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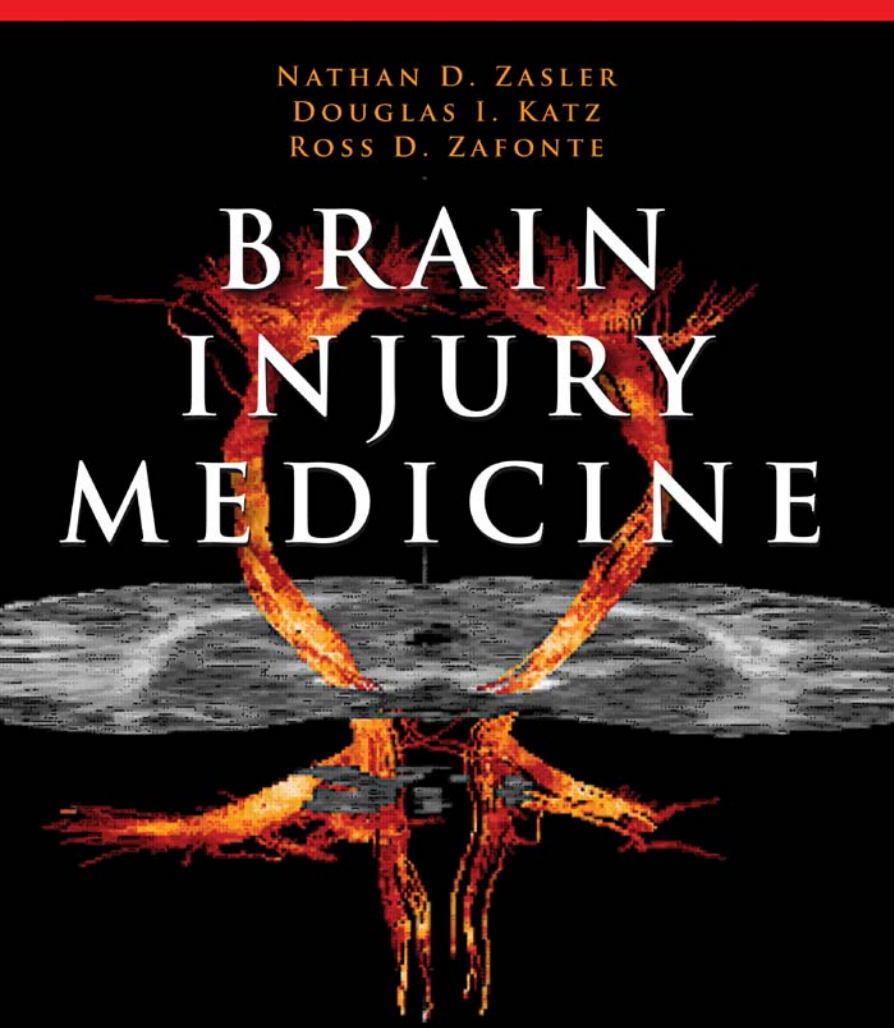
BRAIN INJURY MEDICINE



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17 Life Expectancy

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1. INTRODUCTION

Rehabilitation needs and long-term planning for persons with severe traumatic brain injury (TBI) are covered in depth in other chapters of this volume. Here we consider one important aspect of long-term planning, namely longevity.

It is well known that mortality after severe TBI is exceptionally high in the acute post-injury period. It is perhaps less well known that long term mortality (2 years or more post-injury) is also increased, by comparison with the general population. It follows as a mathematical consequence that the life expectancy is reduced.

There are many studies of short-term survival after TBI. Detailed long-term data, however, and resulting research studies, are relatively sparse. The largest group studied on a long-term basis appears to be in the California Disabilities Database, which includes approximately 4,000 persons with disability secondary to TBI.

In this chapter we review what is known about life expectancy in TBI and present some new findings. Section 2 gives a brief review of key actuarial ideas needed for a discussion of life expectancy. Section 3 discusses the causes of death for which the risk is increased after a serious TBI, and reviews the literature. It is not always recognized that persons with TBI are subject to excess mortality risk from some of these causes. In section 4 we review the literature on life expectancy after TBI, focussing on recent research. After this we discuss the factors that best predict life expectancy (section 5). It will be seen that, as in other types of chronic disability, the severity of motor dysfunction is the most important predictor of reduction in life expectancy. Later, in sections 6 and 7, we present some new findings on life expectancy and long-term decline in function after TBI. We discuss the effect of quality of care on life expectancy in section 8, the estimation of life expectancy in individual cases in section 9, and offer some conclusions in section 10.

2. TERMINOLOGY

It will prove helpful in the later sections to be familiar with the following terms:

- **Survival time**: the actual number of years lived by a given patient or member of a study population. A patient alive at the end of a study period is said to have a **censored** survival time as of that date.
- **Life expectancy**: the **average** survival time in a large group of similar persons. Note that this is not a prediction about any individual's actual survival time, as some survival times will be much longer and others much shorter than average.
- **Median survival time**: the time after which exactly half of a large group of persons are still alive. If all

the survival times are known (uncensored) and ordered from smallest to largest, the median is the middle value.

- **Exposure time**: the total number of person-years lived by all the members of a study population during the study period.
- **Mortality probability**: The chance of dying in a given period (e.g., a year). Like all probabilities, this number is between 0 and 1 inclusive.
- **Mortality rate**: The number of deaths in a study population divided by the number of person-years of exposure time. This is always larger than the mortality probability over the same period. Except in very high-risk populations, where the mortality rate could be greater than 1.0, however, the difference between the two is small.
- **Standardized mortality ratio (SMR):** the ratio of the observed number of deaths in a study population to the expected number, where the latter is what would arise from a suitably chosen reference group (often the age- and sex-matched general population in a given country). For example, an SMR of 2 means that the study population has twice the death rate of the reference group, after adjustment for age and sex differences. For further discussion, see Kahn & Sempos (1).
- **Relative risk (RR):** the ratio of the mortality rate in a study population to the mortality rate in the reference population. Unlike the SMR, the expected number is not standardized to the age and sex distribution in the reference population. The RR is often termed the **mortality ratio** (MR) in the actuarial literature.
- **Excess death rate (EDR):** the difference between the death rate in a study population and that in the reference population.
- **Life table**: a standard table summarizing mortality information about a group. Life tables are constructed for entire populations (2–6) or for suitably large subgroups (7–11). The table derives entirely from a set of age-specific mortality rates, and gives the life expectancy at every age. The median survival time can be easily computed from table entries (12, 13).

3. CAUSES OF DEATH AFTER TBI

It is clear from the published literature that there is an increase in long-term mortality in persons who have suffered a severe TBI. The published studies are, however, not entirely consistent on which causes of death account for the excess.

In the very short term, the primary cause of death is the brain damage itself. One of the largest studies was that of Sekulovic and Ceramilac (14), who summarized autopsies of 499 deaths occurring within 30 days of traumatic brain injury. They found that 78% of the deaths were due to injury to brain stem, brain edema, or brain compression. Of the remainder, the most frequent cause was pneumonia.

The definition of "longer term" varies among the studies. For example, Baguley et al. (15) considered patients who had been released from the hospital into rehabilitation facilities, while Shavelle et al. (16) considered one year or longer post injury.

The published studies make clear that, even in the long-term, death rates from many different causes are elevated for persons with TBI by comparison with the general population. These causes are considered below.

- **Epilepsy.** We refer here to post-traumatic epilepsy, rather than post-traumatic seizures. Post-traumatic epilepsy refers to recurrent long-term episodes often observed in persons with TBI, while the term post-traumatic seizures is generally applied to events in the first post-injury week.

  The classic studies of World War II veterans with TBI first documented the increased mortality risk from post-traumatic epilepsy (17). Later studies similarly addressed World War I veterans and reported the same finding (18, 19). This was confirmed in Roberts' long-term follow-up of patients in England during the 1960's and 70's (20, 21) and in Rish et al.'s study of veterans from the Vietnam war (22). More recently Shavelle et al., in their study of Californians with long-term mental disabilities from TBI, estimated a standardized mortality ratio (SMR) for seizures of 24 by comparison to the general population (16). Even patients with less severe disabilities were subject to an increased risk.

  The literature shows that epilepsy is more common in penetrating head injuries, such as gunshot wounds, than in non-penetrating injuries (23–27). One might expect that the severity of epilepsy would be greater, and therefore the mortality risk higher, for those with penetrating injuries. There does not appear to be any available evidence on this, however.
- **Suicide.** Roberts (20) found an increased suicide rate (SMR = 3) over the long term. A similar finding, and one documented in greater detail, was reported by Teasdale & Engberg (27). The latter authors, in their large study of Danish patients with TBI, found a suicide rate approximately four times that of the general population. They point out that persons with certain psychiatric conditions may be prone both to have accidents causing TBI and to commit suicide, though it seems unlikely that this could explain most of the association. A recent study by Pentland et al. (150) also found an increased proportion (1.3% of all deaths) due to suicide.

No increase in the suicide rate was observed by Walker and Blumer (28) or Shavelle et al. (16).

- **Respiratory infections and pneumonia**. Many studies document the increased risk of death due to these causes in patients with severe TBI. This is especially marked in persons who have become nonambulatory. Shavelle et al. (16) reported an approximately ten-fold increase in the mortality rate from respiratory causes, and Pentland et al. (150; Figure 2) found it to be the leading cause of death in this population after cardiac diseases. It appears that it is primarily the immobility, not the brain injury per se, that increases the risk; for example, a similar finding is reported in patients immobilized by spinal cord injury (29, 30).
- **Meningitis** was reported as an increased risk by Roberts (20), but not by other researchers (15, 16, 22).
- **Diseases of the circulatory system** are the leading cause of death in Western countries, and in the long-term the risk of death appears to be even higher in persons with severe TBI. Shavelle et al. (16) reported an approximately tripled mortality rate from these causes, by comparison with the general population, which by itself indicates a substantial reduction in life expectancy. Not surprisingly, the increase was largest among patients who had become nonambulatory. Weiss et al. (19) also found a long-term increase in the death rate from diseases of the circulatory system.

  There are at least two mechanisms that could contribute to the increase in circulatory disease, and related deaths. First, persons confined to a wheelchair often take little exercise, and this alone increases the long-term risk of circulatory disease (31–35). Secondly, paraplegia appears to increase the risk of embolisms that travel from the lower body to the brain or lungs, and are often fatal. We are not aware of any studies that quantify these effects after TBI specifically, but a similar pattern of increased mortality has been observed in persons immobilized from spinal cord injury (29, 30) or cerebral palsy (59).

  As with others who are immobile, persons suffering a TBI have an increased incidence of morbidity due to deep vein thrombosis, pressure sores, sepsis and urinary tract infections (36–48). However, there do not appear to be any studies documenting increased long-term mortality due to these causes. Of the 135 deaths described in Table 17-1 below, only one was due to any of the above (urinary sepsis).

Walker et al. (18) suggested that an injured brain makes the entire body more vulnerable to the stresses of aging. Lewin et al. (21, p. 1535) doubted Walker's hypothesis, pointing out that in their own study only a small number of causes of death appeared to be elevated in their TBI population. As noted earlier, however, the much larger study of Shavelle et al. (16) found increased mortality from most major causes other than cancer, which may support the view of Walker et al.

TABLE 17-1
Causes of Death for Persons Injured at Ages 10 or Older Who Died 5 or More Years Later

Cause of Death (ICD-9 codes)	Number	%
Cancer (140–239)	9	7
Seizures (345, 436, 780.3)	14	10
Circulatory (390–459, except 436)	26	19
Respiratory (460–519)	15	11
Digestive (520–579)	6	4
Urinary/kidney (580–599)	4	3
Choking/suffocation (910–915)	3	2
Other external (800+, except 910–915)	13	10
All other causes, including missing	45	33
Total	135	100

Table 17-1 shows causes of death for persons injured at ages 10 or older, who died 5 or more years after injury. The data are from the California Disabilities Database over the period 1988 to 1999 (49).

Excluding the "All other causes" category, the largest category was circulatory diseases. The comparatively small proportion of cancer deaths reflects the increased number of premature deaths to other causes; for example, there were more deaths due to respiratory diseases and seizures than to cancer.

4. RECENT LITERATURE ON LIFE EXPECTANCY

There is an abundant literature on short-term survival after TBI. The focus here is on the major recent studies on long-term survival. For a detailed history of studies prior to 1979 see Roberts (20, chapter 4).

- Walker and Erculei (17, 50) studied 364 World War II head-injured men from injury to 15 years later. The authors found a death rate 3 to 4 times greater than expected. They analyzed the frequency and severity of seizures, noting that men with post-traumatic seizures did not, on average, survive as long as those without seizures.
- Walker et al. (18) analyzed survival data through 1965 on 574 German World War I head-injured men. This ambitious study included a contemporary

control series of 581 unwounded veterans receiving meritorious medals. They constructed life tables and found a roughly 4-year reduction in life expectancy in the TBI group, with a larger reduction for those with epilepsy.

- Roberts (20) followed 469 patients who were amnesic or unconscious for a week or longer after a severe head injury. His analysis concentrated on the 366 who were discharged alive from hospital. He found that the chance of dying in the first 20 years after injury was elevated only in those injured at ages 5 to 25, and concluded that the effect of TBI on life expectancy was a 5-year reduction (20, p.146).

  It appears from Roberts' Table 5.3 that some 80–90% of these persons could walk unassisted. If so, his conclusion would not apply to the most severely injured patients who were wheelchair-dependent or even bedridden. It has sometimes been inferred, incorrectly, that the Roberts' estimated 5-year reduction applied regardless of the severity of disabilities. Roberts himself evidently did not hold this view, as he reported that persons with the most extreme disabilities rarely survived ten years (20, p.142).
- Rish, Dillon and Weiss (22) studied 1127 Vietnam veterans who survived one week or longer after a penetrating head injury. The all-cause SMR over the 15-year study period exceeded 4 during years 1–3, ranged from 2 to 4 during years 4–11 and 13 post-injury, and was (probably because of the small sample size) less than 1 for years 12, 14 and 15. The authors concluded that the study population may have "approached the norm."
- Corkin, Sullivan and Carr (51) studied 190 World War II veterans with penetrating head injuries and a matched set of 106 with peripheral nerve injuries. They reported that head injury coupled with epilepsy reduced life expectancy compared to the control group, but that head injury alone did not.
- Walker and Blumer (28) studied 244 World War II head-injured men with post-traumatic epilepsy and found a death rate several times higher than in the general population.
- Strauss, Shavelle and Anderson (52) studied 946 children and adolescents aged 5 to 21 who suffered a TBI, following the subjects for up to 9 years. They constructed life tables stratified by a crude mobility scale (none, poor, fair/good). The resulting reductions in life expectancy, compared with the general population, ranged from very large (40 years) in persons with the most severe disabilities to quite small (2 years) in those who retained good mobility.
- Baguley et al. (15) studied 476 patients injured from 1986 to 1996. During the average follow up time of 5 years there were 27 deaths, compared to 6.7 expected, giving an SMR of 4.0. The difference was highly statistically significant, again demonstrating that life expectancy after TBI cannot be considered normal.
- Shavelle and Strauss (53) computed excess death rates for persons with TBI, beginning two years after injury. The population studied was the largest in the literature, with 2629 subjects and 268 deaths in the 1988 to 1997 study period. As in their previous studies, these authors found that excess death rates were relatively small for ambulatory persons, but much larger for those who had become nonambulatory.
- Brown et al. (151) followed up on 1,448 persons with TBI, of whom 164 (11%) were described as having moderate to severe injuries. They found that persons with mild TBI exhibited a small but statistically significant reduction in long-term survival. For those with moderate or severe TBI, long-term survival of those who survived the first six months was similar to those with mild TBI. A difficulty in interpreting this last finding is that the "moderate to severe" range presumably contained a mixture of persons with extremely severe disabilities (for whom the life expectancy is without question markedly decreased) and persons with much less severe disabilities. The overall effect therefore depends on the relative proportions.
- Harrison-Felix et al. (152) followed 2178 persons with TBI who completed inpatient rehabilitation in one of 15 National Institute on Disability and Rehabilitation Research-funded TBI Model Systems of Care. They estimated an average reduction in life expectancy of 7 years. In a follow up publication jointly written with the present authors (153), they indicated a general approach to estimating the life expectancy of an individual of a given age, sex, and score on the Disability Rating Scale. For example, according to the Model Systems data the life expectancy of a young adult with an "extremely severe" disability is 50% of normal. This again indicates how life expectancy after TBI varies greatly according to the severity of the injury.

While some of the studies — most notably, those of subjects without epilepsy — did not report a substantial reduction in life expectancy in some groups, this may be because persons in those groups were less severely disabled. There can be no question that mortality is markedly increased among the most severely disabled patients, a pattern well documented also in cerebral palsy (54–65) and spinal cord injury (19, 30, 66–70). In discussions of life expectancy of persons with TBI, therefore, it is important to consider the severity of disability.

Persons with more severe injuries are much more likely now than in the past to survive the early high-risk period (22). Other things being equal, it may therefore be

that the more recent studies have a higher proportion of severely disabled persons. This would have obvious implications for the comparison of older and newer studies.

5. FACTORS RELATED TO SURVIVAL

The best predictors for survival in the *short* term are clinical measures such as the patient's Glasgow coma scale and duration of post-traumatic amnesia. The concern in this chapter, however, is with factors predictive of long-term survival.

For persons with TBI as well as in the general population, age is of course the most obvious determinant of life expectancy. Apart from age, the key factor is the severity of disability, especially motor dysfunction. This can be measured by simple functional items such as the patient's ability to walk, use hands, and self-feed. Other factors (such as preserved cognitive function or epilepsy) have a relatively small effect once motor function has been accounted for.

We now consider the factors that have been considered significant for life expectancy, citing the available evidence.

- **Age**. The increase in mortality of persons with TBI with age has been documented in many studies (52, 53, 71–74).
- **Sex**. In the general population, mortality of males at most ages is appreciably higher than that of females (2–6). For example, in the U.S. general population males age 30 to 60 have about twice the risk of death as females (2). Similar sex-differences have also been observed in persons with TBI (35). As would be expected, the difference is most marked in persons with milder disabilities and all but disappears at the most severe end of the spectrum. For example, no sex difference was been found in the survival of persons in the permanent vegetative state (75).
- **Time since injury** is certainly an important factor in the short-term. The mortality risk declines steadily during the first two years after injury as the patient's condition stabilizes. In the much longer term, however, there is no clear evidence of a trend, once severity of disability is taken into account. For example, mortality rates of persons 5 years post-injury do not seem markedly higher than otherwise comparable persons 10 years post-injury (49).

  Because mortality after severe TBI is so high shortly after injury, it has sometimes been suggested that individuals vary greatly in their "toughness": only the tough survive the initial post-acute period, and these individuals are likely to survive much longer. No doubt individuals do vary to some extent in their abilities to survive major trauma. A more plausible explanation, however, is the well-known "healthy survivor" effect: persons with the most severe injuries die first, and the remainder have better survival because their injuries are, on average, less severe. This explanation is consistent with our finding that after the first few years, mortality rates are fairly constant over time once mobility and other factors are taken into account.
- **Mobility** is the most powerful predictor of long-term survival after TBI. Using the extensive California Disabilities Database, Strauss, Shavelle and Anderson (52) found a large difference in survival based on an overall mobility scale (none, poor, fair/good). The risk of death for persons with no mobility was approximately four times higher than those with fair or good mobility, even after adjustment for several other factors.

  Shavelle and Strauss (53) subsequently computed age-specific mortality rates for three levels of ambulation (walks well alone; walks with support or unsteadily alone; does not walk). The age-specific mortality risks relative to the general population ranged from as low as 1.3 to as high as 17. Additional research indicates that, as would be expected, still more precise discrimination can be made based on more refined measures of motor function (49). Similarly, Baguley et al. (15) found that Functional Assessment Measure score was associated with survival.
- **Feeding ability**. Strauss, Shavelle and Anderson (52) found a sharp contrast in survival between four groups of persons: those requiring a feeding tube (RR = 6.6 compared to the best group), those fed orally by others (RR = 2.9), those who could finger feed (RR = 2.1), and those who could use utensils (the best group, with RR = 1 by convention).
  The inability to self-feed is an indirect measure of neurological compromise. It seems likely it is this compromise that causes the increased mortality, and the inability to self-feed is primarily a marker for it.
- **Need for ventilator support, oxygen, and/or frequent suctioning; history of respiratory problems**. We recently investigated the effect of these factors (49). Each was much more common in persons who could not walk and who required a feeding tube than in persons who were higher-functioning. In the former group, the univariate effect — that is, when no adjustment for mobility, etc. was made — was statistically significant and large: the relative risks for the factors ranged from 2 to 6. However, once age, sex, mobility and feeding were accounted for the (multivariate) relative risk was less than 1.2 for each factor.
- **Deficits in cognitive function and ability to communicate** are strongly correlated with severity of motor dysfunction. Although cognitive and communicative

functions are strong univariate predictors of mortality, their effects are modest when motor function is taken into account (49, 52). The same finding has been documented in persons with cerebral palsy (61, 62).

- **Epilepsy**. Many authors have found that epilepsy was strongly associated with reduced survival (17, 19, 50, 51). However, as others have suggested, this was likely because the presence of post-traumatic epilepsy is highly correlated with the extent of brain damage (17, 22). That is, epilepsy served as a marker for injury severity. Nevertheless, epilepsy is an independent risk factor for increased mortality. We recently confirmed this, and additionally found that in those who cannot walk, the relative risk of death for persons with generalized tonic-clonic seizures is 1.2 compared to others (49). In a separate study of people with minimal physical disabilities, Strauss et al. (76) similarly documented the increased mortality associated with recent seizures.
- **Calendar year**. The question is whether survival rates have improved over the years for a patient of given age and severity of disability. This would be termed a *secular trend*. The available data does not reveal any evidence of such a trend in recent (1980+) years (15, 49, 52). This may seem paradoxical because (i) as noted in other chapters of this volume, advances in rehabilitation have improved functional outcome after TBI, and (ii) as documented above, functional outcome, specifically mobility and feeding skills, are key factors associated with life expectancy. Thus it may well be that among patients with similar *initial* injuries, survival now is better than in previous decades because functional outcome is better. The cited research (15, 49, 52), however, looked at a different issue: comparison of survival now and in the past of patients who have the same *functional outcome*.

Several other factors should be mentioned as possible predictors of survival:

- **Poor education**. This factor was noted by Corkin, Sullivan and Carr (51). They suggest many reasons for the increased risk of death, including subsequent occupation and access to health care. To our knowledge other researchers have neither confirmed nor disproved this.
- **Depth of brain injury**. Weiss et al. (19) found that, as expected, the survival was poorer in persons with deeper (greater than 3 cm) brain injuries, although the difference was not statistically significant.
- **Penetrating versus closed head injuries**. Baguley et al. (15), in comparing the literature, concluded that there was no evidence of a difference. After controlling for functional abilities we too could find no difference, though the power of this comparison was low (49). Zafonte et al. (77) also found no difference in functional outcome at one year post-injury. On a related point, we found no difference in survival (49) between those who suffered skull fractures (ICD-9 codes 800–804) versus intracranial injuries (850–854). Finally, it may be that the effect of epilepsy is different in penetrating versus closed injuries, though evidence on this does not appear to be available.
- **Duration of unconsciousness**. Neither Shavelle and coworkers (49, 52) nor Weiss et al. (19) found this to be a significant factor. Lyle et al. (78) found that duration of coma was associated with both recovery and survival to 2 years, but it is not clear if this result would hold true if attention was restricted to those alive at 1 year post-injury, and if the functional outcome — e.g., mobility — was accounted for.
- **Glasgow coma scale (GCS) and the duration of post-traumatic amnesia (PTA)**. Again, these factors are measures of the severity of the injury, are highly correlated with short-term survival, and therefore have a relationship to subsequent longevity. We are not aware of any evidence, however, that either of these factors is associated with subsequent long-term survival given the functional outcome one year post injury.
- **Maladaptive behaviors –** such as drug use, other substance abuse, suicide attempts, assault, aggression, self-injurious behavior, and lack of safety awareness – are much more common in those who have suffered a TBI or other central nervous system trauma than in the general population. For example, several studies report an association between CNS trauma and criminal behavior, especially violent crime (79–81). Such behaviour is also more frequent in persons with TBI than in others with comparable levels of functioning whose disabilities are due to cerebral palsy, autism, and other conditions (32).

  These behaviors, with the exception of safety awareness, were *positive* factors for life expectancy when considered in isolation (49). That is, for example, persons who abused drugs had a *lower* mortality rate (and thus higher life expectancy) than those who did not. This is not surprising as those who could exhibit the behaviors were much less severely disabled, on average, than those who could not. In fact, these factors had a small *negative* effect on survival once functional abilities were taken into account (49).

  Maladaptive behaviors in general have all been shown to be associated with increased mortality. For a review of the epidemiological data, see Harris & Barraclough (82). As these authors show, a major component of the increase is deaths due to unnatural causes, including accidents, suicide and homicide.

It may be that the reduced life expectancy of relatively high-functioning persons with TBI in part reflects an increased rate of unnatural deaths associated with behavioral problems.

- **APOE 4**. It is also possible that the APOE 4 allele plays a role. As noted by Baguley et al. (15) in citing Teasdale et al. (83) and Friedman et al. (84), patients with the APOE 4 allele are more likely to suffer unfavorable outcome after severe traumatic brain injury. Recent research (85, 86) on this issue has found that the presence of the APOE 4 allele is associated with poorer memory performance and rehabilitation outcome after TBI. Research by Liberman et al. (87), however, did not show a consistent influence of APOE genotype on outcome. We are not aware of any data on the independent effect of this allele on long-term survival.
- **Quality of care** is addressed separately in section 8.
- **Other factors relevant to life expectancy in the general population** are also relevant for persons with TBI. These include pre-injury health status and history of smoking, alcohol and drug abuse, obesity, etc. Scientific literature on the effect of most of these factors is available.
- There are **factors uncommon in the general population** that can affect the mortality risk of persons with TBI. Examples are difficulties with chewing and swallowing, contractures, pressure sores (for persons with limited mobility), bowel and bladder dysfunction, frequency of infections, and psychological factors (attitude to the disability, depression, aggressive behavior, etc.). For many of these factors, published studies of the effect on mortality are not available.

6. NEW ESTIMATES OF LIFE EXPECTANCY IN TBI

Tables 17-2 and 17-3 show our most recent findings (49). These represent a refinement of the data presented in our

TABLE 17-2
Female Life Expectancy by Age and Severity of Disability

Age	PVS[a]	Cannot Walk		Some Walking Ability[d]	Walks Well Alone[e]	General Population
		Fed by Others[b]	Self Feeds[c]			
10	12	27	46	55	61	70.0
20	11	26	40	48	54	60.2
30	10	22	33	41	46	50.5
40	9	16	26	31	36	41.0
50	7	11	19	23	27	31.7

[a]Permanent vegetative state: No purposeful motor or cognitive function. Requires a feeding tube.
[b]Does not feed self, must be fed completely (either orally or by a feeding tube).
[c]Can feed self with fingers or utensils, with assistance and/or spillage.
[d]Walks with support, or unsteadily alone at least 10 feet but does not balance well.
[e]Walks well alone for at least 20 feet, and balances well.

TABLE 17–3
Male Life Expectancy by Age and Severity of Disability

Age	PVS[a]	Cannot Walk		Some Walking Ability[d]	Walks Well Alone[e]	General Population
		Fed by Others[b]	Self Feeds[c]			
10	12	27	46	50	56	64.3
20	11	26	40	44	49	54.7
30	10	22	33	37	41	45.4
40	9	16	26	28	32	36.2
50	7	11	19	20	23	27.4

[a]Permanent vegetative state: No purposeful motor or cognitive function. Requires a feeding tube.
[b]Does not feed self, must be fed completely (either orally or by a feeding tube).
[c]Can feed self with fingers or utensils, with assistance and/or spillage.
[d]Walks with support, or unsteadily alone at least 10 feet but does not balance well.
[e]Walks well alone for at least 20 feet, and balances well.

earlier publications, and take account of age, sex, and walking and feeding ability. For comparison, life expectancies in the permanent vegetative state (PVS) and the U.S. general population are also shown. As can be seen, the remaining life expectancy decreases both with age and with severity of injury.

At the most severe end of the disability spectrum, the permanent vegetative state (PVS), the life expectancy is at most 12 years, and no significant differences were found between the sexes. The PVS analyses are specific to persons with acquired injuries, including TBI and near-drowning, and who will require gastrostomy feeding for life. The corresponding figures (not shown) for persons with congenital conditions, degenerative diseases, or who require a ventilator are lower still.

Persons in the minimally conscious state (MCS) – a group that has received recent attention in the clinical literature (88–90) – have slightly higher cognitive function than those in the PVS. A study of infants who were immobile and in the MCS ("IMCS") found that their survival was only slightly better than those in the PVS (91). Thus, once again, mobility is seen to be a more important predictor of survival than cognitive function. A subsequent analysis of 2,534 children and adults who were in the IMCS gave the same finding (49).

The nonambulatory group covers a wide range of functional abilities. At the low end of the range are persons in the vegetative state, and those who are immobile and require gastrostomy feeding. At the high end are persons who feed themselves, and have reasonable self care skills, even though they cannot walk. Tables 17-2 and 17-3 include a simple stratification on the basis of self-feeding, an important predictor of life expectancy. Further distinctions can of course usefully be made.

It should be pointed out that there are persons whose residual TBI is so mild that they do not require services (e.g., occupational and physical therapy) on an ongoing basis. These persons would not be in the California data base, and their life expectancies may be higher than any group described above. In the best case, where the effects of the TBI are minimal, the life expectancy is of course essentially normal, or even better than normal (if, for example, the person was a nonsmoker, took regular exercise, maintained a good weight, etc.).

Persons in the highest functioning group of the table — those who can walk well alone and balance well — nevertheless have disabilities severe enough to require ongoing services. The aggregate life expectancy is reduced by 4 to 9 years compared to the general population. As expected, the difference is smallest for the oldest persons. Note that there is no sex difference in life expectancy in the most severely disabled category, but a substantial difference among the higher functioning groups.

The TBI figures in Tables 17-2 and 17-3 do not take account of whether the person needs a feeding tube. This need is uncommon in the higher-functioning groups, but about half of the persons over age 10 who cannot walk and cannot feed themselves do require a feeding tube, and their life expectancy is lower. Also not considered are specific fine and gross motor skills and cognitive ability, all of which affect life expectancy to some extent.

Technical Note The scientific methods underlying the study of life expectancy are well-documented in the actuarial, epidemiological and statistical literature; see, for example, Singer (91), Kahn and Sempos (1), Collett (92), Schoen (93) and Anderson (12). Full details on the specific methods used to compute the results in Tables 17-2 and 17-3 are described elsewhere (75, 94, 95). A brief summary follows:

- The analyses were based on data from 1,723 persons at all ages (PVS) and 3,598 persons over age 10 (TBI).
- A data set of person-months was constructed — PVS: 56,229 person-months; TBI: 285,424 person-months. Each person-month was associated with the subject's age, severity of disability, etc., and an indicator variable for whether the person died in that month.
- Logistic regression was used to compute the annual mortality rates. The following factors were used:
  - **PVS analyses**: age, time since injury, etiology, and need for feeding tube.
  - **TBI analyses**: age, sex, time since injury, and the walking and feeding categories listed in the table.
- The PVS analyses provided mortality rates for all ages. The TBI analyses provided rates at the starting ages and a model was used to compute rates at subsequent ages. A life table or survival curve was then constructed, with the life expectancy obtained directly in the former case, and as the area beneath the curve in the latter.

7. LONG-TERM DECLINE IN FUNCTION

In the short term, patients with TBI often regain some functioning in the first year post-injury (96–98), but the rate of recovery slows thereafter (28, 99, 100). An exception is the elderly, who have a low rate of recovery even in the first year (101–104).

It appears that, over the long term, patients with TBI will lose functional abilities faster than those in the general population:

- Lewin et al. (21) reported progressive intellectual deterioration in their patients, more so than would occur in the general population.
- A relevant comparison may be with persons who have suffered repeated ("chronic") TBI, as contrasted to acute TBI. Chronic TBI can result from boxing

(105, 106) and possibly from "heading the ball" in soccer (107–110). It is an often-progressive neurological condition with many of the same pathological characteristics as Alzheimer's disease (110–112).

We investigated this issue of long-term decline in our TBI database, concentrating on one important functional measure: ambulation.

Figure 17-1 shows the long-term prognosis for a group of 100% who initially could walk with support (crutches, braces, etc.) two years post-injury. Of these, roughly 15% died within the next 8 years, 20% lost the ability to walk, 55% did not change, and 10% could walk well alone. That is, of those still alive twice as many declined in functioning as improved.

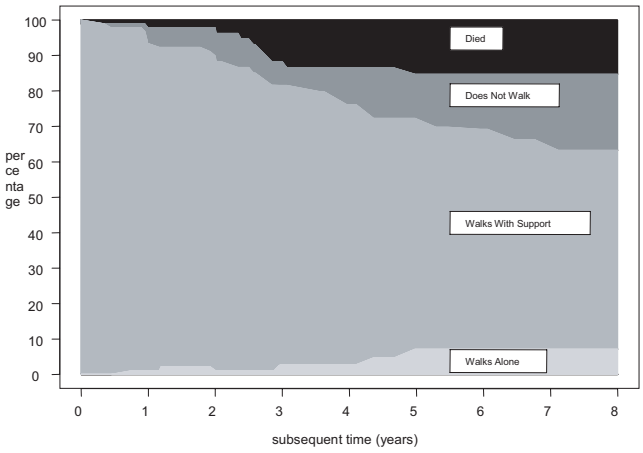

FIGURE 17-1

Long-term change in ambulation for adults aged 40 and over

Technical Note The curves for the cohort, including the survival curve, were computed using the Aalen-Johansen estimator (113). This statistical method was developed as an extension of the usual Kaplan-Meier (114) estimator to address the case of multiple live states (115). Day (116) showed that, in statistical parlance, the estimator is consistent and more efficient than the extended Kaplan-Meier estimator proposed by Strauss and Shavelle (117). The latter has previously been used to produce similar diagrams involving improvement or decline in function of persons with developmental disabilities (62, 118).

8. QUALITY OF CARE AND LIFE EXPECTANCY

Quality of care is a rather vague term that is frequently raised in discussions of life expectancy. It seems to cover a variety of issues, including:

- The expertise of the caregivers, ranging from highly qualified professionals to relatively unskilled (and low paid) staff. A complicating factor is that caregivers are often family members, who generally do not have formal qualifications but in some cases become highly skilled carers.
- The accessibility of physicians and emergency services.
- The quantity of care and equipment provided, which is often a reflection of the funds available.

The effect of quality of care on life expectancy surely depends on what is being compared. If, for example, it is good care versus negligent or even deliberately substandard care, the difference in life expectancy will doubtless be large. This comparison, however, is generally not of interest. The most relevant comparison is between:

a. The normal, standard care available in most Western societies, and
b. The care expected given that the patient has a carefully prepared and well-funded life care plan.

It might be argued that the care embodied in (b) represents the best case in practice, as one cannot forecast exactly what care the patient will receive, or will choose to receive, in the coming decades.

The issue is evidently a complex one and we do not attempt to draw any definitive conclusions. Nevertheless, these observations may be helpful:

- Some states or countries provide services to persons with disabilities as an entitlement. For example, California provides annual person-centered individual program plans plus provision of all indicated care. In such cases it may not be clear what is the difference, if any, between (a) and (b) above.
- Strauss et al. carried out a series of studies in California that compared mortality in large long-term state facilities, private group homes, and the patient's own family home (119–127). The authors found that mortality rates in the group homes and in family homes were comparable. Mortality rates in the state facilities, however, were generally lower, corresponding to modestly higher life expectancies. Reasons for the difference, which are related to quality of care, include round the clock supervision, continuity of care, centralized record keeping, and immediate access to medical attention (127).
- It is sometimes asserted that quality of care is the most important determinant of life expectancy. If the comparison is between (a) and (b) above, this assertion is incorrect: the most important determinant is undoubtedly the severity of the disability. For example, literature from many countries documents that young patients in the permanent vegetative state have mortality rates up to 500 times larger than in the general population (75, 128–136). If quality of

care is as important a determinant of mortality risk, then death rates under "standard" care would have to be 500 times higher than they would be under option (b). This is an extremely large ratio; to put it in perspective, heavy smokers are subject to mortality rates that are only 2–3 times that of the general population (137, 138).

- Researchers at The Dartmouth Atlas Project have found that more care (beyond what is reasonable and necessary) does not significantly prolong the life span of persons in the general population (139–142). Their website also provides an annotated list of 387 additional references supporting this conclusion (143).
- Finally, it may be noted that life insurance companies offer reduced premiums to persons with favorable risk characteristics, such as having ideal weight and being a nonsmoker. To our knowledge, (i) they do not give discounted rates to physicians or to the wealthy, both of whom have access to high quality health care, and (ii) life annuity underwriters do not routinely adjust for quality of care when pricing their structured settlements.

9. ESTIMATION OF LIFE EXPECTANCY IN INDIVIDUAL CASES

Life expectancy is an important factor in assessing the lifetime cost of future care for an individual with TBI. As we have seen, a sensible discussion requires, at a minimum, some familiarity with both the basic actuarial concepts and the relevant scientific literature. In practice, however, persons concerned with life expectancy assessment often lack this background, and as a result erroneous views are frequently advanced. We discuss some of the more significant issues below.

Much unnecessary confusion arises from the misuse of the term life expectancy when survival time is intended.

- For example, a terminally ill patient may ask the treating physician about life expectancy, but usually neither is interested in averages. Even in cases where the survival time will be limited to a few months or years, it is impossible to predict it with accuracy (144, 145). This forces the physician either to refuse to opine, and appear unhelpful, or to offer what is known about the average survival time in such cases. Even if the quoted average is appropriate, however, the patient's actual survival time will likely be very different and the doctor will appear to be "wrong" (146, 147).
- In the legal arena, on the other hand, predictions of actual survival time are generally not required. For example, it is impossible to predict the survival time of a normal 70 year-old male: according to government statistics 10% of such males will die in the next 4 years while another 10% will live well into their 90's (2). But the *average* survival time — i.e., the life expectancy — is given by standard government life tables and is widely accepted by courts as the basis for compensation. It may be argued that the same reasoning should apply to persons with reduced life expectancy, including those with TBI.
- We note that if one insists upon making a prediction of survival time, then either the life expectancy or the median survival time is a possible choice. The latter has the useful interpretation of being the time at which the patient is as likely as not to be still alive. In the case of persons at high risk, such as those who are immobile and tube fed, the life expectancy is higher than the median (75).

A common misconception is that if a person's current mortality risk is low then the life expectancy is nearly normal.

- The argument runs, for example, that although a given patient has severe epilepsy he is unlikely to die of it, and therefore "on the balance of probabilities the epilepsy will not reduce his life expectancy." This argument again reflects confusion of life expectancy and survival time. In a very large group, *some* of the individuals will die of epilepsy, even though they are not the majority, and this reduces the *average* survival time – i.e., the life expectancy.
- An illustration of this point is the comparison of males and females. Males have life expectancies about 6 years shorter than females. It would thus be a mistake to argue that because a given 10 year-old boy is in perfect health and is currently subject to an extremely low mortality risk his life expectancy is the same as that of a 10 year-old girl.
- Further, the effect of even a moderate additional mortality risk on life expectancy is often underestimated. For example, if a 10 year-old girl has a medical condition that raises her mortality risk by only 5 deaths per 1000 persons per year for life, the result is a life expectancy reduction of 11 years.

It is often asserted that "Published studies are all based on large groups and it is impossible to predict the life expectancy of an individual."

- Confusion of life expectancy and survival time aside, the assertion is essentially that because a scientific analysis cannot take account of *every* factor relevant to life expectancy of a given individual, *nothing* scientific can be said about an individual's prognosis for survival.

- If this were true then standard government life tables would be irrelevant to an individual, and economists and others have been wrong to refer to them. It would also mean that life insurance actuaries and medical directors, who routinely decide whether to offer insurance to individuals and at what price, have no basis for making such decisions.

Frequently the view is expressed that high quality medical care will ensure a normal life expectancy. This is incorrect, as was discussed in the previous section.

The life expectancy literature on cerebral palsy, spinal cord injury and other conditions is extensive, and the comparison with these conditions to TBI may be helpful.

- The comparison with *cerebral palsy* (59–65) may provide a useful lower bound to the life expectancy in TBI, as persons with TBI appear to be subject to similar or slightly lower mortality risks than those with comparably severe cerebral palsy (52).

  For example, the life expectancy of a 15 year-old male with cerebral palsy who can lift his head when lying on his stomach but cannot roll over or sit independently, and who is fed orally by others, has been estimated to be 22.8 additional years (62). This may therefore be a reasonable approximation to, though perhaps a slight underestimate of, the life expectancy of a similar TBI patient.
- Similarly, comparison with the *spinally-injured* patient, though imperfect, may be useful. For example, the life expectancy of a young paraplegic has been well documented to be reduced by 10 years or more (66–69). Such persons are unable to walk, but generally have unimpaired cognitive function, no bulbar dysfunction, and have normal upper body function and self-care skills with their hands. They therefore compare favorably in most respects with persons with TBI who have lost the ability to walk. (Some caveat is necessary here because spinally-injured patients are more at risk of certain medical conditions, including spinal degeneration and bowel and bladder problems.)
- For a person with TBI who is cognitively near-normal and ambulatory but still has some permanent difficulties with motor function, there is still some modest reduction in life expectancy. This may be seen by comparison with *uninjured persons who live a sedentary life style*, whose life expectancy may be argued to represent an upper bound in many cases. A permanently sedentary lifestyle is known to lead to increased risk of heart disease and other conditions (148, 149), and can be shown to lead to a reduction of about 4 years.
- Finally, if the patient has only minimal physical disability but suffers *from mental disorder or severe behavioral problems*, the literature on excess mortality in such conditions may be applicable (82).

Taking Account of Multiple Factors

Although ambulation and self-feeding are valuable predictors of expected longevity, there are other factors with some relevance. Some of these were discussed in section 5, and in addition there are refinements to mobility and self-care (can the subject roll over, sit or stand without support, carry on conversations, dress and bathe himself, etc.). Further, there are factors, such as bulbar dysfunction and hospital admissions for pneumonia, that must have some predictive value but for which there appears to be no relevant mortality data.

How can all these factors be incorporated into an estimate of a given individual's life expectancy? It is evidently not feasible to take them all into account in a scientific analysis. The rational approach is to work with the available data as far as possible – perhaps taking account of key factors such as mobility and self-care skills – and then to consider other factors for which data are not available. It may then be reasonable to argue for an adjustment, either upwards or downwards, to the evidence-based estimate. The input of a clinician can be very helpful in describing these factors and their effect on the individual's prognosis.

An alternative view is sometimes expressed: that the scientific approach should be abandoned because such an analysis cannot take account of *every* factor. Instead, a life expectancy is chosen on the basis of, for example, clinical introspection. It seems to us that this position is untenable: the existing mortality data should at least provide a *starting point* for any rational discussion.

10. CONCLUSIONS

An individual's *life expectancy* is the average number of additional years of life in a large group of similar persons. In many cases it can be estimated with some precision. Life expectancy should be distinguished from the individual's actual *survival time*, which is impossible to predict with accuracy, even in the uninjured general population.

We have seen that mortality is increased after TBI, many causes of death being more common than in the general population. These include pneumonia and other respiratory diseases, seizures, accidents (including choking), and – importantly – diseases of the circulatory system, related to immobility.

The key predictors of survival are mobility and self-care skills (notably, the abilities to walk and to self-feed). The life expectancy of persons who walk and self-feed is only modestly reduced by comparison with the general population, whereas nonambulatory persons with minimal

self-care skills suffer a much greater reduction. An extreme case is a gastrostomy-dependent patient in the permanent vegetative state, where the life expectancy is 10 years or less.

To estimate a given individual's life expectancy one can use the literature and existing data to account for some key predictors. Subsequently, it is reasonable to consider additional factors, which have not been taken into account, and to argue for a further adjustment. The alternative approaches of simply assuming that general population figures apply, or of proposing an estimate solely on the basis of clinical intuition, lack scientific justification and are in our view untenable. The existing population data must surely provide at least a starting point.

Finally, we note two factors relevant to life expectancy that have been insufficiently studied. The first is the prospect for improvement in function after the first few post-injury years. Although it is sometimes stated that almost all the meaningful recovery in function occurs during the first two years, it is a matter of clinical observation that substantial improvement sometimes occurs considerably later. There have been cases of persons emerging from the vegetative state after three or more years, although remaining with severe motor and cognitive dysfunction. It appears that there are no studies documenting the frequency of these late recoveries, or the degree of improvement that may occur.

Second, little is known about the decline in function of persons with TBI in old age. For example, if a young adult suffers a TBI and after several years is able to walk unsteadily and to carry on conversations with somewhat slurred speech, what can be expected in the subsequent decades, and what is the expected pattern of decline in old age? Further research on these questions would be valuable.

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