Mortality following rehabilitation in the Traumatic Brain Injury Model Systems of Care

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Abstract. While many outcomes after traumatic brain injury (TBI) have been systematically investigated, the most basic of all outcomes – survival – has been neglected. The purpose of this study was to investigate mortality in a cohort of 2,178 individuals with TBI completing inpatient rehabilitation in one of 15 National Institute on Disability and Rehabilitation Research-funded TBI Model Systems of care. The study hypotheses were: (1) relative to the general population, TBI increases mortality and decreases life expectancy in individuals with TBI completing inpatient rehabilitation and surviving to one-year post-injury; and (2) within the TBI population, the risk of death is greater in certain TBI subgroups. Results indicate that individuals with TBI were twice as likely to die compared to individuals in the general population of similar age, gender and race, resulting in an estimated average life expectancy reduction of seven years for individuals with TBI. Within the TBI population, the strongest independent risk factors for death after one-year post-injury were older age and not being employed at injury, and greater disability at rehabilitation discharge. This information is important to guide decision-making for treatment, utilization of limited medical resources, and planning for ongoing health care needs and lifetime planning.

Keywords: Traumatic brain injury, mortality, life expectancy

1. Introduction

1.1. Overview and purpose

Traumatic brain injury (TBI) is a leading cause of death and disability in the United States [55]. Of the 1.59 million Americans who sustain TBI annually [55], 15% are admitted to acute hospitals [54–56], and 20% of those hospitalized require inpatient rehabilitation [4,24,43,57]. While many outcomes after TBI have been systematically studied [62], long-term survival has been neglected. Mortality during the first months after injury is associated with the initial injury, concomitant trauma and treatment received [5, 11,14,17–20,22,23,26,28,36,40]. However, the life expectancy of those who are discharged from inpatient rehabilitation and survive through the first year post-injury is largely unknown. While some reasonably good estimates of how long people live following TBI have been developed [2,6,16,21,30,32,38,39, 46–48,58–60], previous studies are limited by small sample sizes, non-representative samples due to secular changes over time, geography, and severity of disability. Thus, the question remains, how long are the

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"graduates" of our nation's rehabilitation programs surviving? And most importantly, are there risk factors that contribute to their death, which could be addressed earlier to avoid untimely death? Therefore, the focus of this study is to investigate mortality in a cohort of individuals with TBI who were discharged alive from inpatient rehabilitation.

1.2. Early mortality: Within the first year after injury

Much of the literature on mortality after TBI in adults has focused on predictors of early mortality, less than one year after injury [5,11,14,17–20,22,23,26,28,36, 40]. For example, studies involving hospitalized patients have found that roughly 90% admitted to a hospital with TBI are discharged alive, with factors such as age, admission Glasgow Coma Scale score, associated injuries, hypotension, hypoxia, and intracranial hemorrhage being associated with survival to hospital discharge [5,18–20,22,26,28,36].

Signorini et al. [40] reported that 75% of patients with TBI admitted to a regional trauma center were alive at one year post-injury, with mortality being associated with age, Glasgow Coma Scale score, injury severity, and presence of intracranial hemorrhage. In another study, one year post-injury mortality was 29% among 846 cases of severe TBI, and was predicted by Glasgow Coma Scale score, age, pupillary response and size, hypoxia, hyperthermia, and high intracranial pressure [17]. Gotsch et al. [14] followed a cohort of individuals with TBI from the time of acute hospital discharge and reported that 96% were alive at one year post-discharge.

1.3. Later mortality: After the first year post-injury

Studies of longer term survival have tended to involve registries of military veterans [6,30,58–60], individual clinics [2,21,32], or a specific database compiled by the California Department of Developmental Services [38,39,46,47]. Thus, the ability to generalize from these studies may be limited. Nonetheless, studies comparing death rates among individuals with TBI with the general population found higher rates among those with TBI [2,38,46,58]. For example, Shavelle et al. [38] reported that individuals with TBI ages 15 and older receiving services from the California Department of Developmental Services were 2.77 times more likely to die compared to the general population.

Most comparable to the current investigation are two studies that followed individuals with TBI discharged from inpatient rehabilitation programs. The first study reported a mortality rate of 5.7% after following individuals up to 11 years post-injury, with a median survival time of 17 months post-injury for those who had died [2]. Though a well-designed study, it was performed in Australia on a relatively small cohort of cases ($n = 476$) treated in one hospital; thus, its generalizability may be limited.

The second study reported a mortality rate of 5.3% after following individuals up to 10 years post-injury [16]. Like the present study, this study utilized data from the National Institute on Disability and Rehabilitation Research (NIDRR) funded TBI Model Systems National Database. However, consistent with the nature of longitudinal database studies, the loss to follow-up rate of 38% may have been particularly problematic in this study of mortality [16].

Though life expectancy goes hand-in-hand with mortality, the available literature seems no more complete. Nevertheless, two early studies did suggest that life expectancy was reduced by 3 to 5 years for "highly functioning" (i.e. ambulatory) adults with TBI [21,59].

1.4. Risk factors for later mortality

Risk factors for later mortality are also suggested in the literature. Seizure disorders is one of the earliest factors to be identified as being significantly associated with longer-term mortality after TBI [6,60]; however, this was not a universal finding [30].

A preliminary study utilizing the NIDRR-funded TBI Model Systems National Database found that older age at injury and elevated blood alcohol level at emergency department admission were predictive of later mortality [16]; however, alcohol was not shown to be a significant risk factor in the previously mentioned Australian study [2]. Finally, several recent studies have begun describing a different risk factor: functional status. In fact, function, particularly feeding and mobility is now reported to be a major determinant of life expectancy in both children and adults with TBI [39, 46].

In light of the findings and limitations of these previous investigations, a retrospective inception cohort study of individuals with TBI who completed inpatient rehabilitation and were included in the TBI Model Systems National Database [52] supplemented with vital status data from the Social Security Death Index [35] was conducted. The study hypotheses were:

– TBI increases mortality and decreases life expectancy in individuals with TBI completing inpatient rehabilitation and surviving to one year post-injury, relative to the general population.
– The risk of death is greater in certain TBI subgroups – those that are less functional and older at injury.

2. Methods

The Institutional Review Board (IRB) for Craig Hospital, as well as the IRB of each of the 14 other TBI Model System programs approved this study.

2.1. Data sources

2.1.1. The Traumatic Brain Injury Model Systems National Database

Since 1987, the US Department of Education, National Institute on Disability and Rehabilitation Research (NIDRR) has funded the Traumatic Brain Injury Model Systems of Care. These projects focus on (1) developing and demonstrating a model system of comprehensive care for persons with TBI, and (2) maintaining a standardized national database for innovative analyses of TBI treatment and outcomes. The TBI Model Systems project is a prospective, longitudinal multi-center inception cohort study that examines the course of recovery and outcomes of persons following TBI [50,53].

The TBI Model Systems National Database contains information on cases treated within the 17 TBI Model System programs funded between 1988 and 2002 and are distributed fairly broadly around the United States. TBI is defined as injury to brain tissue caused by an external mechanical force as evidenced by: loss of consciousness due to brain trauma, posttraumatic amnesia, skull fracture, or objective neurologic findings that can be reasonably attributed to TBI on physical or mental status examination. Subjects included in the database, in addition, must (1) be at least 16 years of age, (2) arrive at the participating hospital's acute care emergency department within 24 hours of injury, (3) receive both acute hospital care and inpatient rehabilitation within the defined Model System facilities, and (4) give written informed consent.

At the time of this study, the database contained information on 2,562 individuals treated within the 17 TBI Model System programs with injury dates beginning in 1988 through December 31, 2000 [52]. Infor-

mation in the database is collected during acute care and rehabilitation hospitalization, and annually thereafter on the anniversary of injury. The rate of successful follow-up over all years of follow-up (up to 12 years) is 62% [51]. Since the loss to follow-up has made the tracking of vital status uncertain [7,16], this study supplemented the database with vital status information obtained from the Social Security Death Index [35].

2.1.2. The Social Security Death Index

The Social Security Administration's Death Index (SSDI) was used in this study to determine the vital status of individuals in the TBI Model Systems National Database. The Social Security Administration [3,8,35] is one of a number of US agencies that track vital status [3,12,31,35]. The SSDI was available for public access through the World Wide Web at http://www.ancestry.com [42]. The sensitivity and specificity of the SSDI in determining vital status ranges from 88% to 99% [10,37,61].

2.1.3. Evaluation of the Social Security Death Index

The 15 TBI Model Systems that participated in this study used the SSDI to determine the vital status (as of December 31, 2001) of their cases in the database. Of 138 individuals who were known by the TBI Model System to be deceased, 123 were correctly identified by the SSDI as deceased, for a sensitivity of 89%. Of 747 individuals known to still be alive, none were identified as deceased by the SSDI (100% specificity). Therefore, the results of SSDI searches were deemed accurate enough to update the survival status of those individuals who were lost to follow-up by the Model Systems.

2.2. Statistical analysis

Descriptive statistics (means for continuous variables and proportions for categorical variables) were used to characterize the overall study population. For study hypothesis testing, survival was measured beginning at two different time points: 1) at the time of discharge from inpatient rehabilitation, and 2) at the one-year post-injury anniversary; with follow-up of study subjects being terminated on December 31, 2001. Only deaths occurring after rehabilitation discharge, or after the one-year post-injury anniversary, and before December 31, 2001 were included.

An important use of mortality data is to compare two or more populations that differ in regard to a particular characteristic, such as TBI, while holding constant

other characteristics, particularly age, which may account for observed differences in mortality. One approach used by epidemiologists is to compare the observed number of deaths to the expected number of deaths based on a reference population [13]. The expected number of deaths in the absence of TBI was calculated by applying age-gender-race-specific mortality rates published by the federal government [41] for the calendar year 1994 (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 result. The standardized mortality ratio (SMR) for this TBI population was then calculated as the ratio of actual to expected deaths. Statistical significance of the SMR was determined by calculating its 95% confidence interval, which was considered significant if it did not contain 1.0 [9].

Comparative life expectancy with and without TBI by age, gender and race was also estimated by applying the SMR to the latest age-gender-race-specific mortality rates published by the federal government [25] for the most recent year available at the time of this study (calendar year 2000) for those without TBI, using the methodology described by DeVivo [9].

Finally, to assess the impact of each potential mortality risk factor, Cox proportional hazards regression analysis was conducted taking into account survival time. For this analysis, only individuals surviving to their one-year post-injury anniversary were included ($n = 2,140$). Demographic factors assessed in the analyses were age at injury, gender, race, level of education and employment status at injury. Pre-injury history factors included prior hospitalization for TBI, drug use, problem alcohol use, problem substance use, being arrested, incarceration for felony conviction, suicide attempt, psychiatric hospitalization, being expelled from school, dropping out before high school graduation, being classified as a special education student, and being held back a grade in school. Injury-related risk factors included calendar year and cause of injury, highest Glasgow Coma Scale [49] score in the first 24 hours post-injury, duration of post-traumatic amnesia, and blood alcohol level at emergency department admission. Cranial complications occurring during initial hospitalization considered as risk factors included cerebral spinal fluid leak, intracranial infection, hydrocephalus with shunt, seizures, herniation syndrome, and intracranial hypertension. Other potential risk factors included the Model System where treatment occurred (each center was treated as a dichotomous variable of the center compared to all other centers), acute care and rehabilitation length of stay, third-party sponsor of care, place of discharge after rehabilitation, and the Functional Independence Measure [15] and the Disability Rating Scale [29] (Disability Rating Scale has a score range of 0 indicating no disability, to 30 indicating death) scores at rehabilitation discharge.

Univariate Cox models, controlling for age at injury (being the strongest risk factor) were used as a screen for inclusion in the final analysis. Factors with $p < 0.10$, suggesting age-independent association with mortality, were eligible for inclusion in the final multivariate analysis. Since our primary aim was a mortality prediction model, rather than focusing on the validity of a particular regression coefficient, a forward stepwise selection procedure was used to determine the final model, with $p < 0.05$ required for inclusion of any factor [34]. In addition, the 95% confidence intervals of the adjusted relative risk of each factor were calculated.

3. Results

Among the 2,178 individuals included in the study, a total of 8,793 person-years of life data with TBI were accumulated for analysis, with the length of follow-up ranging from 17 days to 12.8 years post-injury. The mean age of study participants at injury was 37.34 years, 76% were men, 60% were white, and 37% had severe TBI (highest Glasgow Coma Scale score in the first 24 hours post-injury of eight or less). In general, participants in the study were significantly more likely to be older, male, non-white, and have less severe TBI than individuals from the TBI Model Systems that did not participate in the study. Among individuals in the study, 98% experienced post-traumatic amnesia, and the average Disability Rating Scale score at rehabilitation discharge was 6 ($\pm$ 3.7), indicating a moderate amount of continued disability for most persons.

The majority of individuals (62%) were injured as a result of a motor vehicle crash, with 20% of injuries resulting from acts of violence, 16% resulting from falls, and 2% injured by other means. The average length of acute care and rehabilitation hospital stays were 21 days ($\pm$ 17 days) and 30 days ($\pm$ 25 days), respectively. Most individuals (84%) were discharged to a private residence, with 6% going to a nursing home. Slightly more individuals had private insurance (37%) as their third-party sponsor of care than Medicaid (31%), with 14% covered by an HMO/PPO, 9% covered by Medicare, and 10% by other payers.

Table 1
Estimated years of life expectancy by age, with and without TBI[*]

| Age | White | | | | Black | | | | Hispanic | | | |
| | Male | | Female | | Male | | Female | | Male | | Female | |
	TBI	NonTBI	TBI	NonTBI	TBI	NonTBI	TBI	NonTBI	TBI	NonTBI	TBI	NonTBI
20	46	54	52	59	39	48	46	55	48	57	55	63
30	37	45	42	49	31	39	37	45	40	48	46	53
40	28	35	33	39	23	31	28	36	31	39	36	43
50	20	27	24	30	16	23	20	27	23	30	27	34
60	13	18	16	21	11	16	14	19	16	22	19	25
70	7	12	9	14	6	11	8	13	10	15	12	17

[*]Assuming a constant standardized mortality ratio of two among individuals with TBI.

There were 161 deaths following inpatient rehabilitation, a mortality rate of 7.4%. The length of time between injury and death ranged from 49 days to 12.8 years, with a median interval of two years. Thirty-eight (24%) of the individuals who died, did so between the time of rehabilitation discharge and the one year post-injury anniversary. Thus 2,140 cases with 123 deaths were included in the analysis for the second study hypothesis.

Based on age-gender-race-specific mortality rates for the general population, the expected number of deaths in the absence of TBI given the length of time each person was followed was 80.59 for all individuals included in the study. Since 161 deaths were observed, the standardized mortality ratio (SMR) was 2.00 (95% confidence interval = 1.69–2.31); indicating that individuals with TBI were two times more likely to die than individuals of comparable age, gender and race from the general population. The 95% confidence interval for the SMR indicates that this increased risk was statistically significant. The SMR for individuals with TBI who survived past their one-year post-injury anniversary was 1.95 (95% confidence interval = 1.61–2.29), indicating a slightly higher risk for those who died between inpatient rehabilitation discharge and one year post-injury; however, these SMR's were not significantly different.

Table 1 contains the estimated life expectancy in years (calculated on the assumption of a constant SMR of two in individuals with TBI), with and without TBI for various age, gender and race groupings. Life expectancy was shortened between five and nine years depending on age at injury, race, and gender. For example, individuals injured at age 20 have their life expectancy shortened by seven to nine years, while individuals injured at age 70 have their life expectancy shortened by five years. Within a given age-at-injury category, the years by which life expectancy is shortened (relative to non-TBI expectations) rarely varies by more than a year or two depending on gender and race.

On average, TBI appeared to reduce life expectancy in this cohort by about seven years.

Table 2 describes the results of the univariate Cox regression analysis. This analysis (controlling only for age at injury as the strongest predictor) indicated that pre-injury history of attempting suicide, having hydrocephalus requiring a shunt during initial hospitalization, discharge to other than a private residence following rehabilitation, Medicaid as their sponsor of care, pre-injury history of being arrested, a center where treatment occurred, not being employed at injury, having a seizure or intracranial hypertension during initial hospitalization, being in post-traumatic amnesia at the time of rehabilitation discharge, having a blood alcohol level above 200 mg/dl at emergency department admission, having a violence-related injury, less education at injury, greater disability at rehabilitation discharge, less cognitive and motor function, and longer acute care hospitalization and rehabilitation length of stay were associated with an increased risk of death, independent of age, after one year post-TBI.

All of the above variables were then entered into a multivariate Cox regression analysis; older age and not being employed at injury, and greater disability at rehabilitation discharge (measured by the Disability Rating Scale) remained in the model as significant risk factors once all other factors were controlled for (see Table 3). Results indicated that there was a five percent increased risk of death for each additional year of age at injury. Individuals who were employed at the time of injury had a 55% lower risk of death than those who were not employed. There was a 12% increased risk of death for every one-point increase in the Disability Rating Scale score.

4. Discussion

This study found that individuals with TBI in this study were two times more likely to die than individuals

Table 2
Risk factors for death after TBI from Cox regression univariate analysis, adjusted for age at injury

Characteristics	Relative risk	95% confidence interval
Age at injury in years	1.058	1.048–1.068
Level of education at injury:		
– Less than high school (reference group)	1	
– Completed high school or GED	0.768	0.498–1.186
– Greater than high school education	0.526	0.319–0.867
Not employed at injury	0.448	0.293–0.684
Pre-injury history of being arrested	1.786	1.040–3.068
Pre-injury history of attempting suicide	2.857	1.124–7.261
Other than violence-related injury	0.697	0.464–1.039
Post-traumatic amnesia (PTA):		
– Still in PTA at rehab. discharge (reference gp)	1	
– 8+ days in PTA	0.532	0.354–0.801
– < 8 days in PTA/no PTA	0.596	0.327–1.085
Blood alcohol level at emergency dept. admission:		
– 200+ mg/dl (reference group)	1	
– 100–199 mg/dl	0.571	0.272–1.196
– < 100 mg/dl	0.441	0.219–0.889
– Negative	0.627	0.385–1.023
– No BAL testing performed	0.410	0.217–0.774
Hydrocephalus with shunt during hospitalization	2.528	1.275–5.013
Seizure during hospitalization	1.552	0.992–2.428
Intracranial hypertension	1.494	0.941–2.372
Center A	1.648	1.001–2.714
Center B	0.678	0.468–0.981
Center C	0.368	0.115–1.179
Length of acute care hospitalization stay in days	1.008	1.000–1.015
Length of rehabilitation stay in days	1.006	1.001–1.012
Medicaid as sponsor of care	1.882	1.254–2.825
Functional Independence Measure – cognitive subscale score at rehab. discharge	0.944	0.921–0.969
Functional Independence Measure – motor subscale score at rehab. discharge	0.977	0.969–0.986
Disability Rating Scale score at rehab. discharge	1.127	1.082–1.174
Rehabilitation discharge disposition:		
– Private (reference group)	1	
– Nursing home	1.898	1.158–3.111
– Adult home	1.887	0.911–3.909
– Acute hospital	4.759	1.916–11.818
– Rehabilitation hospital	3.938	0.961–16.143
– Other hospital	1.367	0.426–4.382
– Sub-acute	0.511	0.070–3.703
– Other	1.931	0.129–6.718

Table 3
Risk factors for death after TBI from Cox regression multivariate analysis

Characteristics ($n = 2,092$)	Relative risk	95% confidence interval
Age at injury	1.047	1.036–1.057
Employed at injury	0.454	0.295–0.698
Disability Rating Scale score at rehab. Discharge	1.124	1.078–1.172

of comparable age, gender and race from the general population. This finding is consistent with previous studies that found higher death rates among individuals with TBI [2,38,46,58]; such as, Shavelle et al. [38] who reported a slightly higher SMR of 2.77 in individuals with TBI ages 15 and older receiving services from the California Department of Developmental Services compared to the general population.

TBI reduced life expectancy an average of seven years in this study population; which was higher than had been reported in previous studies (i.e., 3–5 years) [6,21,30,32,39,46,47,59]. It should be noted that using a constant SMR with advancing age often results in a slight underestimation of long-term survival probabilities and life expectancy [9].

The strongest risk factors for death after one-year post-injury were older age and not being employed at injury, and greater disability at rehabilitation discharge.

Age, which is associated with co-morbidities such as heart disease and diabetes, was found to be a risk factor in some previous studies [16,21,32] but, surprisingly, not in others [6,46]. This finding confirms that individuals with TBI are more likely to die if they are older at the time of injury, and suggests that individuals with TBI need the same preventive interventions as the general population.

Employment at injury being a protective factor for later mortality following TBI does not appear to have been addressed in previous TBI mortality studies. However, previous studies of the US population found that mortality rates are higher among those not employed [33,44,45]. In fact, epidemiologists have termed this the "healthy worker effect", which suggests that fewer deaths are observed for workers compared to the US population; usually due to the employment of healthy workers [27]. It is also possible that employment represents a proxy for socioeconomic status, which has been shown to be negatively associated with mortality [1]. This finding suggests that those who are not employed at the time of injury deserve particularly close monitoring as they are at a higher risk of death after one year post-injury.

Finally, this study supported recent studies that reported function or disability status as predictive of mortality [2,38,39,46]. Disability was the only risk factor identified that is potentially "modifiable" from a rehabilitation perspective. Findings suggest that rehabilitation efforts focusing on reducing disability may be important to long-term survival. However, further research is needed to determine the causes and risk factors for death for those with greater disability. In the meantime, some comments on potential areas of intervention are given. Early on after TBI, perhaps increasing responsiveness through neurostimulant medication trials; treatment of occult seizures, neuroendocrine dysfunction, intracranial hypertension and hydrocephalus might allow functional gains that modify the disability risk factor. The individual with TBI should not neglect routine medical care which have been established by the medical community to minimize co-morbidities and promote healthy living. For example, age appropriate cancer screening; management of diabetes, hypertension, and hyperlipidemia; and regular aerobic exercise would be prudent. The effects of neglect of such issues begin to appear in the middle-aged and elderly, making this a relevant concern for the older individual with TBI.

Recently, another area receiving attention by rehabilitation researchers is aging with TBI. Perhaps focusing greater attention on physical fitness and lifestyle interventions adapted for individuals with disabilities may improve overall health and function in individuals with TBI as they age. It is also recommended to target individuals at greater risk for later mortality for closer follow-up after inpatient rehabilitation to provide patient and family education regarding the risk of death.

Seizure during acute care hospitalization was *not* found to be an independent risk factor for mortality after TBI in this study. At least two previous studies have found seizure disorder associated with death after TBI [6,60], while one did not demonstrate such a relationship [30]. It is important to note that the present study measured only seizures during initial hospitalization, which may very well have a different relationship with mortality than late-onset seizures.

Substance abuse was also *not* found to be an independent risk factor for mortality after TBI in this study. This supports findings from Baguley et al. [2], but not Hammond et al. [16]. Caution should be taken with these results for the following reasons: the variables measuring pre-injury history of substance were added to the database at a later date (1997); blood alcohol level was not tested on all participants; and no information on post-injury substance use was included in this analysis because of missing data due to loss to follow-up. Thus, missing data appears to be an issue which could bias the results.

Finally, Glasgow Coma Scale (GCS) score, which is commonly accepted as predictive of early mortality was not found to be predictive of mortality after one year post-injury in this study. This is consistent with Zafonte et al. [63] who found no significant relationship between GCS and functional outcome measures at rehabilitation discharge and one-year post-injury. Based on study findings, it appears that clinicians and family members should be concerned with addressing residual disability, rather than the severity of initial injury or functional status, as it is more predictive of later mortality.

Strengths of this study were that it was a multi-center study of individuals receiving inpatient rehabilitation following TBI, with a relatively large sample size, a high rate of vital status follow-up, utilizing the TBI Model Systems National Database which included an extensive array of important risk factors for death after TBI. This study did have some limitations. The follow-up period (a maximum of 13 years for the earliest cases) was relatively short for looking at long term mortality. Some previous studies have focused on mortality

between 40 and 60 years post-injury [6,58–60]. This limitation is currently being addressed by the authors in an expanded study.

An inherent limitation in using US general population mortality rates as a comparison are that other important factors beyond age, gender and race are not taken into account. For example, the difference in mortality rates between those with and without TBI may not have been as great if individuals in the study could have been matched on additional characteristics such as socioeconomic status.

Another limitation was that the risk factors considered in this study were all measured during the initial acute care and inpatient rehabilitation hospitalization period. When considering long-term mortality, it would be ideal to assess risk factors closer to the time of death, especially for factors which are likely to change over time. Even though the TBI Model Systems National Database contains much more extensive follow-up information, because of the overall 38% loss to follow-up in the cohort, much of this risk factor information would be subject to the biases associated with being lost or found for system follow-up. Corrigan et al. [7] explore the potential for bias in longitudinal TBI outcome studies and give recommendations for addressing these issues.

Another study limitation was that not all TBI Model Systems participated in this study. Also, because there was a difference in the characteristics of TBI Model System participants that were and were not included in this study, caution should be taken in generalizing study results to all TBI Model Systems. In addition, because this study focused on individuals receiving treatment in one of the federally designated TBI Model Systems of care, it is also possible that these results may not be representative of individuals with TBI receiving inpatient rehabilitation elsewhere.

This study provides important new information regarding mortality, life expectancy and risk factors for death in individuals with TBI receiving inpatient rehabilitation and surviving past one-year post-injury. This information can be used to guide decision-making for health care intervention and lifetime planning in order to avoid untimely death and prolong life after TBI.

Acknowledgments

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