ACRM
AMERICAN CONGRESS OF REHABILITATION MEDICINE

Archives of Physical Medicine and Rehabilitation

journal homepage: www.archives-pmr.org

Archives of Physical Medicine and Rehabilitation 2021;000: 1−4

BRIEF REPORT

Life Expectancy of 1-Year Survivors of Traumatic Brain Injury, 1988-2019: Updated Results From the TBI Model Systems

Jordan C. Brooks, PhD, MPH,[a] Robert M. Shavelle, PhD,[a] David J. Strauss, PhD,[a] Flora M. Hammond, MD,[b] Cynthia L Harrison-Felix, PhD[c,d]

From the [a]Life Expectancy Project, San Francisco, CA; [b]Department of Physical Medicine and Rehabilitation, Indiana University School of Medicine, Indianapolis, IN; [c]Craig Hospital, Englewood, CO; and [d]Department of Physical Medicine and Rehabilitation, University of Colorado, Denver, CO.

Abstract

Objective: To update the life expectancy estimates according to age, sex, mobility, and feeding skills reported in the 2015 study of Brooks et al. To examine trends in survival over the past decade.

Design: Observational cohort study.

Setting: Poisson regression and life table analysis applied to long-term follow-up data on United States (US) Traumatic Brain Injury (TBI) Model Systems patients recorded in the national database. Functional mobility and feeding skills were assessed with FIM.

Participants: A total of 14,803 persons with TBI during the years 1988-2019 who underwent inpatient rehabilitation and provided at least 1 long-term assessment of functional skills 1 year or more postinjury (N=14,803).

Interventions: Not applicable.

Main Outcome Measures: Survival, mortality rates, and life expectancy.

Results: Life expectancy was lower than that of the age- and sex-matched general population. Older age and severity of functional impairments were risk factors for mortality (both $P<.0001$ in regression models). Among ambulatory individuals, mortality was 51% (95% confidence interval, 35%-69%) higher in men than women. Life expectancy of 20-year-old women who walked well (FIM ambulation score 7) was 55 (SE=0.8) additional years to age 75, representing a reduction of 6.9 years from the normal general population figure. For 20-year-old men who walked well, the life expectancy was 49 (SE=0.5) additional years, representing a reduction of 8.1 years from normal. Life expectancies for men and women who did not walk and were fed by others were much lower. There was no significant change in mortality rates during the study period (hazard ratio, 1.008; $P=.07$).

Conclusions: There has been no significant change in the long-term survival of persons with TBI in the US since the late 1980s. The life expectancies reported here are similar to those reported in the 2015 study of Brooks et al, although they are more precise because of the larger sample size and longer follow-up.

Archives of Physical Medicine and Rehabilitation 2021;000:1−4

Accurate life expectancy estimates are a critical component of long-term care planning for persons with traumatic brain injury (TBI) who require lifelong support. Numerous TBI cohort studies have documented increased mortality and reduced life expectancy by comparison with uninjured and general population (GP) reference groups,[1-10] and these often serve as empirical guides to the determination of life expectancy in practice. The data underlying these studies, however, are necessarily historical and their relevance to contemporary patients with TBI depends in part on whether there have been significant secular trends, that is, changes over time, in long-term survival. It is therefore important to examine secular trends and to estimate life expectancy using the most up-to-date empirical data.

The Traumatic Brain Injury (TBI) Model Systems National Database is a multicenter study of the TBI Model Systems Centers Program and is supported by the National Institute on Disability and Rehabilitation Research (NIDRR) of the US Department of Education. However, these contents do not necessarily reflect the opinions or views of the TBI Model Systems Centers, NIDRR, or the US Department of Education.

Disclosures: none

0003-9993/$36 - see front matter © 2021 The American Congress of Rehabilitation Medicine. Published by Elsevier Inc. All rights reserved.
https://doi.org/10.1016/j.apmr.2021.05.015

The 2015 study by Brooks et al[1,2] estimated life expectancies using models of age-, sex-, and disability-specific mortality rates. These were externally validated with empirical follow-up data from 2 separate cohorts with TBI. One of the 2 cohorts included persons who completed inpatient rehabilitation and long-term follow-up assessment with the United States (US) TBI Model Systems (TBIMS) during the years 1988-2010. Life expectancy was related to functional walking and feeding skills. There were no significant secular trends in survival for any of the TBI comparison groups, a finding that contrasted with improvements in US GP life expectancy during the same period.

The present study examines secular trends in TBI survival during the most recent decade, 2010-2019, and updates the life expectancy estimates from Brooks et al[1,2] by applying the same validated analytical methods to an extended and expanded TBIMS national database. The database contains information on new patients who sustained injuries through year 2019 as well as additional follow-up of the previously studied cohort.

Methods

This study was approved by the HCA-HealthOne Institutional Review Board at Craig Hospital for the TBIMS National Data and Statistical Center.

The TBIMS database and analytical methodology were described in the previous study.[1,2] The present study incorporates additional data for persons injured in the years 1988-2019. In brief, the sample included persons who were aged ≥16 years with a moderate to severe TBI, underwent inpatient rehabilitation, and provided complete follow-up assessment data at the 1-year postinjury evaluation or later. Those who died before completing a long-term functional assessment were not included in the analysis. Study participants were classified into 1 of 4 groups based on their walking and feeding skills:

- Walks well: FIM ambulation score of 7.
- Some walking: FIM ambulation score of 6.
- Does not walk, self feeds: FIM ambulation score ≤5 or uses a wheelchair as the primary means of functional mobility, and FIM eating score ≥4.
- Does not walk, fed by others: FIM ambulation score ≤5 or uses a wheelchair as the primary means of functional mobility, and FIM eating score ≤3.

Mortality rates were estimated under the validated Poisson regression model in Brooks et al 2015,[1] which was refit to the updated data. We examined secular trends and time since injury effects by adding time-dependent covariates to the model.

To estimate life expectancies, we constructed standard actuarial life tables that used the maximum of (1) our model-based mortality rates and (2) the age- and sex-specific mortality rates in the US GP as the inputs. SEs were computed using a bootstrap procedure.

List of abbreviations:

CI	**confidence interval**
GP	**general population**
TBI	**traumatic brain injury**
TBIMS	**Traumatic Brain Injury Model Systems**
US	**United States**

Results

The cohort included 14,803 persons (mean age 43±19y, 73% male) who were collectively followed for 115,376 person-years after their first complete long-term follow-up assessment. There were 2268 deaths for an overall mortality rate of 19.7 deaths per 1000 persons per year. Regarding functional abilities and disabilities, 58% walked well, 28% had some walking, 11% did not walk but did feed themselves, and 3% did not walk and were fed by others.

The fitted Poisson regression model is summarized in table 1. Mortality rates increased with age and severity of disability. The highest mortality was observed in persons who did not walk or feed themselves. Mortality increased by 6.4% (95% confidence interval [CI], 6.1%-6.6%) per year of current age among persons who walked or fed themselves. The increase per year of age for those who did not walk and were fed by others was somewhat lower at 4.3% (95% CI, 3.6%-5.0%). Mortality rates for ambulatory men were 51% (95% CI, 35%-69%) higher than those for ambulatory women.

Calendar year (hazard ratio, 1.008; P=.0704) and time since injury (hazard ratio, 1.005; P=.2431) were not significantly associated with mortality rates after current age, sex, and walking and feeding skills had been taken into account.

Updated life expectancies are shown in table 2. The mean number of additional years of survival was inversely related to current age and severity of functional disabilities. For the "walks well" group the absolute reductions from the GP life expectancy were similar for men and women, declining from about 7-8 years at age 20 to about 4 years at age 60. The relative reductions from the GP life expectancy for those who walked well were somewhat smaller for women (13%-15%) than for men (14%-20%). This follows from the fact that GP life expectancies for women are higher than those for men.

Persons with greater functional walking limitations had lower life expectancies. Although the life expectancies for nonambulatory men and women were equivalent, there were notable absolute and relative differences by comparison with the sex-specific GP figures. For example, the life expectancies for 20-year-old men and women in the "does not walk, fed by others" groups were both 24 additional years. For men, this represented a reduction of 33.1 years or 58% from the GP life expectancy. For women, life expectancy was reduced by 37.9 years or 61% from the GP figure.

SEs of the life expectancy estimates reported in table 2 are <1 year in nearly every case.

Discussion

The results reported here update and supersede those in the 2015 study of Brooks et al.[1,2] The life expectancies themselves are not markedly different because mortality rates did not change significantly during the most recent decade. The new estimates, however, are more precise given the larger sample size and longer follow-up. They are also based on the most up-to-date empirical data and therefore should be preferred to those in our earlier study for practical work related to long-term care planning.

There was no improvement in TBI survival during the last decade 2010-2019, a finding that is consistent with the results of our previous study.[1] The reasons underlying this result are not clear and may well be complex. It is notable that improvements in GP life expectancy in many developed countries including the US slowed considerably during the last decade. Some proposed

Table 1 Poisson regression model for long-term mortality rates*

Covariate	Hazard Ratio	95% CI		*P* Value
Male × ambulatory	1.5	1.4	1.7	.0001
Walks well (reference)	1.0	—	—	—
Some walking	1.5	1.4	1.7	.0001
Does not walk, self-feeds	2.8	2.4	3.2	.0001
Does not walk, fed by others	21.1	12.9	34.5	.0001
Age × (ambulatory or self-feeds)	1.06	1.06	1.07	.0001
Age × (does not walk, fed by others)	1.04	1.04	1.05	.0001

* For details see the prior study.[1,2]

Table 2 Life expectancy: additional years (SE)

Sex/Age	Does Not Walk, Fed by Others		Does Not Walk, Self-Feeds		Some Walking		Walks Well		General Population*
Female									
20	24	(1.5)	40	(0.8)	49	(0.8)	55	(0.8)	61.9
30	19	(1.1)	32	(0.7)	40	(0.7)	45	(0.8)	52.2
40	14	(0.8)	25	(0.6)	32	(0.6)	37	(0.7)	42.7
50	11	(0.7)	18	(0.5)	24	(0.6)	29	(0.6)	33.5
60	8	(0.6)	13	(0.4)	18	(0.5)	21	(0.6)	24.8
Male									
20	24	(1.5)	40	(0.8)	43	(0.6)	49	(0.5)	57.1
30	19	(1.1)	32	(0.7)	35	(0.5)	40	(0.5)	47.8
40	14	(0.8)	25	(0.6)	27	(0.5)	32	(0.4)	38.7
50	11	(0.7)	18	(0.5)	20	(0.4)	24	(0.4)	29.9
60	8	(0.6)	13	(0.4)	14	(0.3)	18	(0.3)	21.8

* US general population, 2018.

explanations for stalling life expectancy improvements in the GP include diminishing improvements in cardiovascular mortality, increased alcohol and prescription medication misuse, and higher prevalence of obesity. It is possible that these issues may be exacerbated among persons with TBI. Examination of trends in cause-specific mortality in persons with TBI may provide greater insight into the lack of improvement documented here. Such an analysis is beyond the scope of the present study but may become possible as the TBIMS collect more data.

The updated life expectancies reported here are applicable to persons after a period of 1 year or more postinjury. Time since injury did not have a significant effect on mortality among 1-year survivors after age, sex, and functional disabilities were taken into account. Functional improvement, however, may be observed beyond 1 year and this should be considered for prognosis in individual cases.

Study limitations

Practical limitations are similar to those identified in our 2015 study.[1,2] The walking-feeding comparison groups are broad, and some refinement of the life expectancy figures to reflect a particular individual's pattern of abilities and disabilities may be indicated for prognosis in some cases. For example, the life expectancies for the "does not walk, fed by others" group are too high for persons with the most extreme neurologic disabilities including those with disorders of consciousness or dependence on gastrostomy. Conversely, those for the "walks well" group are overly pessimistic for persons who are able to live completely independently and are capable of remunerative employment. Finally, the figures did not consider additional risk factors such as pre- and postinjury problematic use of alcohol and/or drugs or other psychiatric issues, which are not uncommon among those hospitalized for TBI. These will be considered in a follow-up study. Finally, the data studied here reflect conditions before the onset of the coronavirus pandemic. Its effect on long-term mortality among persons with TBI is an area for future research.

Conclusions

The life expectancy of persons with TBI is lower than that of the age- and sex-matched GP. A key determinant is the severity of impairment in functional walking and feeding skills. There has been no significant secular trend toward improved survival since 1988, including in the most recent decade from 2010-2019.

Keywords

Life expectancy; Rehabilitation; Survival; Traumatic brain injuries

Corresponding author

Jordan C Brooks, PhD, MPH, Life Expectancy Project 1439 17th Ave, San Francisco, CA 94122. *E-mail address:* Brooks@LifeExpectancy.org.

References

1. Brooks JC, Shavelle RM, Strauss DJ, Hammond FM, CL Harrison-Felix. Long-term survival after traumatic brain injury. Part I: external validity of prognostic models. Arch Phys Med Rehabil 2015;96:994–9.
2. Brooks JC, Shavelle RM, Strauss DJ, Hammond FM, CL Harrison-Felix. Long-term survival after traumatic brain injury. Part II: life expectancy. Arch Phys Med Rehabil 2015;96:1000–5.
3. Groswasser Z, Peled I. Survival and mortality following TBI. Brain Inj 2017;32:149–57.
4. Baguley IJ, Nott MT, Howle AA, et al. Late mortality after severe traumatic brain injury in New South Wales: a multicentre study. Med J Aust 2012;196:40–5.
5. Fazel S, Wolf A, Pillas D, et al. Suicide, fatal injuries, and other causes of premature mortality in patients with traumatic brain injury: a 41-year Swedish population study. JAMA Psychiatry 2014;71:326–33.
6. Colantonio A, Escobar MD, Chipman M, et al. Predictors of postacute mortality following traumatic brain injury in a seriously injured population. J Trauma 2008;64:876–82.
7. Fuller GW, Ransom J, Mandrekar J, Brown AW. Long-term survival following traumatic brain injury: a population-based parametric survival analysis. Neuroepidemiology 2016;47:1–10.
8. Ulfarsson T, Lundgren-Nilsson A, Blomstrand C, et al. Ten-year mortality after severe traumatic brain injury in western Sweden: a case control study. Brain Inj 2014;28:1675–81.
9. Ventura T, Harrison-Felix C, Carlson N, et al. Mortality after discharge from acute care hospitalization with traumatic brain injury: a population-based study. Arch Phys Med Rehabil 2010;91:20–9.
10. Cameron CM, Purdie DM, Kliewer EV, McClure RJ. Ten-year outcomes following traumatic brain injury: a population-based cohort. Brain Inj 2008;22:437–49.