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Survival and mortality following TBI

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ABSTRACT

Objectives. Evaluation of life expectancy (LE) post traumatic brain injury (TBI) is important for planning services for patients and for dealing with medico-legal aspects. We hypothesized that LE for patients who survived 2 years post injury is equal to that of the general population (GP).

Methods. A cohort of 279 patients was assembled during a 5-year period and was followed for 22–27 years. During follow-up, 32 patients (11.5%) died, creating a huge censored data (88.5%). Analyses included standard mortality ratio (SMR), Kaplan–Meier method (KM), Cox proportional hazards regression analysis (PH) and calculations of life expectancy.

Results. About 77% of the patients were under 35 years of age at injury. This age cut-off point yielded differences for survival longevity by χ^2 tests ($p < 0.0001$), by KM analysis ($p < 0.0001$) and by Cox PH regression analysis ($p < 0.0001$, HR = 13.95). SMR for the entire cohort was 1.86. Shortening of LE in comparison with the GP is 3.58 years. Estimated shortening of LE by severity for mild, moderate and severe injury were −0.51, 4.11 and 13.77 years, respectively.

Conclusions. Patients with mild TBI have a LE similar to the GP, and a reduction in LE was closely related to moderate and severe brain injury.

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TBI; severity of injury; life expectancy

Introduction

Survival and life expectancy are inherent issues in the study of traumatic brain injury (TBI). Estimations of these issues are complex, because the possible outcomes depend on multiple factors, like the severity of the injury, age, gender, employment, disabilities at the time of discharge from rehabilitation, socio-demographic background, previous medical history, availability of medical facilities and the speed of evacuation from the injury site to a primary care hospital. As noted by Zasler (1), the statistical methods and the parameters used may play a crucial role in the analyses (2). Parameters such as the number of participants and the number of the deceased during the follow-up period influence the statistical methods used and can lead to divergent results. Studies from different countries have produced different results. Even studies from different locations in the USA differed from one another (Brown 2004, Flaada 2007, Ventura 2010) (3–5). Strauss and Shavelle suggested recently that the information they had thought to present the state-of-the-art in life expectancy worldwide, may not reflect the reality outside the USA and wrote: 'whether the CDDS and TBIMS models represented here provide accurate prognosis for person with TBI outside the United State is less clear' (6,7). The outcome and survival of patients with TBI may depend on parameters as was cited above. It is reasonable to assume that in various countries, outcomes and survival differ. According to 'the wellness wheel', introduced by Harrison-Felix et al. (8), in addition to the physical aspect, intellectual and emotional factors also appear to play an important role in life expectancy. These factors were taken into account in the present study.

With the growing number of patients with TBI in Israel, the need has arisen to provide answers to improve medical and rehabilitation services, and to provide answers to medico-legal questions.

According to the Israeli National Trauma Registry data for 2013: out of the total number of hospitalized patients aged 17 or older ($n = 2160$), 7.7% suffered also from brain trauma and 20.46% ($n = 483$) were referred to rehabilitation. Because the numbers in a country like Israel are small in statistical terms, we decided to conduct a long-term follow-up study on a cohort of patients.

Most patients who die as a result of TBI do so in the first year following the injury. We have estimated that the cause of death of the few patients who died during the second year of follow-up was closely related to the initial trauma, especially in patients who were unconscious. Taking this fact into account, we omitted these patients from the present study. Therefore, we included in the study only patients who survived at least two years post injury. We assumed that the survival for these patients is similar to that of the general population of Israel.

Patients and methods

During the years 1979–1985, 334 patients suffering from TBI were consecutively hospitalized for rehabilitation at the Department of TBI Rehabilitation at the Loewenstein Rehabilitation Hospital (LRH). Two hundred seventy-nine patients were of working age

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(18–65 years) at the followed-up period, 8–13 years post injury. Vital status was reassessed for the survivors 14 years later. The total follow-up period lasted up to 27 years, during which 32 patients died. A total of 88.5% (247/279) of patients were alive at the end of the follow-up period.

Data collection

Demographic data were recorded from participants and from patients' files. Special attention was paid to recording the destination of discharge from rehabilitation.

Death certificates of the 32 deceased patients were obtained from the Ministry of Health, which granted special permission to obtain individual data of patients, after the aims of the study were approved by the LRH Helsinki Committee (IRB Committee).

For calculating mortality rates, we obtained data regarding the GP from the Israeli Central Bureau of Statistics through the Israel Center for Disease Control (with their permission), and compared it with the study group data.

Study variables

The study variables are the following:

(1) Pre-injury socio-demographic characteristics such as gender, age at injury, ethnicity, religion, level of education, marital status, employment status and more.
(2) Pre-morbid medical history.
(3) Parameters related to the severity of the injury, such as type and cause of injury, duration of unconsciousness, presence of tracheostomy, existing of additional trauma, developing hydrocephalus and posttraumatic seizures.
(4) Consequences of the injury: extent of physical disabilities, level of ambulation, sphincter control, self-feeding, destination of discharge (home/institute), presence of mental disabilities, communication problems, cognitive and behavioural abnormalities and the need for further therapy at the time of discharge from rehabilitation.
(5) Causes of death and mortality rates.

Mobility

Mobility or ambulation was classified into the following three levels: independent with or without using orthotic devices, needing support by a caregiver and/or self-driving a wheelchair, and entirely dependent.

Severity of injury

Severity of injury was defined at the time of discharge from inpatient rehabilitation as follows:

Mild brain injury

Patients assigned to the group of mild brain injury had no pre-morbid medical history, had worked before the injury, were not unconscious or were unconscious no more than 1 month, did not undergo tracheostomy and had no cerebrospinal fluid (CSF) shunt procedures, the destination of discharge was home, were mobile with or without help or were self-driving a wheelchair, controlled their sphincters, fed themselves, had not at all or had mild or moderate behavioural disturbances, were able to work in the open market or at a sheltered workplace, and received no more than two recommendations for further individual treatments in the community.

Severe brain injury

Patients who suffered from severe brain injury were unconscious for more than 1 month, or were entirely dependent on others in movement, or had to be fed, or had no control of sphincters, or displayed severe behavioural disturbances, or were unable to attend even a sheltered workplace, or the destination of discharge was an institution or psychiatric hospital.

Moderate brain injury

Patients who were not assigned to one of the groups above were assigned to the group of moderate brain damage.

Statistical analysis

The overall study population was characterized by descriptive statistics. Continuous variables were analysed by t-test for means and SDs, with a two-sided p-value of 0.05, which was used as the cut-off value for statistical significance. Categorical variables were analysed using univariate analyses, χ^2 test, Fisher's exact χ^2 test and the Monte Carlo estimate of the exact χ^2 test for small frequency cells ($n < 5$ frequencies). We also used the Spearman rank-order correlation, which provided several non-parametric measures of association between every two variables, with a cut-off point coefficient ≥ 0.3, and with a p-value < 0.05 (4,7,9–24). The above tests were performed to look for possible significant explanatory covariates that would be included in the initial model of the multivariate Cox PH regression analyses.

Standard mortality ratio

One of our primary goals was to compare survival parameters of the TBI population with those of the GP in Israel, which was used as a reference group. The standard mortality ratio (SMR) was computed by comparing the observed number of deaths in the study population with the expected number of deaths of the GP. Mortality rates were stratified by years of the follow-up period (person-years units), quinquennial age groups and gender, and compared with the same stratified mortality rates in the GP. The results were summed. Total SMR for the TBI population was then calculated as the ratio of the summed observed cases of death to the summed expected cases of death. The statistical significance of the SMR was determined by calculating the confidence interval (CI) of 95%, which was considered significant if it did not contain 1.0.

We also computed categorized SMRs by gender, age groups and cause of death, but because of the relatively

small sample size, the numbers in some categories were too small for logical and statistical analysis (1,5–7,10–16,25–35).

Kaplan–Meier method

Another way of estimating the differences between specific groups of patients with TBI and between these groups and the non-TBI reference population is the KM method. The KM method is traditionally used to describe the cumulative incidence of death (estimated survival function) for comparison between various groups. We conducted the KM analysis with log-rank (Mantel–Haenszel) statistical tests, to demonstrate the differences between age-at-injury groups, cause of death and level of injury severity. A p-value of 0.05 was used for statistical significance (1,3–5,9,14,17–22,36–38).

Cox proportional hazards regression analysis

The Cox PH model is a semi-parametric model with maximum partial likelihood estimation, which enabled us to address censoring of survival times (when we do not have the vital status of patients at the end of the study period), time-dependent covariates (covariates that may change during the study period) and discrete (tied) data (when two or more observations had exactly the same survival time) (1,3–5,9,10,15,16,18–23,32,34,37–39).

This model also enabled us, using multivariate regression analysis, to adjust for age at injury, gender and other factors in the study, and to assess the effect of potential mortality risk factors by estimating the hazard of each covariate or interaction covariate. COX regression was also used for calculating and delineating survivor functions and cumulative distribution functions (probability estimates) over time.

The first step in constructing the best final Cox PH regression model was to include in the initial analysis model all the relevant medical explanatory factors, as well as the statistically significant ones that emerged from the preliminary tests noted above.

The second step was to create dummy variables, which are necessary for calculating hazard ratios (HR) for each value of the categorical explanatory variables that have more than two levels.

The third step was to apply the Cox analyses, using the 'PHREG procedure' of the SAS system, with a stepwise regression option, to select the most influential and significant factors for inclusion in the final model. Factors that met a p-value ≤0.25 on the Score χ^2 test for entry, and a p-value ≥0.18 of the Wald χ^2 test for removal were eligible for inclusion in the final multivariate analysis.

The forth step consisted of checking the inclusion of some interaction covariates (products of two or more explanatory covariates), to produce more rational and logical outcomes.

The fifth step tested for violations of the PH assumption of the final model, by validating the proportionality over time of some suspicious covariates. This was accomplished by adding time-dependent covariates, separately for each covariate.

The sixth step focused on the HR and the 95% CI of the adjusted relative risk of each factor, given that the primary goal was a mortality prediction model rather than a particular regression coefficient model. To this end, various combinations and various regroupings of the potential confounders were tested for rational and logical HR outcomes.

After the final model was constructed, a multivariate Cox regression analysis was performed. The results and the following discussion are based on it.

An additional feature of PHREG procedure, in the SAS system, is the ability to produce a table of survival probabilities and survivor function estimates for specific covariates (controlling for other covariates), and delineating them. We used this ability to delineate overlay survivor curves for demonstrating the differences in survival time between groups of patients with TBI, and for additional proof of the PH assumption of some covariates over time in the model. All the curves were paralleled over the axis time, which means that the PH assumption was not violated.

Because the dataset contained 20.8% tied data, the Cox analyses were conducted using the SAS PHREG procedure for a discrete-time model, an exact method that may be described as a proportional odds model (using the log-odds or logit regression equation) (2,7,9,23,39).

Life expectancy for a group of individuals is an estimation of the average future life span of this group. LE is based on a survivor function of the probability to die. The Lifetest procedure of SAS was used to calculate the LE of the TBI sample, based on the KM and the life table methods. Because in statistical terms our sample was relatively small, with an extremely large censored data (88.5%), the mean of the cohort (the LE) was found to be a missing value. Therefore, evaluation of LE was performed using the methodology described by De Vivo (5,16,31,34), that is by applying the SMR of patients with TBI to the latest age–gender-specific mortality rates of the Israeli population, available at the time of the study (25,26). Other extrapolation regression methods, like the Monte Carlo method, logistic regression, Poisson regression and the Lifereg procedure of SAS were also tried (1,7,19,25,28,29,33,36,38). All of the analyses were conducted using the SAS system, version 9.2 (SAS Institute, Inc., Cary, NC, USA), enabled by Tel-Aviv University.

Results

Descriptive results

The current study was based on a cohort of 279 patients, all of whom were conscious 2 years post injury. Patients were followed-up for 22–27 years post injury. Thirty-two patients (11.5%) died during the follow-up period. Significantly higher mortality rates were observed in patients who were not employed before the injury and in those having premorbid diseases (p = 0.0317, $p < 0.0001$, respectively). Analysis of the factors related to trauma and of the causes of the trauma showed survival was not affected by the initial Glasgow Coma Scale (GCS) score or by whether the trauma was caused by a blunt or penetrating injury. The need to perform a tracheotomy (p = 0.03) and for a CSF shunt (p = 0.05) were linked with higher mortality.

Factors observed at the time of discharge from inpatient rehabilitation, such as lack of sphincter control (0.0039), inability to self-feed (p = 0.0118), being discharged to an institution (p = 0.0265) and the need for further comprehensive rehabilitation treatment (p = 0.0412), were linked to higher mortality. Poor

mobility had a negative effect on survival (p = 0.0154). The presence of cognitive and behavioural deficits was linked to poor survival (p = 0.033, p = 0.026, respectively), but language disturbances (either aphasia or dysarthria) did not. All these descriptive results were analysed by χ^2 tests. Causes of death, obtained from official death certificates, are presented in Table 1. None of the causes of death mentioned in the death certificates appears to be directly related to brain trauma.

Age at the time of injury

The mean age at injury of the entire cohort was 26.6 years (SD = 11.87), and the median was 23.0 years. The mean age of the deceased at death (n = 32) was 40.16 years (SD = 13.76), with median of 44.5 years. For patients who survived the end of the follow-up period (n = 247), the mean age at injury was 24.85 years (SD = 10.42), with a median of 22.0 years. The difference between survivors and non-survivors was statistically significant, with a p-value of 0.0226 obtained by t-test.

Table 1. Causes of death based on death certificates (ICD codes).

Causes	n	%
Heart disease	8	25
Cancer	5	15.63
Infectious diseases	2	6.25
Diabetes	1	3.13
Chronic liver disease	1	3.13
CVA	2	6.25
Accident	4	12.5
Suicide	1	3.13
Influenza, pneumonia, COPD	2	6.25
Other external and other	6	18.75
Total	32	100

The cut-off point of 35 years for age at injury was chosen after checking the relationships between age-at-injury groups and well-known parameters related to TBI.

Patients with an age at injury under 35 years were more likely to recover consciousness than were older patients (χ^2 test, p = 0.006), and survived longer (p < 0.0001).

This significant difference was manifest only for male patients. There were no differences in the severity of the injury and of behavioural disturbances between the above groups.

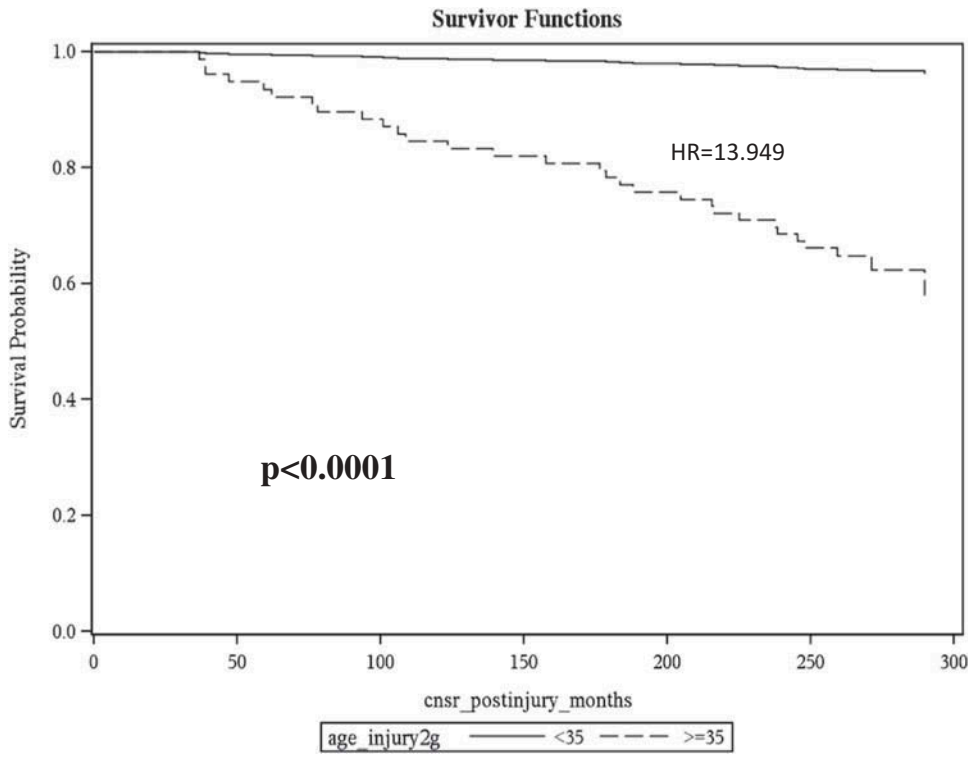
Significant differences were observed between the groups of deceased and surviving patients regarding age at injury, severity of injury and severity of behavioural disturbances.

KM analysis yielded similar results regarding the age-at-injury groups (p < 0.0001), as did the Cox PH regression analysis (p < 0.0001, HR = 13.95), as shown in Figure 1.

The frequency distribution of cumulative post-injury years of the deceased patients is shown in Figure 2, the linear graph indicates mainly the effect of age.

Severity of injury

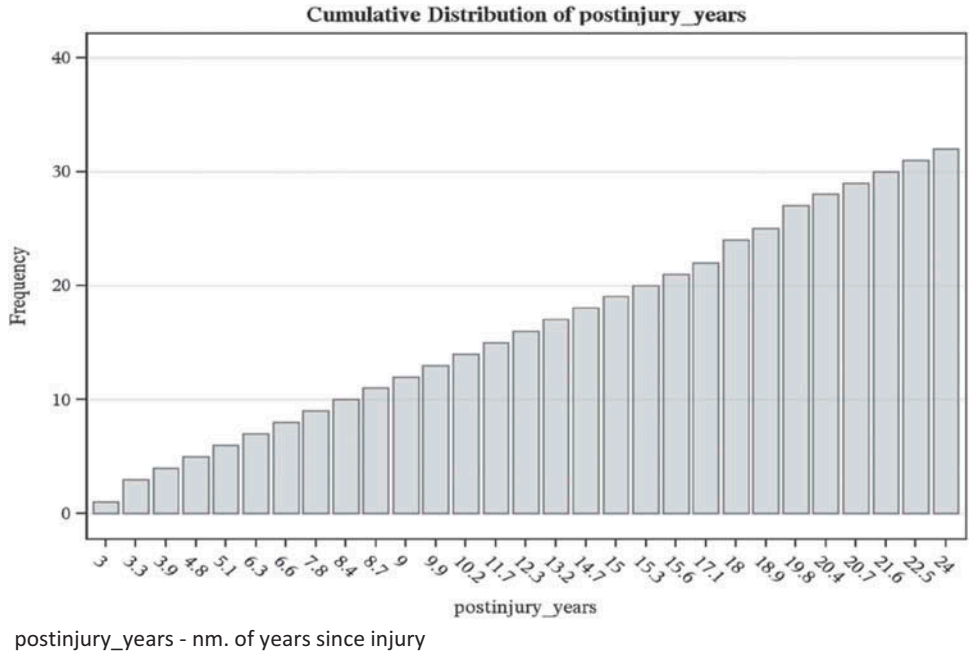
Patients were assigned to groups of mild, moderate and severe brain injury at time of discharge from inpatient rehabilitation. Table 2 shows these assignments by vital status, using a χ^2 test (p = 0.008).



Cnsr_postinjury_months - nm. of mothes since injury

Age_injury2g - 2 groups by age at injury: age<35 *vs* age>=35

Figure 1. COX proportional hazard multivariate regression analysis.



postinjury_years - nm. of years since injury

Figure 2. TBI mortality graph (n = 32 deceased patients).

Table 2. Severity of injury by vital status.

	Mild		Moderate		Severe		Total	
Vital status	*n*	%	*n*	%	*n*	%	*n*	%
Alive	112	94.9	97	85.8	38	79.2	247	88.5
Deceased	6	5.1	16	14.2	10	20.8	32	11.5
Total	118	42.3	113	40.5	48	17.2	279	100

p = 0.0079 (χ^2 test).

SMR

Comparison of the mortality rates for patients with TBI and for the GP, presented in Figure 3, shows that almost no differences were seen in patients who were less than 35 years old at the time of injury, and the gap between these two groups tends to increase in older age. The SMR for the entire cohort is 1.86, with a CI of 1.35–2.49.Figure 4 shows the survivor functions of the above three groups.

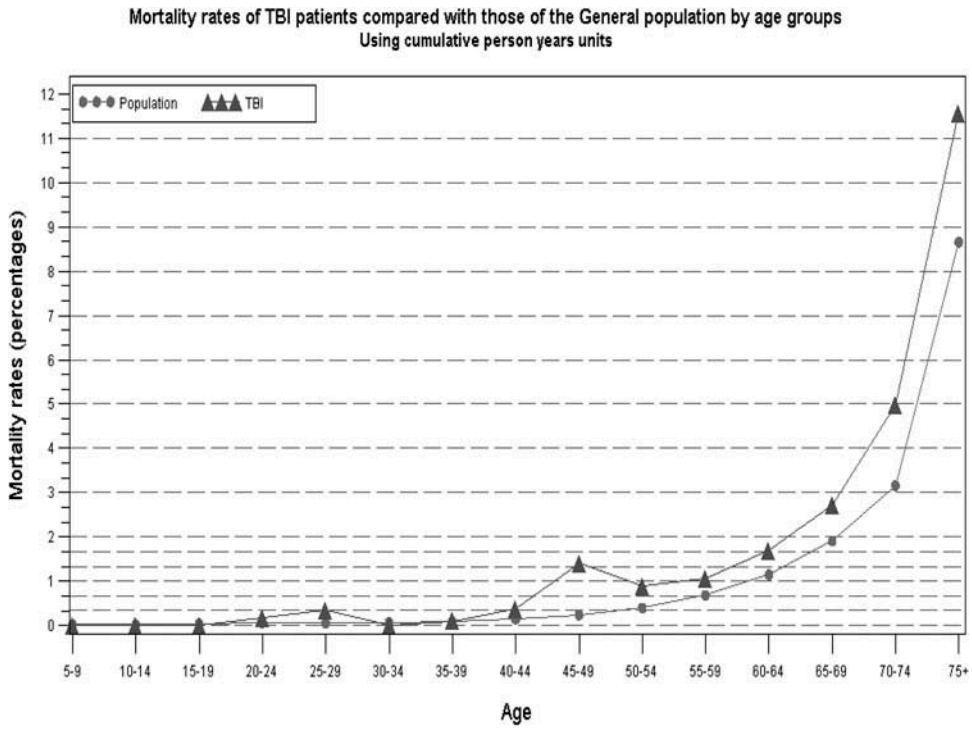


Figure 3. Comparison of mortality rates using person-years units.

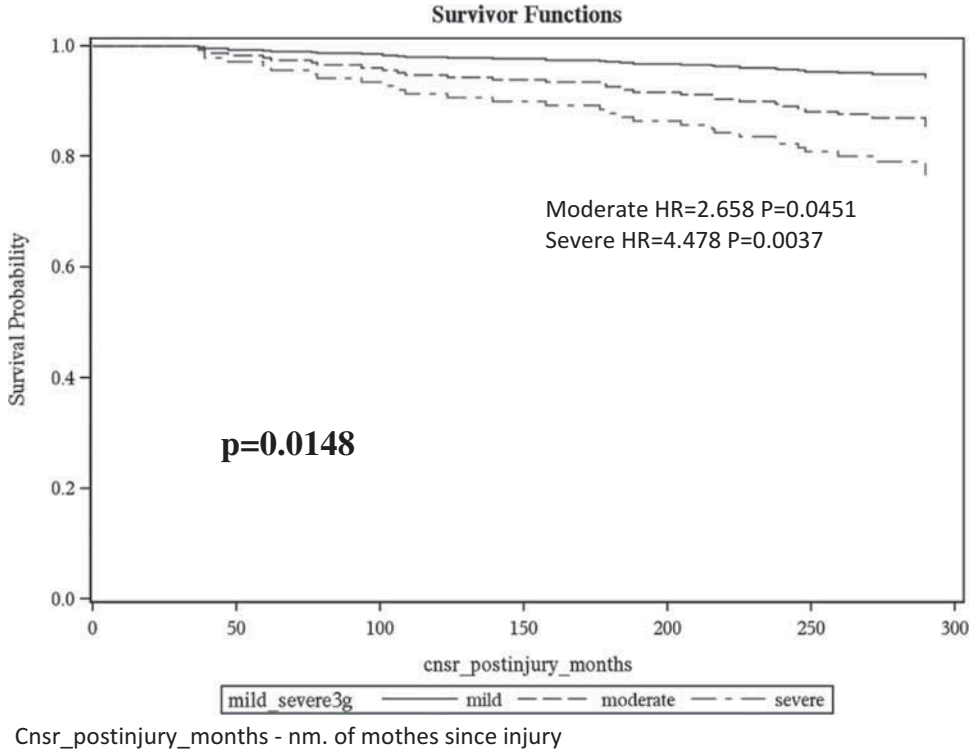


Figure 4. COX proportional hazard multivariate regression analysis.

Life expectancy

As noted, the calculations of the estimated LE of patients with TBI followed De Vivo method (10,16,31,34), and show that LE was 3.64 years shorter for males and 3.31 years shorter for females than the LE of these gender groups of the GP. For the entire group, LE was 3.58 years shorter when compared with the GP (Table 3).

SMRs and LE were calculated separately for levels of severity (Table 3).

The relatively small number of participants in the cohort disabled us to reveal logical and significant findings for the subgroups of gender and severity.

Cox proportional hazards multivariate regression analysis

The eligible initial factors for including in the regression model were age at injury, employment status before injury, pre-morbid medical history, type of injury (blunt/penetrating) and cause of injury (like MVA, falls), duration of unconsciousness, tracheostomy, shunt, hematoma, hydrocephalus, epilepsy, additional trauma, level of ambulation, sphincter control, self-feeding, destination at discharge (home/institution), communicative, cognitive and behavioural abnormalities, level of severity (mild/moderate/severe), ability and the kind of return to work or school, need for medication at the time of discharge and type of recommended treatments, if any, after discharge. The results of the stepwise regression option for selecting the most influential and statistically significant factors for inclusion in the model yielded age at injury, the interaction of (level of severity) × (self-feeding) × (control of sphincters), employment status before the injury, additional trauma, hydrocephalus, pre-morbid medical history, need for further therapy at the time of discharge from rehabilitation, behavioural abnormalities and the destination of discharge (home/institution). Because our primary goal was to create a mortality prediction model, we focused on HRs, the 95% CIs of the adjusted relative risk of each of the above factors and the significance of the p-value of the Wald χ^2 test. The results of the tests described above produced a final model with five covariates, 'the best model for this cohort', as summarized in Table 4.

Mortality rates were higher for the moderate and severe groups than for the mild group. The HR for moderate versus mild injury was 2.66 (p = 0.0451), and for severe versus mild injury was 4.48 (p = 0.0037). Analysis of mild versus moderate or severe injury produced an HR of 3.2 (p = 0.0109).

Table 3. SMR and LE differences between patients with TBI versus matched general population.

Injury severity	*n*	Deceased	SMR	95% CI of SMR	Males LE difference, *n* = 228	Females LE difference, *n* = 51	Total LE difference
Mild	118	6	0.88	0.38–1.73	−0.52	−0.47	−0.51
Moderate	113	16	1.99	1.25–3.02	4.18	3.81	4.11
Severe	48	10	4.31	2.33–7.30	14.0	12.75	13.77
Total	279	32 (30M+2F)	1.86	1.35–2.50	3.64	3.31	3.58

Table 4. Final model of the PH regression analysis.

Covariates	Description	*p*-Value	Hazard ratio	95% CI of HR
Age at injury	Age at injury by years	<0.0001	1.083	1.047–1.119
Interaction of svr3 g_feed_sphinct	Interaction of injury severity and self-feeding and sphincters control	0.0007	1.143	1.058–1.235
Hydroc	Having hydrocephalus	0.0157	4.028	1.301–12.476
Med_history2 g	Pre- morbid medical history	0.0080	3.210	1.355–7.602
Behav_severity2 g	Severe behavioural disturbances	0.1388	3.555	0.663–19.064
	Mild and moderate behavioural disturbances	0.3800	0.685	0.295–1.593

Covariates met $p \leq 0.25$ of the score χ^2 test for entry, and $p \geq 0.18$ of the Wald χ^2 test for removal, were eligible for inclusion in the final multivariate analysis.

Discussion

The series presented in this article, although relatively small, is unique because of the long period of follow-up (22–27 years) of a cohort of TBI patients. The entire cohort included inpatients at the only centre in the country dedicated to rehabilitation of patients with TBI at the time when the cohort was assembled. The cohort is assumed to represent the entire Israeli population of TBI patients, followed by almost the same team for many years under the guidance of the first author.

The risk of dying after TBI is much higher immediately after the injury and during the first months thereafter. The exclusion of patients who died during the first 2 years post-injury is a unique feature of the present study. In previously published studies, only patients who died during the first 6 months post injury were excluded, and only a minority of studies excluded patients who died during the first year post-injury (4,6,7,11,33,34). Another unique feature of the present study is the detailed definition of severity of injury, which was supported by statistical analysis, with significant differences between the groups ($p = 0.008$ of χ^2 test). All patients included in the study regained consciousness.

The descriptive results are quite similar to findings in other studies. Higher mortality was associated with unemployment before injury. The need to perform a tracheotomy or CSF shunting during hospitalization was also associated with higher mortality rates, as were patients who lacked sphincter control, needed help feeding and had poor mobility at the time of discharge from rehabilitation. Pre-injury morbidity, behavioural and cognitive disturbances, discharge to an institution and the need for further treatments in more than two areas (occupational therapy, speech therapy, neuro-psychology, physiotherapy, etc.) were also associated with higher mortality rates.

Most of our patients (77.06%) were under 35 years of age at the time of injury (mean = 26.6); these patients survived longer ($p < 0.0001$) than did older patients, and more of them recovered consciousness than did older patients ($p = 0.006$).

We described in detail the statistical analyses we conducted because different choices of statistical methods may yield different results. The final five covariates of the model in the Cox PH multivariate regression analysis are partially different from previous studies. The covariates age at injury and the interaction of the three covariates (severity of injury, dependence on others for feeding and sphincter control) were found in previous studies as affect survival. The additional unique outcomes found in the current study were the presence of pre-morbid diseases, hydrocephalus and the presence of behavioural disturbances (Table 2). Employment post-injury was not entered in the final model, contrary to findings of other studies (5,10,15,16,19,33,34). A possible explanation for these differences maybe based on the social support system in Israel, where most patients have adequate access to the medical system and are usually compensated by the National Insurance Institute, the Ministry of Defense, and insurance companies.

Similar to other findings, HRs for mortality were higher for patients with moderate versus mild severity (HR = 2.66, $p = 0.0451$) and severe versus mild severity (HR = 4.48, $p = 0.0037$) (3–5).

We presented the survivor functions of the Cox PH regression analysis rather than the traditional KM curves because Cox regression and its survivor functions are based on a semiparametric procedure, which produces a PH model with adjusted covariates. By contrast, the KM method computes nonparametric estimates of the survival distribution functions, and its survival functions are based on crude covariate analysis. At present, the KM method and its survival curves are used mainly for preliminary examination of the data and for evaluating the fit of regression models to the data. The curves look quite similar in the two procedures.

The SMR for the entire group (1.86) was found to be quite similar to SMRs described in other publications (5–7,10–16,27,28,33–35). The LE of the GP is based on life tables ranging from 0 to 100 years of age, whereas the calculations of the estimated LE of our patients were based on an age at injury range of 6–56 years. As noted, the small database prevented partition into various subgroups. Therefore, only the total SMR was used for comparison with different SMRs of the GP. This probably caused a bias that affects the values of the SMR and LE.

The importance of studies conducted in different countries calculating LE has become more salient recently, because even values of LE from different centres in the same country differ (5,7). In a recent study by Brooks et al. (2015), the authors expressed their hesitations about the use of outcomes of data gathered in the USA for use in other countries (7). Comparison of the results of the present study with other reports regarding SMR and LE values was limited because of the younger age of patients (77% under 35 years of age at injury), the exclusion of patients who died in the first 2 years post-injury, and the adequate access of most, if not all, patients to medical services in Israel. Nevertheless, the values reported in other studies resemble the present findings (1,5,16,33,34,36).

To the best of our knowledge, most of the researchers in the USA use the method of De Vivo to estimate LE; we used the same method. Other regression methods, like the Monte Carlo, are often used outside the USA (1,7,19,25,28,29,33,36,38).

In our opinion, and according to the advice of experts in survival analysis, all the aforementioned estimations of LE may yield results that do not fully represent LE in reality. This also applies to the present study, especially because of the extremely high percentage of censored data. Zasler (1) noted that if 50% of the subjects have censored survival time, it is not correct to calculate life expectancy for the entire cohort. In any case, our calculations reflect the current status of statistical analysis regarding LE in populations with high percentages of censored data.

Study limitations

From the 279 cohort participants, 30 male and 2 female patients died, during the follow-up period (total of 11.5%). This extremely large percentage of censored data (88.5%), the small number of deaths of females and the large percentage of patients under 35 years of age at injury (77%) precluded the possibility of showing sub-group partitions that may have statistical significance.

Conclusions

The long-term survival of patients with TBI, who survived the first 2 years after injury, was related to age at injury below 35 years of age and severity of injury. Survival of patients with mild brain injury was similar to that of the GP, whereas LE was shorter for patients with moderate or severe brain damage. Most patients (88.5%) were alive at the end of the research period.

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All the analyses were conducted using the SAS system, version 9.2, by SAS Institute Inc., Cary, NC, USA, provided by Tel-Aviv University.

Declaration of interest

The authors report no conflicts of interest.

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