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Life Expectancy after Inpatient Rehabilitation for Traumatic Brain Injury in the United States

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Abstract

This study characterized life expectancy after traumatic brain injury (TBI). The TBI Model Systems (TBIMS) National Database (NDB) was weighted to represent those ≥ 16 years of age completing inpatient rehabilitation for TBI in the United States (US) between 2001 and 2010. Analyses included Standardized Mortality Ratios (SMRs), Cox regression, and life expectancy. The US mortality rates by age, sex, race, and cause of death for 2005 and 2010 were used for comparison purposes. Results indicated that a total of 1325 deaths occurred in the weighted cohort of 6913 individuals. Individuals with TBI were 2.23 times more likely to die than individuals of comparable age, sex, and race in the general population, with a reduced average life expectancy of 9 years. Independent risk factors for death were: older age, male gender, less-than-high school education, previously married at injury, not employed at injury, more recent year of injury, fall-related TBI, not discharged home after rehabilitation, less functional independence, and greater disability. Individuals with TBI were at greatest risk of death from seizures; accidental poisonings; sepsis; aspiration pneumonia; respiratory, mental/behavioral, or nervous system conditions; and other external causes of injury and poisoning, compared with individuals in the general population of similar age, gender, and race. This study confirms prior life expectancy study findings, and provides evidence that the TBIMS NDB is representative of the larger population of adults receiving inpatient rehabilitation for TBI in the US. There is an increased risk of death for individuals with TBI requiring inpatient rehabilitation.

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Introduction

Traumatic brain injury (TBI) is a leading cause of death and disability in young people in the United States (US).[1] Accurate estimation of life expectancy is needed for future cost prediction, long-term planning, prevention and treatment development, and trend monitoring.

The participants of the longitudinal TBI Model Systems (TBIMS) National Database (NDB) cohort, a population of people who received comprehensive inpatient rehabilitation at specialized brain injury centers, were found to be twice as likely to die, and estimated to have life expectancy reduced by 7 years on average compared with individuals of similar age, sex, and race in the general population.[2]

Studies of life expectancy after TBI reveal that post-injury case fatality rates are higher initially in the first several months, with a subsequent decrease by 6–12 months post-injury.[3,4] Compared with the general population, individuals with greater TBI severity seem to more commonly die from seizures, septicemia, pneumonia, and respiratory conditions.[5] High levels of immobility and functional dependency have been found to be related to greater mortality risk.[6] Other factors associated with reduced life expectancy include mechanism of injury, comorbid injuries, age, sex, ethnicity, history of substance use and abuse, poor general health, post-injury lifestyle, and type of health insurance coverage.[4,7–13]

The prospective, longitudinal TBIMS NDB is a valuable resource for learning about long-term outcomes from TBI, including death and life expectancy. Over the past two decades, several studies of this cohort have informed the knowledge base on life expectancy and causes of death after TBI. The most recent of these studies[14] revealed that life expectancy was shortened by an average of 6.7 years. The standardized mortality ratios (SMRs) decreased as survival time increased, although SMR elevations continued even after 10 years post-injury. This study found an overall SMR of 2.25 and significantly elevated SMRs for all age groups, both sexes, all race/ethnic groups (except Native Americans), and all injury severity groups. For all cause-of-death categories, SMRs were elevated, especially for seizures, aspiration pneumonia, sepsis, accidental poisonings, and falls. Multivariate Cox regression found several variables to be independent risk factors for death, including age at injury, sex, race/ethnic group, marital status at time of injury, employment status at time of injury, year of injury, pre-injury drug use, days unconscious, functional independence and disability at time of rehabilitation discharge, and comorbid spinal cord injury.

To date, a limitation of the TBIMS mortality findings has been a lack of knowing how these results represent the US population of individuals who receive inpatient rehabilitation for a primary diagnosis of TBI. A recent study compared the combined populations of the Uniform Data System for Medical Rehabilitation and eRehabData who were admitted for acute inpatient rehabilitation for TBI from October 2001 through December 2007 with the

TBIMS NDB participants admitted to rehabilitation during the same time period.[15] The majority of differences found between these two populations were age related, with the TBIMS-NDB cohort including fewer individuals > 65 years. Between the two populations, for those > 65 years, there were differences in pre-injury vocational status, type of health insurance coverage, age distribution, and rehabilitation length of stay. A more recent study extended the representativeness of the TBIMS NDB from the 2001–2007 time frame, out to 2010.[16] This work has led to the ability to apply weighting computations to the TBIMS NDB to make it representative of the US population of individuals ≥ 16 years of age who were admitted to acute inpatient rehabilitation. The purpose of the current investigation is to use this weighted data set to re-examine life expectancy for individuals with TBI ≥ 16 years of age receiving inpatient rehabilitation. Using the weighted TBIMS data set, this study addresses the following questions: 1) Does TBI decrease life expectancy? 2) What are the characteristics associated with the risk of death following rehabilitation after TBI? 3) Are individuals with TBI at greater risk for certain causes of death?

Methods

The Hospital Corporation of America–HealthONE Institutional Review Board for Craig Hospital authorized this study as part of the TBIMS National Data and Statistical Center. Since 1987, the US Department of Education's National Institute on Disability and Rehabilitation Research (NIDRR) has funded the TBIMS. One of the major components of the TBIMS program is a standardized NDB for innovative analyses of TBI treatment and outcomes.[17] The TBIMS NDB contains information on cases treated within the 23 TBIMS centers, funded between 1988 and 2013, which are located throughout the US. For the purposes of the NDB, TBI is defined as damage to brain tissue caused by an external mechanical force, as evidenced by medically documented loss of consciousness or post-traumatic amnesia (PTA) caused by brain trauma or by objective neurological findings that can be reasonably attributed to TBI on physical examination or mental status examination. In addition, subjects included in the database must 1) meet at least one of the following criteria for moderate to severe TBI: PTA > 24 h, trauma-related intracranial neuroimaging abnormalities, loss of consciousness > 30 min, or a Glasgow Coma Scale score (GCS) in the emergency department of < 13 (unless caused by intubation, sedation, or intoxication); 2) be at least 16 years of age at the time of injury; 3) present to the Model System's acute care hospital within 72 h of injury; 4) receive both acute hospital care and comprehensive rehabilitation in a designated brain injury inpatient unit within the Model System; and 5) provide informed consent to participate or have a proxy provide consent.[18]

For purposes of this study, the TBIMS NDB as of March 30, 2013 was limited to 7373 individuals treated within 20 TBIMS Centers, with inpatient rehabilitation admission dates beginning between October 1, 2001 and December 31, 2010, and with follow-up or death dates through December 31, 2011. This sample was further reduced to 6913 cases because of missing data on key variables necessary to calculate the SMRs (e.g., race/ethnicity, gender, age, death status, date of death). Information in the database was collected during acute care and rehabilitation hospitalization, and at 1 year, 2 years, 5 years and every 5 years thereafter at the approximate anniversary of injury. The rate of successful follow-up across all follow-up time points is 80%.[18]

TBIMS staff attempted to contact individuals for an interview; if they were told that the person had died, or a search in the Social Security Death Index indicated that the person had died, the death date was entered in the NDB. TBIMS staff then attempted to obtain the death certificate, which was sent to the TBIMS National Data and Statistical Center (NDSC) for the purpose of coding causes of death using the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) codes and entering those codes into the NDB. ICD-9-CM is used to code cause of death for the NDB to maintain coding consistency across years since the NDB began prior to the implementation of ICD-10. One primary cause of death, one secondary cause of death, and one external cause injury and poisoning (E-code) cause of death are recorded in the NDB based on guidelines specified for coding for the NDB, which could include both Cause of Death Part I and Part II of the death certificate.[19] If an E-code is indicated as a cause of death, it becomes the primary cause of death. For the purposes of this study, only the primary cause of death was used.

If *between follow-up interviews* center staff learned that a participant had died (e.g., perhaps through a clinical contact or the participant's medical record), the date of death was recorded in the NDB at that time. If contact with the participant or a knowledgeable proxy at a routine follow-up was not made, center staff attempted to verify the vital status of participants using the Social Security Administration's Death Index (SSDI). If a person was not listed in the SSDI as deceased and could not be found, he or she was reported as lost at that time. Even if a person were reported as lost at one scheduled interview, the staff would attempt to contact the individual at the next scheduled follow-up. Cases reported as lost were censored at the previous follow-up point at which the person's vital status could be verified (i.e., the person or a proxy was interviewed, the person or a proxy refused to be interviewed, the person withdrew from the study, or the person was incarcerated).

The TBIMS NDB can be weighted to represent individuals who received inpatient rehabilitation for a primary diagnosis of TBI in the US. The TBIMS NDB data were weighted using an iterative proportional fitting (IPF) procedure (also called "raking") that simultaneously aligns the proportions of numerous sample characteristics, such as age and gender, with those of the larger population. In this case, sample distributions were the distributions of the categorical characteristics of the TBIMS NDB, and the populations' values were the distributions of the categorical characteristics of the US TBI rehabilitation population included in the article by Cuthbert and coworkers.[16] Variables included as part of the raking procedure, including the categorical distributions used, have been previously reported.[20] One requirement of raking is that proportions within both the sample and population must be ≥ 5%; therefore, instances in which either the US TBI rehabilitation population characteristics or those of the TBIMS NDB were found to be below this threshold were combined with additional categories. Missing values for these characteristics were rare (< 33%) in the TBIMS NDB; however, those subjects with missing data across any of these variables had the missing value imputed using the estimation maximization algorithm prior to implementation of the raking procedure. At the completion of raking, weights were assessed by weight trimming, a process in which extreme weights (e.g. weights beyond the 95th or 99th percentiles) are removed, to reduce the mean squared error in subsequent analyses. However, in this particular case, weight trimming was not found to reduce the mean squared error for any of the evaluated outcomes; therefore, no weight

trimming was performed. All raking was completed using SAS Version 9.3. Raking was completed prior to all analyses performed, as described in the Statistical analysis.

Statistical analysis

The data analysis for this study was performed using SAS software, Version 9.3 for Windows (SAS software, Version 9.3 of the SAS System for Windows, SAS Institute Inc., Cary, NC). Descriptive statistics (means for continuous variables and counts and proportions for categorical variables) were used to characterize the study sample. Vital status was determined as indicated. Only deaths occurring after discharge from the initial inpatient rehabilitation and before January 1, 2012, were included in the study.

The expected number of deaths in the absence of TBI was calculated by applying age-sex-race-specific mortality rates published by the federal government[21] for the calendar year 2005 (the median person-years of follow-up in the study) to each year of follow-up for each person in the study, and summing the results. The SMR for this TBI population was calculated as the ratio of actual number of deaths to the expected number of deaths. Statistical significance of the SMR was determined by calculating the 95% confidence interval, which was considered significant if that confidence interval did not contain one.[22]

SMRs were also calculated for age, race, gender, TBI severity (based on GCS score at emergency department admission) and time post-injury, and specific causes of death. For the cause of death-specific SMRs, the expected number of deaths in the absence of TBI was calculated using the methodology described previously, with the age-sex-race-specific mortality rates taken into account for each cause of death category.[21] In 1999, the federal government transitioned from using ICD-9 to ICD-10 for coding the cause of death. The cause of death mortality rates based on ICD-10 code categories were used to calculate expected deaths for the SMRs, and these were then matched to observed causes of death by ICD-9 code categories, because the NDSC had used the ICD-9 to code the death certificates (ICD-9/ICD-10 code category crosswalk, which was matched by organ system categories from the CDC WONDER system).

Comparative life expectancy with and without TBI by age, sex, and race was estimated by applying the overall SMR for those with TBI to the latest age-sex-race-specific mortality rates published by the federal government for the most recent year available at the time of this study (calendar year 2010), using the methodology described by DeVivo.[22] It is of note that this methodology assumes a constant SMR with advancing age, and often results in a slight underestimation of long-term survival probabilities and life expectancy.

Finally, to assess the impact of each potential mortality risk factor, Cox proportional hazards regression analysis based on the weights generated by the IPF was conducted, taking into account the number of days in the study. A backward selection procedure was used so that each risk factor had the opportunity to be considered in the model reduction process. Only risk factors that exhibited a significant relationship ($p < 0.05$) with the outcome of interest were retained. Demographic factors assessed in the analyses were age at injury, sex, race/ethnic group, level of education, marital status, and employment status at injury. Pre-injury drug use and alcohol use were also used as factors. Injury-related risk factors included

calendar year of injury (i.e., to determine if risk of death was greater having had an injury a decade earlier than more recently, for example because of improvements in medical care), and cause of injury. Other potential risk factors included the number of days from injury to inpatient rehabilitation discharge, third-party sponsor for rehabilitation care, place of discharge after rehabilitation, and the Functional Independence Measure (FIM) Scores (Motor and Cognitive)[23] and the Disability Rating Scale (DRS)[24] scores at rehabilitation discharge. For the purposes of this study, DRS had a score range of 0, indicating no disability, to 29, indicating extreme vegetative state.

Results

The final study sample was 6913 cases. (The weighting creates decimal places of the number of individuals and this is also reflected in the number of deaths; however, these overall values have been rounded, with the exception of the observed and expected deaths.) This sample represented 146,708 cases once weighted to the national population. This sample included participants from 20 participating TBIMS centers, with a total of 20,314 person-years of life with TBI included for analysis. The length of follow-up in the study ranged from 1 day to 10.2 years beyond discharge from in-patient rehabilitation. There were 1325 deaths during the length of the study, producing a mortality rate of 19.2%; with 446 of these deaths (34%) occurring between inpatient rehabilitation discharge and one year post-injury.

Table 1 summarizes the study sample characteristics and compares the individuals who died with those who were alive at the end of the study period. The average age at injury of all the study participants was 55 years; 65% were men; and 80% were white. The largest proportion of injuries resulted from falls (47%), 38% of injuries were vehicular related, and 7% were from acts of violence. The majority of the individuals in the study had a mild TBI based on their GCS score recorded at the time of hospital emergency department admission (i.e., a GCS score of 13–15) (52%). However, this cohort had on average 5 days of unconsciousness, and 19 days of PTA, indicating more severe TBI. Individuals in the study had moderate disability on average, based on their DRS score at the time of inpatient rehabilitation discharge. It is of note that cases in the TBIMS NDB must meet at least one criterion of moderate to severe TBI, as indicated in the inclusion criteria mentioned previously, and, therefore, even with a GCS score in the mild range, these cases would have had another of the injury severity indicators (i.e., PTA, positive neuroimaging findings, duration of unconsciousness) in the moderate to severe range. Individuals who died tended to be older and more likely to have had TBIs resulting from falls, but had less severe TBIs (based on GCS). However, these characteristics of the results may be misleading, in that the risk factors are not independent from one another. The Cox regression analysis addresses these associations.

Table 2 contains the SMRs by study participant characteristics. Based on age-sex-race-specific mortality rates for the US general population, in the absence of TBI, and given the length of time each person was followed, the expected number of deaths for all individuals included in the study was 595. As 1325 deaths were observed, the SMR was 2.23, indicating that individuals with TBI were more than twice as likely to die during the time period of the

study as individuals of comparable age, sex and race in the general population. For those individuals who survived at least until their 1 year post-injury anniversary, the SMR was lower (1.54), indicating that the risk of death was greater within the 1st year post-injury. As age at injury increased, SMRs generally decreased, but still remained elevated up to age 85. Males had a greater excess mortality (i.e., a greater number of deaths than expected) than females, and Asians had the highest excess mortality of any race/ethnicity category. Finally, the risk of death generally increased as injury severity (based on GCS) increased.

The estimated life expectancy in years (calculated under the assumption of a constant SMR of 2.23 in individuals with TBI), for various age, sex, and race groups, with and without TBI is given in Table 3. For example, in the US general population, a white male, age 35, has an estimated life expectancy of 38 more years (or until age 73); whereas the same individual who sustains a TBI at age 35, has an estimated life expectancy of only 31 more years (or until age 66). Life expectancy was shortened between 1 and 10 years, depending upon age at injury, race, and sex. On average, TBI reduced life expectancy in this cohort by 9 years.

The results of the multivariate Cox regression analysis to identify the independent risk factors for death after TBI are provided in Table 4. There was a 3% *increased* risk of death for each additional year of age at injury. Females had a 53% *lower* risk of death than males. Those with a bachelor's degree at the time of injury had a 24% *lower* risk of death than those with less than a high school education. Those who were divorced, widowed, or separated at the time of TBI had a 37% *greater* risk of death, and those who were never married had a 27% *lower* risk of death, than those who were married. Persons who were competitively employed (i.e., minimum wage or greater, legal or illegal employment, including on leave with pay) at the time of injury had a *lower* risk of death than those who were unemployed, retired, or reported another type of primary productive activity such as homemaking or volunteering. There was a 19% *increased* risk of death for every 1 year increase in calendar year of injury (i.e., those injured in 2008 had a 19% increased risk of death over those injured in 2007). Individuals whose TBI was the result of a fall were at a 36% *greater* risk of death than individuals injured as a result of a vehicular crash. Those who were discharged from inpatient rehabilitation to anywhere other than their home were at an 18% *greater* risk of death than those discharged home. There was a 1% *lower* risk of death for every one point increase in the discharge FIM motor subscale score (i.e., higher motor functional independence). Finally, there was a 7% *increased* risk of death for every one point increase in the DRS score (i.e., greater disability).

Deaths by primary cause are provided in Table 5, as are the cause of death-specific SMRs for the causes accounting for the greatest proportion of deaths, or those identified in the literature as potentially being greater than expected for individuals with TBI. The largest number of deaths was secondary to circulatory conditions (26%), with the majority of those being caused by ischemic or other heart disease. The next largest portion of deaths was attributable to respiratory conditions (13%), with almost half of those being from pneumonia. The third largest group was secondary to neoplasms (9%), which were predominantly lung cancer. In addition, 7% of deaths were from external causes of injury and poisoning, and 6% were caused by infectious diseases (sepsis).

For all individual causes that were examined, the cause-specific SMR was greater than expected and statistically significant, except for digestive conditions. Individuals with TBI were 50 times more likely to die of seizures, 10 times more likely to die of unintentional poisoning, 9 times more likely to die of sepsis, 6 times more likely to die of aspiration pneumonia, 5 times more likely to die of a fall or homicide, 4 times more likely to die of pneumonia or all external causes of injury and poisoning combined, 3 times more likely to die of a vehicular crash, more than 2 times more likely to die of suicide or all respiratory conditions combined, 2 times more likely to die of mental or behavioral conditions, or nervous system conditions, and 1.4 times more likely to die of circulatory conditions, than individuals in the general population of similar age, gender, and race.

Discussion

This study reexamines the findings of the 2012 TBIMS NDB study on life expectancy by reanalyzing the data with weighting to represent the US population of individuals admitted to inpatient rehabilitation with a primary diagnosis of TBI. It should be noted that any differences in findings between this study and the 2012 TBIMS study are likely to be explained by two conditions. First, there is the effect of the weighting to the US population of individuals admitted to inpatient rehabilitation with a primary diagnosis of TBI. Because the weighted population is older, these age effects can alter the findings. Second, there are differences between the unweighted TBIMS cohorts used in each of these studies, which could result in some differences in findings simply based on the time frame of the studies. The previous study included 8573 individuals followed between 1988 and 2009, which resulted in 41,662 person-years of life with TBI, and used general population data for calculating SMRs and life expectancy from 1999 and 2007, respectively. This current study included 6913 individuals followed between 2001 and 2011, which resulted in 20,314 person-years of life with TBI, and used general population data for calculating SMRs and life expectancy from 2005 and 2010, respectively. It is notable that the makeup of the US population admitted to rehabilitation for a primary diagnosis of TBI has been changing during the decade covered and, therefore, a few years' difference can result in different estimates.[15,16]

Similar to the 2012 study findings, individuals in this weighted sample were more than twice as likely to die as individuals of similar age, sex, and race in the general population without TBI. As with the prior study, SMR was highest for 15–19-year-olds (SMR 11.58) and decreased with increasing age. However, in the current study, the SMR for those ≥ 85 years of age was similar to that in the general population for that age group. In both the prior study and this study with weighting, we found shortened life expectancy for both genders when compared with the general population (SMR for males was 2.60 and for females it was 1.75). All GCS levels of injury severity were again found to present a greater risk of death than for the general population, with sedated, severe, and moderate GCS scores having much higher SMRs than mild scores.

We again found Asians to have the greatest increase in mortality, with all races at greater risk than the general population. As in the 2012 TBIMS study, among individuals with TBI, neither Asian descent nor any other race/ethnicity was a significant independent risk factor

for death. It is the relatively *low* rates of death in the Asian general population that produce a high SMR for Asians with TBI, but the latter group's death rate is not significantly different from that of other ethnic/race categories within the TBI sample.

Consistent with the prior study, risk factors of death identified in this study included older age, male gender, lower education, being divorced/widowed/separated, being unemployed/retired/volunteer/homemaking/other rather than employed, a more recent calendar year of injury, TBI caused by a fall, discharge to a non-private residence, and greater disability and functional dependence. TBI reduced life expectancy rates by an average of 9 years, compared with 6.7 years in the prior study.

Because the weighted population was older on average, it is not unexpected that the mortality rate was twice that reported in the 2012 TBIMS study (19.2% vs. 9.8% respectively). Causes of death were most commonly (listed in decreasing magnitude of SMR): cardiovascular disease, respiratory disease (particularly pneumonia), neoplasm, external causes of injury and poisoning, and infectious disease. There was an expected change in the rank order of the most frequently occurring causes of death in this study, compared with the 2012 TBIMS study, with those causes more commonly occurring in the elderly ranking closer to the top in this study because of the prevalence of an older population. The causes most highly increased in TBI, compared with the general population (listed in decreasing magnitude of SMR) were seizure, accidental poisoning, sepsis, aspiration pneumonia, fall, homicide, pneumonia, vehicular accidents, suicide, mental disorders, nervous system conditions, and circulatory conditions.

Death from digestive causes was not greater than for the general population, which is in contrast to prior studies (including the 2012 TBIMS NDB study), which have found digestive conditions as a cause of death to occur two to three times more often than in the general population.[5,13,14] In this current TBIMS cohort, the un-weighted death number from digestive conditions represented 2.91% of all deaths. The weighting drops this 2.06%, indicating fewer deaths from digestive conditions in the weighted cohort. Additionally the unweighted SMR for deaths from digestive conditions is 2.61, and is statistically significant (as in the 2012 TBIMS study). However, in the weighted cohort, the SMR drops to 1.51 and is no longer significant. Therefore, the change in this finding from the previous study is likely to be the result of the weighted cohort representing older individuals. We found in the previous study that the deaths related to digestive conditions tended to be in younger individuals and were often related to cirrhosis or other alcohol-related conditions.

This study confirms prior findings that people with TBI are at much higher risk of dying from seizure than the general population (50 times more likely in the present study, 33 times more likely in the 2012 study, and 15–37 times more likely in several other studies.[5,13,14] Unfortunately, the reason one dies from seizure after TBI is still not well understood. Therefore, there is still inadequate knowledge about whether these deaths could be prevented and, if so, how that could be achieved. The current scientific evidence does not support the use of prophylactic anticonvulsants to prevent seizures in the years after TBI.[25,26] We do not know, from the available studies and the data available for this study, the seizure history of those who did and did not die. For example, we do not know if those who died had a history

of seizures, if they were on anticonvulsant therapy, and if the anticonvulsant treatment was therapeutic. Fortunately, seizure is a *relatively* infrequent cause of death. The infrequent and unexpected nature also makes it difficult to study.

Many studies have found that infections from septicemia, aspiration pneumonia, and pneumonia cause a higher than expected number of deaths among individuals with TBI than in the general population. Future studies need to collect clinically relevant information about what factors caused or contributed to these infections, if these infections represented repeated episodes, and if the infections might have been prevented or detected and treated earlier.

External causes of injury and poisoning (specifically, fall, accidental poisoning, homicide, vehicular accidents, and suicide) are consistently more common among people with TBI than the general population, pointing to an important area needing clinical and research attention. Review of the 22 cases of accidental poisoning reveals that 21 of the deaths were the result of toxicity from either alcohol or narcotic agents or a combination of alcohol and narcotic(s). The remaining case was the result of acetaminophen toxicity. It is not known if these cases of narcotics toxicity represented prescribed or illicit use. Clinical education of our patients about the risk of death from these substances, screening for drug and alcohol abuse, and prompt referral for treatment when needed appears warranted.

Falling is a leading cause of TBI and, a risk factor for death after TBI, and appears to be a more common cause of death after experiencing a TBI. Clearly, it is important after TBI to assess the risk of fall, provide education about fall prevention, remove environmental barriers, and correct (when possible) physiologic contributors (e.g., impairments in balance, vision, muscle tone, and cognitive function). The greater than expected number of homicides and suicides among those with TBI points to the need to identify those at high risk, to identify methods of controlling impulsive and aggressive behaviors and emotional dysregulation, and to develop screening and education programs. Further research is needed in this area to potentially prevent deaths from injury.

Prior studies, including the 2012 TBIMS NDB study, have found digestive conditions as a cause of death to occur two to three times more often among those with TBI than in the general population.[5,13,14] Further information about the digestive causes and the individual's medical history would be needed to use this finding to prevent such deaths. Important information for clinicians and researchers to consider would include the presence of alcohol use or abuse, liver disease, and medication effects.

Findings from this study inform clinical practice about risk factors that can be planned for upon discharge from inpatient rehabilitation. Behavior regulation is a common issue after TBI, and is often compounded by the presence of physical disabilities when patients leave the hospital. Safety assessments as part of discharge planning can help identify patient needs for monitoring and supervision in their post-discharge environments. Training and education for family members and caregivers can increase prevention of risks, particularly unintentional injuries. Existing programs that help evaluate fall risk such as Stopping Elderly

Accidents, Deaths and Injuries (STEADI) can provide tools for assessment and fall prevention.[27]

Study limitations

Because the sample does not include those who did not require hospitalization or did not receive inpatient rehabilitation, these findings may not represent the broader group of all individuals who experience TBI. It is not known if the deaths that are more common after TBI are specifically caused by the primary or secondary effects of TBI or concurrent injury to other organ systems, or, perhaps, are related to the premorbid conditions that may have predisposed individuals to the original TBI. As with most studies of mortality, missing causes of death may result in an underestimation of some causes of death, and study attrition may lead to an underestimation of the risk of death and life expectancy. The risk factors studied here were limited to the data available in the TBIMS NDB, which until recently has not collected data about general lifestyle and medical health (e.g., medical history, smoking, alcohol, weight, diet, exercise), and does not collect data on other important factors associated with risk of death in the general population (e.g., medications, family history, preventive screenings). The sample available to be weighted to the larger population of those receiving inpatient rehabilitation in the US was not from the same time frame as the 2012 TBIMS life expectancy study, and individuals were not followed for as long in the current study. Therefore, some of the findings may have differed. Regardless, many findings were similar to those previously reported.

Conclusions

This study confirms that the prior 2012 findings of the TBIMS NDB are representative of the larger population of those ≥ 16 years of age who receive inpatient rehabilitation in the US. Similar to prior studies, it appears clear that individuals with TBI who require acute inpatient rehabilitation, taken as a whole, have shortened life expectancy, with consistently identified risk factors and uniquely common causes of death. Many of these causes of death appear to be potentially preventable, particularly injuries and accidental poisonings. Studies of interventions aimed at early mortality prevention would be helpful to determine if premature deaths after TBI can be prevented. The findings of this study support the prevailing concept of TBI as a chronic medical condition that should be managed as such.[28,29]

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Table 1

Demographic and Injury-Related Characteristics

Characteristic	Died during the study period	Alive at the end of the study period	Full sample
Number of cases	1325	5588	6913
Age at injury (mean and SD)	72.4 (22.3)	51.4 (22.0)	55.4 (23.5)
Sex			
Male	65.7%	64.7%	64.9%
Female	34.3%	35.3%	35.1%
Race			
Non-Hispanic White	84.4%	79.2%	80.2%
Black	6.47%	10.1%	9.4%
Hispanic origin	4.6%	7.5%	6.9%
Asian/Pacific Islander	4.5%	3.3%	3.5%
Cause of Injury			
Vehicular	19.6%	42.3%	37.9%
Fall	72.9%	41.4%	47.4%
Violence	3.7%	7.7%	6.9%
Pedestrian	3.1%	5.4%	5.0%
Sports	0.1%	1.7%	1.4%
Other (including falling object)	0.6%	1.6%	1.4%
Glasgow Coma Scale score at emergency department (ED) admission (mean and SD)	13.0 (4.7)	11.5 (4.2)	11.7 (4.3)
Severe (3–8)	10.5%	22.4%	20.2%
Moderate (9–12)	11.3%	10.0%	10.3%
Mild (13–15)	69.1%	48.1%	52.0%
Sedated	9.2%	19.4%	17.5%
Days of post-traumatic amnesia (mean and SD)	18.7 (27.8)	19.5 (16.2)	19.4 (17.4)
Days of unconsciousness(mean and SD)	3.6 (13.2)	5.3 (9.7)	5.0 (10.1)
Functional Independence Measure (FIM) Motor Subscale score at rehabilitation discharge (mean and SD)	54.3 (28.5)	67.7 (15.9)	65.1 (18.3)
FIM Cognitive Subscale score at rehabilitation discharge (mean and SD)	21.3 (10.7)	24.5 (6.1)	23.9 (6.8)
Disability Rating Scale score at rehabilitation discharge	8.3 (6.7)	5.9 (3.2)	6.3 (3.8)

Table 2

Standardized Mortality Ratios (SMRs), by Characteristics of Individuals with TBI During the Time Period of the Study

	Observed deaths	Expected deaths	SMR[a]	95% confidence interval
Overall	1325.4	594.7	**2.23**	2.11–2.35
By time period				
> 1 year post–injury	879.2	570.7	**1.54**	1.44–1.64
Age at injury				
15–19	7.6	0.7	**11.58**	3.37–19.79
20–24	17.1	2.5	**6.86**	3.60–10.11
25–34	26.9	3.3	**8.24**	5.12–11.35
35–44	46.6	4.9	**9.56**	6.82–12.31
45–54	104.2	12.2	**8.55**	6.91–10.19
55–64	107.5	21.3	**5.04**	4.09–5.99
65–74	245.1	55.6	**4.41**	3.86–4.96
75–84	530.0	200.8	**2.64**	2.41–2.86
≥ 85	240.3	293.5	0.82	0.72–0.92
Sex				
Male	871.1	335.7	**2.60**	2.42–2.77
Female	454.2	259.1	**1.75**	1.59–1.92
Race/ethnicity				
White	1118.0	520.0	**2.15**	2.02–2.28
Black	85.7	35.2	**2.43**	1.92–2.95
Hispanic	61.4	22.2	**2.76**	2.07–3.45
Asian	60.2	17.3	**3.49**	2.61–4.37
Glasgow Coma Scale Score at emergency department (ED) admission				
N/A, sedated at ED admission	111.6	26.8	**4.17**	3.40–4.94
Severe (3–8)	127.6	32.7	**3.90**	3.23–4.58
Moderate (9–12)	138.0	29.6	**4.67**	3.89–5.45
Mild (13–15)	837.4	463.4	**1.81**	1.69–1.93

[a]Bolded SMRs are statistically significant; that is, the mortality of individuals with TBI is different from that of the general population.

Table 3

Estimated Years of Life Expectancy, by Race/Ethnicity, Age, and Gender, With and Without TBI[a]

	White				Black				Hispanic				Asian			
	Male		Female		Male		Female		Male		Female		Male		Female	
Age	TBI	NonTBI	TBI	NonTBI	TBI	NonTBI	TBI	NonTBI	TBI	NonTBI	TBI	NonTBI	TBI	NonTBI	TBI	NonTBI
15–19	49	58	55	63	42	52	49	58	43	52	51	58	56	64	60	68
20–24	45	53	50	58	38	47	45	54	39	47	46	54	51	59	55	63
25–34	40	48	46	53	34	43	40	49	35	43	42	49	47	54	50	58
35–44	31	38	36	43	25	34	31	39	26	34	32	39	37	44	41	48
45–54	23	29	27	34	18	25	23	30	19	25	23	30	28	35	31	39
55–64	15	21	19	25	12	18	16	22	12	17	16	21	20	26	22	29
65–74	9	14	12	16	7	12	10	15	6	10	9	13	12	17	15	21
75–84	5	7	6	9	4	7	5	9	3	5	4	7	7	10	8	12
85 +	2	4	2	4	2	4	2	5	1	2	1	3	3	5	4	7

[a]Assuming a standardized mortality ratio (SMR) of 2.23 among individuals with traumatic brain injury (TBI).

Table 4

Multivariate Cox Regression Analysis: Risk Factors for Death after TBI[a]

Characteristics	Relative risk[b]	95% confidence interval
Age at injury	1.03	1.02–1.04
Female	0.47	0.41–0.54
Level of education at injury		
Less than high school (reference group)	–	–
High school/GED	1.07	0.92–1.25
Some college/associates degree	1.16	0.96–1.41
Bachelor's degree	**0.76**	0.61–0.94
Post-bachelor's degree	1.02	0.82–1.28
Marital status at injury		
Married (reference group)	–	–
Never married	**0.73**	0.59–0.91
Divorced/widowed/separated	**1.37**	1.20–1.57
Employment status at injury		
Competitively employed (reference group)	–	–
Unemployed	**2.25**	1.60–3.18
Retired	**2.21**	1.72–2.85
Student (part-time/full-time/special education)	0.96	0.40–2.30
Other (homemaker/volunteer/other)	**3.87**	2.75–5.44
Year of injury	**1.19**	1.16–1.23
Cause of injury		
Vehicular (reference group)	–	–
Falls	**1.36**	1.16–1.61
Pedestrian	0.91	0.64–1.28
All sports	0.30	0.05–2.01
Violence	1.00	0.71–1.40
Other (including falling object)	0.47	0.21–1.06
Discharged to other than private home residence	**1.18**	1.03–1.36
FIM motor score at rehabilitation discharge	**0.98**	0.98–0.99
DRS score at rehabilitation discharge	**1.07**	1.06–1.09

[a]Based on 6113 cases with complete information.

[b]Bolded relative risk figures are statistically significant.

TBI, traumatic brain injury: FIM, Functional Independence Measure; DRS, Disability Rating Scale.

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Table 5

Causes of Death, and Standardized Mortality Ratios (SMRs) for Selected Causes

Organ system (ICD-9/ICD-10 codes)	Observed deaths	Percent	Expected deaths	SMR[a]	95% CI
Circulatory (390–459/I00–I99):	340.8	26%	239.8	**1.42**	1.27–1.57
Ischemic heart disease (410–414)	126.6	9.6%			
Other heart disease (420–429)	81.2	6.1%			
Cerebrovascular disease (430–439)	69.0	5.2%			
Hypertensive disease (401–405)	29.8	2.2%			
Arterial disease (440–449)	20.1	1.5%			
Pulmonary circulation disease (415–417)	12.9	1.0%			
Venous disease (451–459)	1.2	< 1%			
Respiratory (460–519/J00–J98):	176.6	13%	67.5	**2.62**	2.23–3.00
Pneumonia (480–486/J12–J18)	80.0	6%	19.3	**4.15**	3.24–5.06
Chronic obstructive pulmonary disease (COPD) and allied conditions (490–496)	38.3	3%			
Aspiration pneumonia (507/J69)	36.6	3%	5.7	**6.40**	4.33–8.48
Other respiratory disease	21.7	2%			
Neoplasm (140–239):	116.3	9%			
Other/unspecified site (190–199)	22.6	1.7%			
Respiratory (160–169)	21.0	1.6%			
Genitourinary (179–189)	20.1	1.5%			
Uncertain behavior/unspecified nature (235–239)	19.0	1.4%			
Digestive organs (150–159)	16.3	1.2%			
Lymphatic/hematopoietic (200–208)	12.7	1.0%			
Bone, breast (170–176)	3.9	< 1%			
Neuroendocrine (209)	0.6	< 1%			
External causes of injury and poisoning (E800–E999/V01–Y89):	92.8	7%	23.7	**3.91**	3.12–4.71
Fall (E880–E888/W00/W19)	30.7	2%	5.7	**5.35**	3.46–7.24
Accidental poisonings (E850–E869/X40–X49)	20.7	2%	1.9	**10.68**	6.08–15.28
Vehicular (E800–E848/V01–V99, Y85)	17.6	1%	5.1	**3.44**	1.83–5.05
Suicide (E950–E959/X60–X84, U03)	10.1	< 1%	3.8	**2.64**	1.01–4.27
Homicide (E960–E969/X85–Y09, U01–U02, Y87.1)	7.1	< 1%	1.4	**4.92**	1.30–8.54

Organ system (ICD-9/ICD-10 codes)	Observed deaths	Percent	Expected deaths	SMR[a]	95% CI
Other accidents (E916–E928)	2.0	< 1%			
Injury of unknown intent (E980–E989)	1.9	< 1%			
Submersion, suffocation (E910–E915)	0.8	< 1%			
Adverse effect of treatment (E934)	0.7	< 1%			
Medical complication (E879)	1.3	< 1%			
Infectious disease (001–139):	85.2	6%			
Sepsis (038/A40–A41)	76.3	6%	8.1	**9.37**	7.26–11.47
Other infectious disease	8.9	< 1%			
Nervous system (320–389/G00–G98):	63.8	5%	35.9	**1.78**	1.34–2.21
Hereditary/degenerative CNS disease (330–337)	56.5	4%			
Other nervous system disease	7.3	< 1%			
Mental disorders (290–319/F00–F99)	47.4	4%	21.8	**2.17**	1.55–2.79
Diseases of the genitourinary system (580–629)	35.9	3%			
Diseases of the digestive system (520–579/K00–K92)	27.4	2%	18.2	1.51	0.94–2.07
Other signs, symptoms, ill–defined conditions (780–799, not 780.3)	24.4	2%			
Diseases of the endocrine, immune, systems (240–279)	21.2	2%			
Seizure (780.3/G40–G41, R56.8)	13.3	1%	0.3	**50.00**	23.15–76.84
Congenital anomalies (747)	10.4	< 1%			
Diseases of blood (280–289)	2.7	< 1%			
Diseases of the skin, subcutaneous, connective tissue (680–739)	0.8	< 1%			
Unknown cause	266.5	20%			
Total deaths	1325.4				

[a]Bolded SMRs are statistically significant; that is, the mortality of individuals with traumatic brain injury (TBI) is different from that of the general population.

ICD, International Classification of Diseases.