Long-Term Survival of Children and Adolescents After Traumatic Brain Injury

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Objective: To obtain information on long-term mortality risk and life expectancy after traumatic brain injury (TBI), to improve planning and for counseling patients and their families. In contrast to the literature for spinal cord injury and other disabilities, there have been few such reports for TBI.

Design: Records were reviewed on 946 persons aged 5 to 21 years who had sustained TBI. All were patients who subsequently received disability services in California, 1987 to 1995.

Results: The chief predictors of mortality were basic functional skills such as mobility and self-feeding. After the initial high-risk period, mortality risk for TBI was much lower than for similarly functioning persons with cerebral palsy (a comparison group), although after 10 years the two sets of mortality rates had largely converged. For high-functioning persons, life expectancies were only 3 to 5 years shorter than for the general population. By contrast, the remaining life expectancy for those without mobility 6 months after injury was only 15 years.

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TRAUMATIC BRAIN INJURY (TBI) is the leading cause of death among persons under the age of 35 years.[1] Although the prognosis for survival during the first few years after TBI has been extensively studied, there are few reports on long-term prognosis (10 years or more). One is the classic study of Roberts and associates,[2,3] who followed some 500 patients, most of whom had severe disabilities, for up to 25 years. They estimated a reduction in life expectancy of 4 to 5 years among patients who became mobile enough to walk unaided. This is consistent with an earlier study of ex-soldiers of the First World War.[4] Roberts was able to establish causes of death for patients who died after the initial high-risk period, and concluded that many causes were no more common among the brain-injured than in the general population. Exceptions included epilepsy, meningitis, accidents and suicides, and respiratory disease.

Severely abbreviated life expectancies have been found in certain groups with severe mental and physical disabilities. For example, patients in a persistent vegetative state rarely survive 10 years,[5] and a median survival time of only 3 years has been reported for a cohort of infants with the most severe developmental disabilities.[6] Long-term survival and life expectancy after spinal cord injury has also been studied.[7-12] Corresponding results after TBI, suitably stratified by clinical or functional status, however, appear not to have been reported previously. Such information is helpful for future planning and for counseling patients and their families.

This study reports on 946 children and adolescents with TBI who suffered permanent or long-term mental disability and received any services from the State of California for such disabilities from 1987 to 1995. Because all subjects in this population suffered long-term disability, they constitute a much more severely injured group than the short-term survivors in most epidemiologic series. Although limited information was available regarding patients' histories shortly after their injuries (for example, neither initial Glasgow Coma Scale scores nor durations of posttraumatic amnesia were available), an extensive evaluation at about 6 months after injury and annually thereafter was available for each patient. Furthermore, the group was sufficiently large that we were able to study the effect on survival of several prognostic factors, such as functional ability, which could then be used to stratify the group. The main questions were:

1. What are the most important predictors of long-term survival after TBI?
2. How does the mortality risk of brain-injured persons compare with that of comparable persons whose deficits are congenital or perinatal? How does the answer depend on time since injury?
3. What is the long-term prognosis and life expectancy of persons with TBI?

MATERIALS AND METHODS

The Instrument

Patients' condition and functional abilities were assessed from the Client Development Evaluation Report (CDER).[13] The CDER, which contains some 200 medical, psychological, and functional items, is completed approximately annually for all persons receiving services from the State of California for developmental disabilities. Services include board and care, physical, occupational, and speech therapies, and travel. The reliability of the items used here have been evaluated elsewhere and found to be satisfactory,[14-17] with reliability coefficients[18] generally exceeding .90. The instrument has been in use since 1980.

Inclusion Criteria

The subjects were 946 persons who suffered TBI at ages between 5 and 21 years and received services for developmental disabilities from the State of California between 1987 and 1995. California has an entitlement program guaranteeing services to all persons with developmental disabilities, regardless of family income or other criteria.

Since 1987, the CDER has included ICD9 codes[19] for cause of the developmental disability. Subjects were included if their etiology code was in the range 800 to 804 (skull fracture) or 850

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to 854 (intracranial injury without skull fracture). This definition has been used by others.[20]

Sixty to 90 days after injury, initial interviews were carried out for patients still requiring state services, and (beginning in 1980) the first CDER evaluation was filled out several months thereafter. A patient's first evaluation is thus completed approximately 6 months after injury. Most (581) subjects in the study were injured after 1987; the remaining 365 were injured earlier, some as early as the 1960s. During the 1987 to 1995 period, 38 subjects died.

Variables

The end-point in the study was death. Mortality information was derived from annual tapes issued by the California Department of Health Services. We were unable to gain access to the medical records of the deceased persons.

The principal risk factors were deficits in the basic functional skills of mobility and feeding. For mobility, five CDER items were used: rolling and sitting, hand use, arm use, ability to creep and crawl, and ambulation. Each was originally coded on a scale of between four and nine levels. For example, "Rolling and Sitting" is a nine-point scale, ranging from "cannot lift head when lying on stomach" to "assumes and maintains sitting position independently."

Following previous work,[21] we constructed a four-point mobility scale as follows:

1. No mobility—subject is rated at the lowest level on all five items.
2. Poor mobility—subject has at least as many ratings at the lowest level as at the highest.
3. Fair mobility—subject has more items rated at the highest level than at the lowest.
4. Good mobility—subject has all five ratings at the highest level.

Categories 3 and 4 were combined in this study, because the distinction between the two had little predictive power. Within category 1, we initially distinguished the subgroup judged to be in vegetative state, according to the CDER-based definition of Ashwal and colleagues.[5] There were 21 such subjects. Although mortality in this small subgroup was somewhat higher than for other persons in category 1, the overall results were not noticeably affected by whether vegetative subjects were included. We therefore chose to drop the vegetative distinction in the subsequent analysis.

Finally, we used the indicators of feeding skill that were found in previous work to be powerful predictors of mortality.[21,22] The four levels were: (1) fed by gastrostomy tube; (2) fed by others, without a feeding tube; (3) attempts to finger-feed, needs assistance; and (4) some self-feeding (even if only with fingers).

Statistical Methods

Risk factors were assessed using the Cox proportional hazards model.[23] Data were subject to left truncation,[24] because we have no record of patients who died before receiving a TBI evaluation. It was therefore convenient to implement the analysis using the pooled repeated observations methodology.[21,25] The technique also conveniently handles time-varying covariates, such as mobility. In this method, each month lived in the 1987 to 1995 study period by each subject is taken as a unit of analysis, with a binary outcome (lived/died in that month), and covariates such as mobility, age, and time since injury. Further details on these issues may be obtained from the authors.

A subject's survival time was counted from the date of the first evaluation indicating TBI. For some subjects, information before this first TBI evaluation was available. To include this earlier time as time at risk would introduce a bias, however, because a subject's presence in the study guarantees that he or she survived at least until receiving an ICD9 code for TBI in 1987 or later. In consequence, it was appropriate to use data on subjects only during the 9-year "window" 1987 to 1995.

The survival analyses presented here, spanning 33 years, give the probability that a patient initially at a given level of functioning survives to a given age. The survival curves may be interpreted as conventional Kaplan-Meier estimators.[24] Because no subject provided more than 9 years of data, however, more complex methods were needed. Essentially, the experience of persons of different ages during the study period were combined as in the "period life table." This approach, which is routinely employed by demographers and actuaries,[26] applies to a synthetic cohort whose members are subject to the age-specific mortality rates observed during the study period. Finally, we constructed conventional life tables to compute remaining life expectancies for persons of specified age and mobility. Unlike the above-mentioned survival curves, these analyses apply to subjects whose mobility has stabilized. Again, details on all these methodologic issues are available from the authors.

RESULTS

Profile of Patients

Table 1 shows the profile of age, gender, disabilities, and functional skills of the 946 subjects at the time of their first CDER evaluation. The table shows an excess of males over females, as was found in other studies.[27] The large numbers of patients in the age-groups with driving privileges (ages 16 and older) is as expected. Regarding functional skills, most of the patients were high functioning at the first CDER evaluation, but there were a substantial minority of low-functioning patients. As noted previously, in this respect the sample differs markedly from those generally seen in prospective studies.

It might be thought that there would be an "unhealthy stayer" effect in the study, as patients who make a full recovery generally withdraw from the system. To investigate this, we computed the proportion of patients receiving services in 1987 who were still doing so 5 years later (81%). We compared this with the corresponding proportion for children with cerebral palsy (83%), because it is known that such children rarely improve to the point of no longer requiring services. The two figures are similar, suggesting that the early withdrawal of brain-injured patients whose condition improved was not a major issue.

Risk Factors

Table 2 shows the effect of the various risk factors on mortality, other factors in the table held constant, according to a proportional hazards survival analysis. The first row shows that males had 20% higher mortality risk than females, a statistically significant difference ($p < .05$). This effect, which appears not to have been reported in previous studies, may simply reflect the approximately doubled age-specific mortality rates of males relative to females in the general population.

The effect of having no mobility, compared with the referent group ("fair or good mobility"), was to increase the mortality rate almost fourfold, other things being equal. Those with some, but poor, mobility were at double the risk. The need for gastrostomy feeding was associated with a relative risk of 6.6, compared with the referent group (those able to feed them-

Table 1: Characteristics of the 946 Persons With TBI

Characteristic/Levels	Percentage
Age at injury, rounded to nearest year (% male)	
5-6 (72)	11.3
7-9 (66)	13.4
10-12 (70)	12.7
13-15 (63)	17.9
16-18 (71)	28.5
19-21 (78)	16.2
Rolling and sitting (partially collapsed)	
Does not lift head when lying on stomach	12.6
Lifts head and/or chest	5.0
Some rolling, side to side and/or front to back	4.5
Sits with minimal to no support	9.2
Assumes and maintains sitting position independently	68.7
Hand use	
No functional use	14.5
Uses raking motion or grasps	16.5
Uses thumb and fingers in opposition	11.6
Uses fingers independently of each other	57.4
Ambulation	
Does not walk	29.9
Walks with support	10.1
Walks unsteadily at least 10 feet	11.5
Walks well at least 20 feet	48.4
Mobility scale (see text)	
None	8.9
Poor	21.1
Moderate	29.7
Good	40.3
Time between injury and first TBI evaluation	
Approximately 6mo	65.5
6mo to 5yrs	7.9
5yrs to 10yrs	14.0
10yrs to 15yrs	8.4
15yrs or longer	4.2
Year of injury	
1960-1979	14.8
1980-1986	23.8
1987-1995	61.4
Persistent vegetative state	
Yes	2.2
No	97.8
Feeding (partially collapsed)	
Tube fed	13.7
Fed entirely by others	7.1
Attempts to feed but needs assistance	2.5
Has some self-feeding	76.7
Word usage	
No use of words	26.0
Uses simple one-syllable words	18.0
Has limited vocabulary	32.2
Has broad vocabulary, and uses correctly	23.8
Receptive nonverbal communication	
Does not demonstrate understanding of gestures	28.8
Demonstrates understanding of simple gestures	25.9
Demonstrates understanding of complex gestures	18.1
Understands a series of gestures	27.3

Table 2: Mortality Risk Factors After TBI

Risk Factor	df*	Relative Risk	95% Confidence Interval
Male gender	1	1.20†	1.03-1.39
No mobility§	1	3.73‡	2.74-5.07
Poor mobility§	1	1.96‡	1.53-2.50
Tube fed¶	1	6.61‡	4.97-8.79
Fed completely by others¶	1	2.86‡	2.22-3.69
Attempts to finger feed, needs assistance¶	1	2.08‡	1.44-2.99

Not included in the table: effects of age, time since injury (see fig 1), ICD9 classification of injury.
* Degrees of freedom.
†‡ Mortality risk for patient with the given condition, compared with the referent group; † indicates an effect significantly different from 1.0, $p < .05$; ‡ $p < .01$.
§ Compared with the referent group, those with fair or good mobility.
¶ Compared with the referent group, those able to feed themselves.

selves). These mortality patterns were consistent with those previously observed in patients with other kinds of disabilities.[28,29]

The effects of several factors are not shown in table 2. *Cognitive skills*, such as verbal and nonverbal communication, did not contribute significantly to the prediction of mortality when the other factors were taken into account. *Age* was used in the subsequent construction of survival curves and life tables; during the decade after injury, there was no systematic relationship between age at injury and mortality risk. Regarding *location and type of injury, and duration of unconsciousness*, as given by ICD9 codes, a few such variables made a statistically significant contribution to the mortality prediction, but their effects in clinical terms were small. This may reflect the fact that the majority of patients were coded as "unspecified" with respect to the these items.

The data also did not suggest any *secular trend* in risk-adjusted mortality rates over time. This was perhaps not surprising, because the study period spanned only 9 years. The available data did not permit comparisons with conditions before 1987.

We opted to present the results regarding *time since injury* in figure 1 rather than include them in table 2. We contrasted the TBI group with persons in our database who had cerebral palsy—a comparison group whose mental disabilities were congenital or perinatal. From this group we chose at random 5,457 persons whose ages were comparable to persons with TBI. The analysis shown in table 2 is based on the combined data; in this way we could control for the effects of age and functional skills when contrasting the survival of persons with TBI to that of persons with congenital disabilities.

Figure 1 shows that the relative risk depends strongly on time since injury. In the critical first few days or weeks after brain injury, mortality risk for brain-injured patients is of course much higher than for the comparison group. Figure 1 indicates, however, that after an initial period of 1 or 2 years the risk for those with TBI is less than half that for the comparison group. In the long run, mortality rates in the two groups appear to converge.

Causes of death, as specified by ICD9 cause of death codes, are shown in table 3. Unfortunately, most of the codes correspond merely to "late effects of injury." In view of this, it seemed inappropriate to compare cause-specific rates with that of the general population, as Roberts was able to do.[3] Nevertheless, certain causes (eg, grand mal seizures and violent deaths

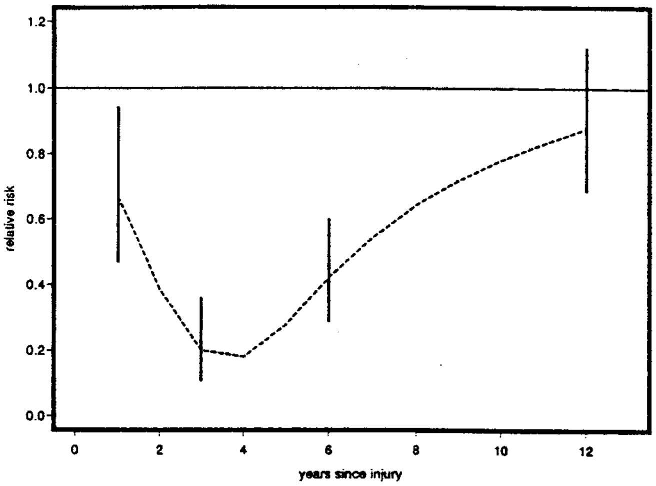

Fig 1. Risk for persons with TBI compared with those with cerebral palsy. Plotted values are mortality risks, relative to people with cerebral palsy, after adjustment for age, functional abilities, and other factors. Vertical bars represent one-standard-error bounds. The relative risk in TBI diminishes after the first postinjury year, then slowly approaches that of cerebral palsy.

due to burning, suffocation, and suicide) did appear to be more frequent here than in the general population. Overall, even excluding the 19 "late effects" deaths, there were 19 observed deaths, compared with an expected number (after adjustment for age and gender) of 5.53 in the general population, for a standardized mortality ratio of $19/5.53 = 3.4$. This is significantly larger than 1.0 ($p < .001$).

Excess Mortality Among High-Functioning Persons With TBI

Although functional skills were the major predictor of mortality, even high-functioning patients were subject to an excess mortality compared with the general population. For example, among those who were fully able to sit unaided, there were 9 deaths compared with an expected 4.1 deaths in the general population (after adjustment for age and gender). The standardized mortality ratio of 2.2 ($=9/4.1$) was significantly larger than 1.0 ($p < .05$).

For simplicity and clarity, we dropped the feeding variable for the remainder of the study and worked solely with mobility. The resulting loss of information was only moderate because mobility is strongly associated with feeding skills.

Table 3: Causes of Death

Late effects of accidental injury	19
Subsequent vehicle and other accidents	3
Infections	3
Pulmonary	2
Epilepsy (grand mal)	2
Cerebrovascular	1
Suffocation	1
Burning	1
Suicide	1
Unspecified	2
Missing	3
Total	38

From ICD9-coded data.

Long-Term Survival

Figure 2 shows the probabilities of survival through age 50 for a 17-year-old patient. The three curves correspond to fair/good mobility, poor mobility, and none. These results may be used for prognostic purposes, because they do not assume that the patient's condition will remain static. Instead, they take into account the probabilities of change in functioning over the first 9 years. It may be seen that the immobile patients (some of whom are in a vegetative or near-vegetative state) were subject to high mortality, with only a 66% chance of surviving 8 additional years and only a 25% chance of surviving to age 50. Among the patients initially with fair or good mobility, by contrast, survival rates were very high.

Life Expectancy

Table 4 reports life expectancies for patients whose level of mobility had stabilized into one of the three groups. For brevity, only results for males are given, with corresponding life expectancies for US males shown for comparison. Again, it may be seen that life expectancies are severely reduced for immobilized patients, whereas the age-specific life expectancies for those with good mobility approach those of the general population.

DISCUSSION

This study focussed on children and adolescents, who form the largest group of survivors of head injury and have the greatest potential for years of productive living. As in all epidemiologic studies, the issue of generalizability arises. The study was based on a system that provides board and care, therapies, and related services. It therefore excludes (1) persons with injuries so severe that they died in the first few days or months and (2) those whose injuries were mild enough that long-term services were not needed. In California, no children are excluded because of income requirements. It is our impression that almost all eligible persons with serious disabilities do avail themselves of at least some state services and are thus included in the database. Unfortunately, however, information on this issue is difficult to obtain. This aside, the study appears to be reflective of survivors whose condition has stabilized to a level at which long-term rehabilitative services are required. This is a population of considerable relevance to estimation of long-term effects and costs of head injury.

It was shown that deficits in basic functional skills, such as mobility and feeding, are powerful predictors of mortality. Once these were considered, age and measures of cognitive functioning contributed modestly at best. This pattern has been observed previously with groups of children with other disabilities, such as cerebral palsy.[29,30] Variables such as type of injury and duration of unconsciousness also contributed rather little to mortality prediction after functional ability was controlled. However, this may be explained partly by the large proportion of patients coded as "unspecified" on these items.

Mortality in patients with TBI was, after the initial period of high risk, substantially lower than for comparable persons with congenital or perinatal conditions (fig 1). Hazard rates in the two groups converge slowly as time since injury increases, the difference being statistically insignificant a decade after injury. One interpretation is that normal persons involved in accidents are constitutionally more robust than those with congenital defects. After years of disability, however, the differences may tend to blur.

It has been suggested anecdotally that individuals who survive several years after TBI may in some way be "tougher" than those who succumb in, say, the first year, and that this

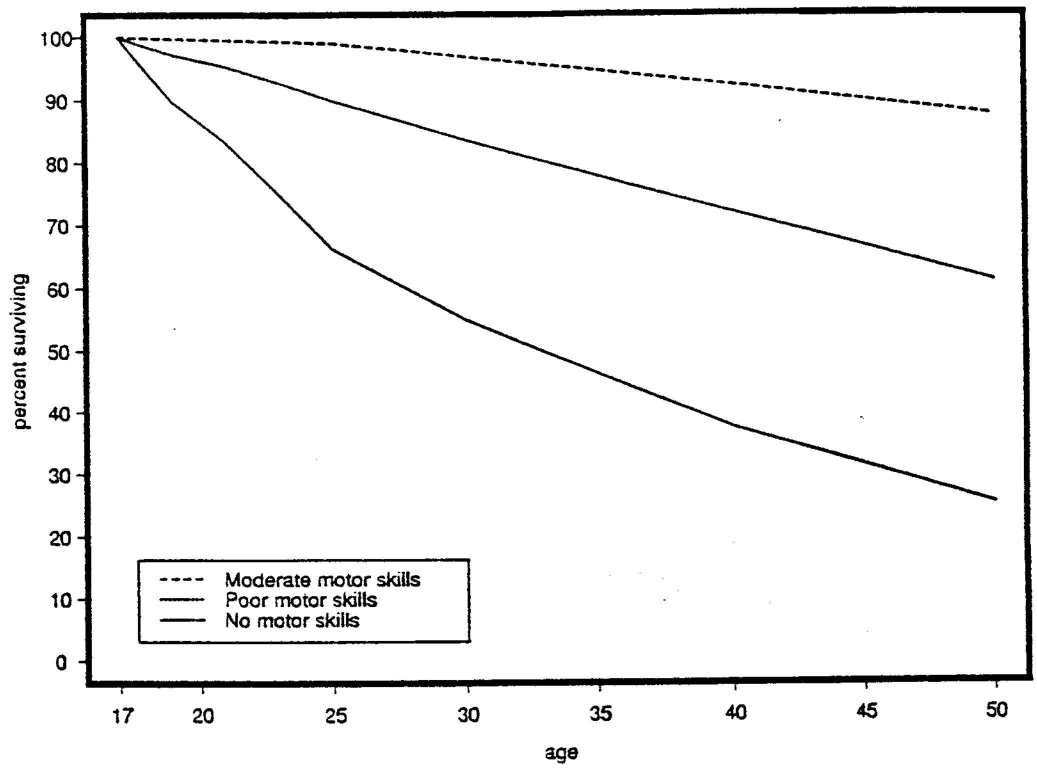

Fig 2. Survival curves for 17-year-olds with TBI. For explanation of motor skills, see text. Each curve can be viewed as tracking a cohort of persons injured at age 17, following them through age 50. Because the study period is only 9 years, a "period life table" approach has been used.[26]

could explain why mortality rates decline after the initial posttraumatic period. No doubt individuals do differ to some extent in their capacity to recover from these injuries, but the decline in mortality rate after the initial period surely also reflects a healthy survivor effect: persons who die during the first year have, on average, sustained more serious injuries than the survivors, so the survivors have a better subsequent prognosis. As noted, we found that in the long run TBI survivors have mortality similar to that of persons with comparable but congenital disabilities; this does not support the idea that long-term TBI survivors are unusually robust.

We estimated that life expectancies for persons stabilizing at a high level of mobility were only about 3 years shorter than for the general population. This is consistent with other reports.[3,4] The much poorer long-term prognosis for patients with severe and permanent mobility deficits, however, appears not to have been documented previously. This may reflect the unusually large group of persons with long-term sequelae of TBI that was available for study here.

Some limitations of the study should be noted. First, we have incomplete information related to the immediate posttraumatic clinical factors. It would be of interest to determine whether the type of head injury, duration of posttraumatic amnesia, and other factors contribute to the prediction of survival when the patient's functional level at 6 months is known. Our epidemiologic experience leads us to speculate that functional items would still be the best predictors.

Second, the short time span of the study may appear to be a drawback. In fact, however, this is advantageous to the extent that only relatively current medical practices are reflected. The issues are essentially those of the relative merits of cohort and period life tables.[26] Briefly, a period life table is obtained by combining the mortality experience of a population of diverse ages during a fixed short period, rather than by following an actual cohort. In the current study, the 9-year study interval corresponds to the "period" of the life table.

Finally, the results shown in figure 2 and table 4 rely on a simple stratification according to mobility and should be regarded as preliminary approximations. A more accurate prognosis corresponding to any specific profile of age, functional level, and disabilities may be obtained using the methods developed here.

Table 4: Remaining Life Expectancies (Years) for Males, by Mobility

Age	Level of Mobility: None	Poor	Fair/Good	1992 US Males: General Population
15	14.9	34.2	54.8	58.3
20	14.4	32.3	51.0	53.7
25	14.1	30.4	47.1	49.1
30	13.0	27.9	43.0	44.5
35	12.5	25.7	39.0	40.0
40	11.3	23.0	34.8	35.5
45	11.1	20.8	30.8	31.1
50	10.0	17.9	26.5	26.8

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