SKULL, ANTERIOR FOSSA, OPEN
08011120	FRACTURE, SKULL, BASE, OPEN
08011121	FRACTURE, SKULL, OPEN
08011130	FRACTURE, SKULL, MIDDLE FOSSA, OPEN
08011140	FRACTURE, SKULL, POSTERIOR FOSSA, OPEN
08011150	FRACTURE, SKULL, OCCIPITAL, OPEN
08011160	FRACTURE, SKULL, ANTRUM, OPEN
08011170	FRACTURE, SKULL, ETHMOID, OPEN
08011180	FRACTURE, SKULL, SPHENOID, OPEN
08011190	FRACTURE, SKULL, TEMPORAL, OPEN
08011210	FRACTURE, MALLEUS, OPEN
08019000	FRACTURE, SKULL BASE, LATE EFFECT
08019110	FRACTURE, SKULL, ANTERIOR FOSSA, LATE EFFECT
08019120	FRACTURE, SKULL, BASE, LATE EFFECT
08019130	FRACTURE, SKULL, MIDDLE FOSSA, LATE EFFECT
08019140	FRACTURE, SKULL, POSTERIOR FOSSA, LATE EFFECT
08019150	FRACTURE, SKULL, OCCIPITAL, LATE EFFECT
08019160	FRACTURE, SKULL, ANTRUM, LATE EFFECT

Mayo Adapted HICD-A	CODE DESCRIPTION
08019170	FRACTURE, SKULL, ETHMOID, LATE EFFECT
08019180	FRACTURE, SKULL, SPHENOID, LATE EFFECT
08019190	FRACTURE, SKULL, TEMPORAL, LATE EFFECT
08019210	FRACTURE, MALLEUS, LATE EFFECT
08019220	FRACTURE, MALLEUS, OLD
08020000	FRACTURE, NASAL, CLOSED
08020110	FRACTURE, NOSE
08021000	FRACTURE, NASAL, OPEN
08021110	FRACTURE, NOSE, OPEN
08022000	FRACTURE, MANDIBLE, CLOSED
08022110	FRACTURE, JAW, LOWER
08022111	FRACTURE, MANDIBLE
08022112	FRACTURE, MAXILLA, INFERIOR, SEE ALSO FRACTURE, MANDIBLE
08022210	FRACTURE, JAW, NOS
08023000	FRACTURE, MANDIBLE, OPEN
08023110	FRACTURE, MANDIBLE, OPEN
08023111	FRACTURE, JAW, LOWER, OPEN
08023210	FRACTURE, JAW, NOS, OPEN
08024000	FRACTURE, FACIAL BONE, NEC, CLOSED
08024110	FRACTURE, PALATE
08024120	FRACTURE, ORBIT
08024121	FRACTURE, ORBIT, BLOWOUT
08024130	FRACTURE, JAW, UPPER
08024131	FRACTURE, MAXILLA
08024132	FRACTURE, MAXILLARY ANTRUM
08024133	FRACTURE, ANTRUM, MAXILLARY
08024134	FRACTURE, LA FORTE’S, SEE ALSO FRACTURE MAXILLA
08024140	FRACTURE, MALAR BONE
08024150	FRACTURE, FACE BONE
08024151	FRACTURE, FACIAL
08024160	FRACTURE, ZYGOMA
08025000	FRACTURE, FACIAL BONE, NEC, OPEN
08025110	FRACTURE, PALATE, OPEN
08025120	FRACTURE, ORBIT, OPEN
08025130	FRACTURE, JAW, UPPER, OPEN
08025131	FRACTURE, MAXILLA, OPEN
08025132	FRACTURE, MAXILLARY ANTRUM, OPEN
08025140	FRACTURE, MALAR BONE
08025150	FRACTURE, FACE BONE
08025151	FRACTURE, FACIAL
08025160	FRACTURE, ZYGOMA, OPEN
08029000	FRACTURE, FACIAL BONE, NEC, LATE EFFECT

Mayo Adapted HICD-A	CODE DESCRIPTION
08029110	FRACTURE, PALATE, LATE EFFECT
08029120	FRACTURE, ORBIT, LATE EFFECT
08029130	FRACTURE, JAW, UPPER, LATE EFFECT
08029131	FRACTURE, MAXILLA, LATE EFFECT
08029132	FRACTURE, MAXILLARY ANTRUM, LATE EFFECT
08029141	FRACTURE, MALAR BONE, LATE EFFECT
08029151	FRACTURE, FACIAL, LATE EFFECT
08029152	FRACTURE, FACE BONE, LATE EFFECT
08029160	FRACTURE, ZYGOMA, LATE EFFECT
08029170	FRACTURE, NOSE, LATE EFFECT
08029180	FRACTURE, MANDIBLE, LATE EFFECT
08029181	FRACTURE, JAW, LOWER, LATE EFFECT
08029190	FRACTURE, JAW, NOS, LATE EFFECT
08029210	FRACTURE, PALATE, OLD
08029220	FRACTURE, ORBIT, OLD
08029230	FRACTURE, MAXILLA, OLD
08029231	FRACTURE, JAW, UPPER, OLD
08029240	FRACTURE, MALAR BONE, OLD
08029250	FRACTURE, FACE BONE, OLD
08029251	FRACTURE, FACIAL, OLD
08029260	FRACTURE, ZYGOMA, OLD
08029270	FRACTURE, NOSE, OLD
08029280	FRACTURE, MANDIBLE, OLD
08029281	FRACTURE, JAW, LOWER, OLD
08029290	FRACTURE, JAW, NOS, OLD
08030000	FRACTURE, SKULL, NEC, CLOSED
08030110	FRACTURE, SKULL, NOS
08031000	FRACTURE, SKULL, NEC, OPEN
08031110	FRACTURE, SKULL, NOS, OPEN
08039000	FRACTURE, SKULL, LATE EFFECT
08039110	FRACTURE, SKULL, NOS, LATE EFFECT
08039210	FRACTURE, SKULL, OLD
08500000	CONCUSSION, CURRENT
08500110	CONCUSSION, NOS
08500120	CONCUSSION, BRAIN, WITHOUT SKULL FRACTURE
08500130	COMMOTIO CEREBRI (WITHOUT SKULL FRACTURE)
08509000	CONCUSSION, LATE EFFECT
08509110	ENCEPHALOPATHY, DUE TO TRAUMA
08509111	ENCEPHALOPATHY, POST-TRAUMATIC
08509112	PORENCEPHALY, POST-TRAUMATIC
08509210	CONCUSSION, LATE EFFECT
08509211	SYNDROME, CONCUSSION (LATE EFFECT)

Mayo Adapted HICD-A	CODE DESCRIPTION
08510000	LACERATION, OR CONTUSION, CEREBRAL
08510110	CONTUSION, BRAIN
08510111	CONTRA COUP (COUP CONTRA COUP)
08510120	LACERATION, TENTORIUM CEREBELLI
08510121	LACERATION, CORTEX, CEREBRAL
08510122	LACERATION, CEREBRAL
08510123	LACERATION, CEREBELLUM
08510130	COMPRESSION, BRAIN, DUE TO LACERATION OR CONTUSION
08511000	LACERATION, CEREBRAL, OPEN
08511110	WOUND, BULLET, INTRACRANIAL
08511111	WOUND, GUNSHOT, INTRACRANIAL
08511120	CONTUSION, BRAIN, WITH OPEN INTRACRANIAL WOUND
08511121	WOUND, OPEN, BRAIN
08511122	LACERATION, CEREBRAL, WITH OPEN INTRACRANIAL WOUND
08519000	LACERATION, CEREBRAL, LATE EFFECT
08519110	WOUND, OPEN, BRAIN, LATE EFFECT
08519120	CONTUSION, BRAIN, LATE EFFECT
08519130	LACERATION, CEREBRAL, LATE EFFECT
08520000	HEMORRHAGE, SUBARACHNOID, SUBDURAL OR EXTRADURAL
08520110	HEMATOMA, SUBARACHNOID, TRAUMATIC
08520111	HEMORRHAGE, SUBARACHNOID, TRAUMATIC
08520120	HEMATOMA, SUBDURAL, TRAUMATIC
08520121	HEMORRHAGE, SUBDURAL, TRAUMATIC
08520122	HEMATOMA, EPIDURAL, TRAUMATIC
08521000	HEMORRHAGE, SUBARACHNOIN, SUBDURAL OR EXTRADURAL, OPEN
08521110	HEMATOMA, SUBARACHNOID, TRAUMATIC
08521111	HEMORRHAGE, SUBARACHNOID, TRAUMATIC
08521120	HEMATOMA, SUBDURAL, TRAUMATIC
08521121	HEMORRHAGE, SUBDURAL, WITH OPEN INTRACRANIAL WOUND
08529000	HEMORRHAGE, SUBARACHNOID, SUBDURAL OR EXTRADURAL, LATE EFFECT
08529110	HEMORRHAGE, SUBARACHNOID, LATE EFFECT
08529111	HEMATOMA, SUBARACHNOID, LATE EFFECT, TRAUMATIC
08529112	HEMIPLEGIA, SUBARACHNOID, LATE EFFECT, HEMORRHAGE, TRAUMATIC
08529120	HEMORRHAGE, SUBDURAL, LATE EFFECT, TRAUMATIC
08529121	HEMATOMA, SUBDURAL, LATE EFFECT, TRAUMATIC
08529122	HEMIPLEGIA, SUBDURAL, LATE EFFECT, TRAUMATIC
08529130	HEMATOMA, EXTRADURAL, LATE EFFECT, TRAUMATIC
08529131	HEMORRHAGE, EXTRADURAL, LATE EFFECT, TRAUMATIC
08529132	HEMIPLEGIA, ALTERNANS FACIA, EXTRADURAL, LATE EFFECT, TRAUMATIC

Mayo Adapted HICD-A	CODE DESCRIPTION
08530000	HEMORRHAGE, INTRACRANIAL, NEC
08530110	COMPRESSION, BRAIN, DUE TO INJURY
08530120	HEMORRHAGE, BRAIN, TRAUMATIC
08530121	HEMIPLEGIA, BRAIN, TRAUMATIC
08530122	HEMATOMA, BRAIN, TRAUMATIC
08531000	HEMORRHAGE, INTRACRANIAL, NEC, OPEN
08531110	HEMIPLEGIA, BRAIN, WITH OPEN INTRACRANIAL WOUND
08531111	HEMORRHAGE, BRAIN, WITH OPEN INTRACRANIAL WOUND
08531112	HEMATOMA, BRAIN, WITH OPEN INTRACRANIAL WOUND
08539000	HEMORRHAGE, INTRACRANIAL, NEC, LATE EFFECT
08539110	HEMIPLEGIA, BRAIN, HEMORRHAGE, LATE EFFECT, TRAUMATIC
08539111	HEMORRHAGE, BRAIN, LATE EFFECT, TRAUMATIC
08539112	HEMATOMA, BRAIN, LATE EFFECT, TRAUMATIC
08540000	INJURY, INTRACRANIAL, NEC
08540110	INJURY, INTRACRANIAL, NOS
08540210	INJURY, HEAD, NEC, (INTRACRANIAL)–CHI
08540220	SYNDROME, HEAD, TRAUMATIC
08540310	CONCUSSION, OSSEOUS LABYRINTH
08540311	CONCUSSION, LABYRINTH
08541000	INJURY, INTRACRANIAL, NEC, OPEN
08541110	INJURY, HEAD, NEC, (INTRACRANIAL), WITH OPEN INTRACRANIAL WOUND
08541120	INJURY, INTRACRANIAL, WITH OPEN INTRACRANIAL WOUND
08541210	LACERATION, INTRACRANIAL
08541220	FOREIGN BODY, INTRACRANIAL
08541230	WOUND, OPEN, INTRACRANIAL
08549000	INJURY, INTRACRANIAL, NEC, LATE EFFECT
08549110	IRRITATION, BRAIN, BY SCAR TISSUE
08549120	EPILEPSY, TRAUMATIC
08549130	INJURY, HEAD, NEC, (INTRACRANIAL), LATE EFFECT
08549131	POSTURING, DECEREBRATE, POST-TRAUMATIC
08549140	INJURY, INTRACRANIAL, LATE EFFECT
08690130	CONCUSSION, BLAST
08730000	LACERATION, SCALP
08730110	WOUND, OPEN, HEAD
08730120	INJURY, SCALP, NOS
08730130	WOUND, OPEN, SCALP
08730131	LACERATION, SCALP
08731000	LACERATION, SCALP, COMPLICATED
08731110	WOUND, OPEN, HEAD, NEC, COMPLICATED
08731111	FOREIGN BODY, HEAD, NEC
08731120	INJURY, SCALP, COMPLICATED

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Mayo Adapted HICD-A	CODE DESCRIPTION
08731130	WOUND, OPEN, SCALP, COMPLICATED
08731140	WOUND, OPEN, INFECTED, HEAD, CODE ALSO BY SITE, COMPLICATED
08737140	WOUND, OPEN, FOREHEAD
08738140	WOUND, OPEN, FOREHEAD, COMPLICATED
09002210	INJURY, HEAD, ARTERY, NEC
09002220	INJURY, HEAD, VEIN, NEC
09002230	ANEURYSM, HEAD, ARTERY, NEC, TRAUMATIC
09003110	INJURY, HEAD, ARTERY, NOS
09003120	INJURY, HEAD, VEIN, NOS
09003130	ANEURYSM, HEAD, ARTERY, NOS, TRAUMATIC
09003132	FISTULA, ARTERIOVENOUS, HEAD, TRAUMATIC
09003141	HEMATOMA, ARTERIAL, HEAD, CODE ALSO INJURY, VASCULAR BY SITE
09100140	INJURY, SCALP, SUPERFICIAL, NOS
09100141	INJURY, HEAD, SUPERFICIAL
09101140	INJURY, SCALP, SUPERFICIAL, INFECTED
09198000	INJURY, MULTIPLE, NOS
09198110	INJURY, MULTIPLE SITES, NEC
09198111	INJURY, NOS
09198112	TRAUMA, NOS, SEE ALSO INJURY BY SITE
09198113	AVULSION, NOS, SEE ALSO WOUND/INJURY TYPE SPECIFIED
09198114	SWELLING, TRAUMATIC-SEE ALSO INJURY BY SITE
09198120	INJURY, MULTIPLE SITES, NOS
09198130	HEMATOMA, SUBUNGUAL, NOS
09199111	SYNDROME, POST TRAUMATIC
09200160	CONTUSION, HEAD
09200161	HEMATOMA, HEAD
09200162	CONTUSION, FOREHEAD
09200170	CONTUSION, SCALP
09200171	CONTUSION, CAPITIS
09200172	HEMATOMA, SCALP
09200180	HEMATOMA, PERICRANIAL
09209110	HEMATOMA, PERICRANIAL, LATE EFFECT
09209113	HEMATOMA, CAPITIS, LATE EFFECT
09209117	HEMATOMA, SCALP, LATE EFFECT
09250110	HEMATOMA, SCALP, LATE EFFECT
09250111	CONTUSION, MULTIPLE SITES
09250112	ECCHYMOSIS, TRAUMATIC, NOS, SEE ALSO CONTUSION
ICD-9-CM	**CODE DESCRIPTION**
294.0	AMNESTIC SYNDROME
310.0	FRONTAL LOBE SYNDROME

Mayo Adapted HICD-A	CODE DESCRIPTION
310.2	POSTCONCUSSION SYNDROME
432	OTHER AND UNSPECIFIED INTRACRANIAL HEMORRHAGE
767.0	SUBDURAL AND CEREBRAL HEMORRHAGE DUE TO BIRTH TRAUMA
767.9	UNSPECIFIED BIRTH TRAUMA
780.0	ALTERATION OF CONSCIOUSNESS
800	FRACTURE OF VAULT OF SKULL
801	FRACTURE OF BASE OF SKULL
802	FRACTURE OF FACE BONES
803	OTHER AND UNQUALIFIED SKULL FRACTURES
804	MULTIPLE FRACTURES INVOLVING SKULL OR FACE WITH OTHER BONES
850	CONCUSSION
851	CEREBRAL LACERATION AND CONTUSION
852	SUBARACHNOID, SUBDURAL, AND EXTRADURAL HEMORRHAGE, FOLLOWING INJURY
853	OTHER AND UNSPECIFIED INTRACRANIAL HEMORRHAGE FOLLOWING INJURY
854	INTRACRANIAL INJURY OF OTHER AND UNSPECIFIED NATURE
873.0	OPEN WOUND OF SCALP, WITHOUT MENTION OF COMPLICATION
873.1	OPEN WOUND OF SCALP, COMPLICATED
873.42	OPEN WOUND OF FOREHEAD, UNCOMPLICATED
873.52	OPEN WOUND OF FOREHEAD, COMPLICATED
873.8	OTHER AND UNSPECIFIED OPEN WOUND OF HEAD WITHOUT MENTION OF COMPLICATION
900.9	INJURY TO UNSPECIFIED BLOOD VESSEL OF HEAD AND NECK
905.0	LATE EFFECT OF FRACTURE OF SKULL AND FACE BONES
906.0	LATE EFFECT OF OPEN WOUND OF HEAD, NECK, AND TRUNK
906.3	LATE EFFECT OF CONTUSION
907.0	LATE EFFECT OF INTRACRANIAL INJURY WITHOUT MENTION OF SKULL FRACTURE
908.6	LATE EFFECT OF CERTAIN COMPLICATIONS OF TRAUMA
910.8	OTHER AND UNSPECIFIED SUPERFICIAL INJURY OF FACE, NECK, AND SCALP W/O MENTION OF INFECTION
910.9	OTHER AND UNSPECIFIED SUPERFICIAL INJURY OF FACE, NECK, AND SCALP INFECTED
920	CONTUSION OF FACE, SCALP, AND NECK EXCEPT EYE(S)
959.8	OTHER AND UNSPECIFIED INJURY TO OTHER SPECIFIED SITES, INCLUDING MULTIPLE
959.9	OTHER AND UNSPECIFIED INJURY TO UNSPECIFIED SITE

From Leibson CL, Brown AW, Hall Long K, et al. Medical care costs associated with traumatic brain injury over the full spectrum of disease: a controlled population-based study. J Neurotrauma. 2012;29(11):2038–2049.

APPENDIX 2.

Mayo traumatic brain injury (TBI) classification system[a]

A. Classify as Definite TBI if one or more of the following criteria apply:

1. Death due to this TBI
2. Loss of consciousness of 30 minutes or more
3. Post-traumatic anterograde amnesia of 24 hours or more
4. Worst Glasgow Coma Scale full score in first 24 hours <13 (unless invalidated upon review, eg, attributable to intoxication, sedation, systemic shock)
5. One or more of the following present:
    - Intracerebral hematoma
    - Subdural hematoma
    - Epidural hematoma
    - Cerebral contusion
    - Hemorrhagic contusion
    - Penetrating TBI (dura penetrated)
    - Subarachnoid hemorrhage

B. If none of Criteria A apply, classify as Probable TBI if one or more of the following criteria apply:

1. Loss of consciousness of momentary to less than 30 minutes
2. Post-traumatic anterograde amnesia of momentary to less than 24 hours
3. Depressed, basilar or linear skull fracture (dura intact)

C. If none of Criteria A or B apply, classify as Possible (Symptomatic) TBI if one or more of the following symptoms are present:

- Blurred vision
- Confusion (mental state changes)
- Dazed
- Dizziness
- Focal neurologic symptoms
- Headache
- Nausea

[a]Adapted from Malec JF, Brown AW, Leibson CL, Flaada JT, Mandrekar JN, Diehl NN, Perkins PK. The Mayo classification system for traumatic brain injury severity. J Neurotrauma. 2007;24:1417–24.

Abbreviations

GCS	Glasgow Coma Scale
ICD	International Classification of Diseases
ICD-9	International Classification of Diseases, Ninth Revision
ICD-10	International Statistical Classification of Diseases, Tenth Revision
REP	Rochester Epidemiology Project
SMR	standardized mortality ratio

TBI	traumatic brain injury

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Box.

Mayo Clinic TBI Classification System

1. Classify as *definite (moderate-severe) TBI* if ≥1 of the following criteria:

    a. Death due to TBI

    b. ≥30 min of loss of consciousness

    c. ≥24 h of anterograde posttraumatic amnesia

    d. Worst GCS score <13 in first 24 h after TBI (unless invalidated on review, including attributable to intoxication, sedation, or systemic shock)

    e. ≥1 of the following:

        i. Intracranial hemorrhage (eg, intracerebral hematoma, subdural hematoma, epidural hematoma, cerebral contusion, hemorrhagic contusion, subarachnoid hemorrhage)

        ii. TBI that penetrated dura mater

        iii. Brainstem injury

2. If none of Criteria 1 applies, then classify as *probable (mild) TBI* if ≥1 of the following:

    a. <30 min of loss of consciousness

    b. <24 h of anterograde posttraumatic amnesia

    c. Depressed, basilar, or linear skull fracture with dura mater intact

3. If neither Criteria 1 nor Criteria 2 applies, then classify as *possible (symptomatic) TBI* if ≥1 of the following:

    a. Blurred vision

    b. Confusion and mental status changes

    c. Dazed

    d. Dizziness

    e. Focal neurologic symptoms

    f. Headache

    g. Nausea

Abbreviations: GCS, Glasgow Coma Scale; TBI, traumatic brain injury. Modified from Malec et al [36].

Table 1.

Collapsed *ICD-10* Categories

Letter category	Underlying cause of death category	Codes in regular case/ referent	Codes in special case/ referent
C, D	Neoplasms (malignant, in situ)	C	C, D
F, G	Mental health/behavioral, nervous system	F, G	F, G
I	Circulatory system	I	I
J	Respiratory system	J	J
S, T, V, W, X	External cause of injury (injury, poison, suicide, assault, exposure)	S, T, U, V, W, X	S, V, W, X
A, B, E, K, M, N, Q, R	Other (infection, endocrine, digestive, musculoskeletal, genitourinary, congenital, signs/ symptoms NOS)	A, B, E, K, M, N, Q, R	E, K, M, N, Q

Abbreviations: *ICD-10*, *International Statistical Classification of Diseases*, *Tenth Revision*; NOS, not otherwise specified.

Table 2.

All Case Cohort Characteristics

Characteristic[a]	Cases, No. (%)			
		Patient age, y[b]		
	Entire sample (N=1,257)	<16 (n=446)	16–64 (n=698)	>64 (n=113)
Male sex	698 (56)	286 (64)	371 (54)	41 (36)
TBI classification				
Definite	105 (8)	20 (5)	58 (8)	27 (24)
Probable	483 (38)	153 (34)	286 (41)	44 (39)
Possible	669 (53)	273 (61)	354 (51)	42 (37)
Mechanism of injury				
Fall	352 (28)	146 (33)	123 (18)	83 (73)
Motor vehicle collision	342 (27)	27 (6)	296 (42)	19 (17)
Sports or recreation	310 (25)	198 (44)	111 (16)	1 (1)
Other	97 (8)	43 (10)	49 (7)	5 (4)
Assault or gunshot	82 (6)	17 (4)	63 (9)	2 (2)
Hit by object	74 (6)	15 (3)	56 (8)	3 (3)

Abbreviation: TBI, traumatic brain injury.

[a]Mean (SD) time to follow-up for cohort, 10.5 (5.98) years.

[b]Mean (SD) age at injury for cohort, 27 (22.0) years.

Table 3.

Proportion of Deaths Among Cases and Their Regular Referents by Injury Severity Over the Entire Study Period

Injury severity	Cases, No. (%) (n=1,257)	Referents, No. (%) (n=1,257)
Definite	50/105 (48)	25/105 (24)
Probable	49/483 (10)	42/483 (9)
Possible	40/669 (6)	31/669 (5)
Total	139/1,257 (11)	98/1,257 (8)

Table 4.

Underlying Cause of Death Listed by Collapsed *ICD-10* Categories for the 1,257 All Regular Case–Regular Referent Pairs Over Entire Study Period

	Over study period, No. (%)		Among 6-mo survivors, No (%)	
Collapsed *ICD-10* category	**All cases[a]**	**Regular referents[b]**	**Regular cases**	**Regular referents**
Neoplasm	16 (11)	15 (15)	14 (15)	13 (14)
Mental health/behavioral, nervous system	12 (9)	18 (19)	12 (13)	17 (18)
Circulatory	38 (27)	32 (33)	32 (34)	30 (33)
Respiratory	5 (4)	3 (3)	4 (4)	3 (3)
External	52 (37)[c]	3 (3)	15 (16)[d]	3 (3)
Other	11 (8)	11 (11)	11 (12)	10 (11)
Unknown cause	5 (4)	16 (16)	5 (5)	16 (17)
Total deaths	139/1,257 (11)[e]	98/1,257 (8)	93/1,177 (8)[f]	92/1,215 (8)

Abbreviation: *ICD-10*, *International Statistical Classification of Diseases*, *Tenth Revision.*

[a]Of the 1,257 cases, 80 had <6 months follow-up, with 46 deaths; for cases with ≥6 months follow-up (n=1,177), there were 93 deaths.

[b]Of the 1,257 regular referents, there were 42 referents with <6 months follow-up, with 6 deaths; for the 1,215 regular referents with ≥6 months follow-up, there were 92 deaths (total, 98 referent deaths).

[c]Difference in deaths by external cause vs all other causes for cases compared with referents, Fisher exact test, $P<.001$.

[d]Difference in deaths by external causes vs all other causes for cases compared with referents, Fisher exact test, $P<.01$.

[e]Difference in total deaths between all cases and regular referents, Fisher exact test, $P=.006$.

[f]Difference in total deaths between regular cases and regular referents, Fisher exact test, $P=.82$.

Table 5.

Underlying Cause of Death Listed by Collapsed *ICD-10* Categories for 221 Special Cases and 441 Matched Special Referents[a] Over Study Period and Among 6-Month Survivors

	Over study period, No. (%)		Among 6-mo survivors, No. (%)	
Collapsed *ICD-10* category	**Special cases**	**Special referents**	**Special cases**	**Special referents**
Neoplasm	4 (13)	11 (18)	3 (16)	10 (18)
Mental health/behavioral, nervous system	2 (6)	7 (11)	2 (11)	6 (11)
Circulatory	8 (25)	19 (31)	7 (37)	14 (25)
Respiratory	1 (3)	8 (13)	1 (5)	8 (14)
External	13 (41)[b]	5 (8)	2 (11)[c]	5 (9)
Other	2 (6)	5 (8)	2 (11)	5 (9)
Unknown cause	2 (6)	6 (10)	2 (11)	8 (14)
Total deaths	32 (14)[d]	61 (14)	19 (9)[e]	56 (13)

Abbreviation: *ICD-10*, *International Statistical Classification of Diseases*, *Tenth Revision*.

[a] Only 1 special referent was identified for 1 of the special cases.

[b] Difference in deaths due to external causes vs all other causes for special cases compared with special referents, Fisher exact test, $P<.001$.

[c] Difference in deaths due to external causes vs all other causes between special cases and special referents, Fisher exact test, $P=1.00$.

[d] Difference in total deaths between special cases and special referents, Fisher exact test, $P=.81$.

[e] Difference in total deaths between special cases and special referents, Fisher exact test, $P=.24$.