Disability 3, 12, and 24 Months After Traumatic Brain Injury Among Children and Adolescents

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KEY WORDS
traumatic brain injury, disability, functional outcome

ABBREVIATIONS
TBI—traumatic brain injury
ED—emergency department
CDC—Centers for Disease Control and Prevention
GCS—Glasgow Coma Scale
CT—computed tomography
AIS—Abbreviated Injury Scale
PedsQL—Pediatric Quality of Life Inventory
ABAS-II—Adaptive Behavior Assessment System-Second Edition
CASP—Child and Adolescent Scale of Participation

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WHAT'S KNOWN ON THIS SUBJECT: Significant impairments have been found in many domains of neuropsychological functioning after TBI, although the degree to which these impairments affect quality of life and activities is not clear.

WHAT THIS STUDY ADDS: Children with moderate or severe TBI and children with mild TBI who had intracranial hemorrhage had substantial reduction in their quality of life, participation in activities, and ability to communicate and care for themselves.

abstract

OBJECTIVE: To examine disability in children and adolescents after traumatic brain injury (TBI) across the spectrum of injury severity.

METHODS: This was a prospective cohort study of children younger than 18 years treated for a TBI ($n = 729$) or an arm injury ($n = 197$) between March 1, 2007, and September 30, 2008. The main outcome measures were disability in health-related quality of life, adaptive skills, and participation in social and community activities 3, 12, and 24 months after injury compared with preinjury functioning.

RESULTS: The health-related quality of life for children with moderate or severe TBI was lower at all follow-up times compared with baseline, but there was some improvement during the first 2 years after injury. Three months after injury, there was a substantial decrease in the level of activities in which children with moderate and severe TBI were able to participate; these activities improved at 12 and 24 months but were still significantly impaired. Communication and self-care abilities in children with moderate and severe TBI were lower at 3 months than at baseline and did not improve by 24 months. Children who met the definition of mild TBI but had an intracranial hemorrhage had lower quality-of-life scores at 3 months.

CONCLUSIONS: Children with moderate or severe TBI and children with mild TBI who had intracranial hemorrhage had substantial long-term reduction in their quality of life, participation in activities with others, and ability to communicate and care for themselves. *Pediatrics* 2011;128:e1129–e1138

Much attention has been focused on mortality from traumatic brain injury (TBI) in children[1–6] and on specific impairments in neuropsychological functioning in survivors.[7–11] Significant impairments have been found in many domains of neuropsychological functioning after TBI,[12–14] although the degree to which these impairments affect quality of life and activities is not clear. Neuropsychological impairments after pediatric TBI are believed to manifest as chronic disability in 2 primary areas: (1) educational/academic[15] and (2) behavioral, social, emotional, and adaptive functioning.[10,16,17] However, large, prospective studies that cover the range of TBI severity have been "relatively rare, and many questions on the range of functional outcomes among children with TBI remain."[11] Not only can impairments from pediatric TBI be long-standing, such that there is no "recovery" of lost skills, but many children also fail to acquire new skills at a developmentally appropriate rate.[18,19]

Young children seem particularly vulnerable to long-term effects, because injury to young brains might severely affect subsequent brain development.[18,20,21] Although the results of most studies suggest that mild TBI does not lead to the long-term neuropsychological sequelae and functional disability associated with severe TBI, there is some evidence of more subtle and perhaps more variable sequelae with mild TBI that might affect return to school and daily functioning. Recent studies have been focused on concussion, but the reports have been concerned primarily with physical symptoms[22,23] and decisions regarding return to play (sports)[24,25] and have not included an examination of disability and functioning in a wider variety of domains.

This study was undertaken to examine level of disability, as measured by health-related quality of life, adaptive skills, and participation in activities, among children and adolescents after TBI. This study adds to the literature an examination of disability in a large sample across the spectrum of severity. We sought to determine the extent of disability in all areas of functioning for children with mild, moderate, or severe TBI and to describe the time course of disability over the 24 months after injury. We hypothesized that disability would be more common in children with more severe injury and that this disability would lessen but not resolve over time since injury. We also hypothesized that there would be no long-term disability in those with mild TBI.

Disability was operationalized according to the World Health Organization model (International Classification of Functioning[26]) as an umbrella term for impairments, activity limitations, and participation restrictions. In this model, TBI potentially affects body function and structures, modified by factors such as age, gender, preexisting functioning, and results in impairments that might be temporary or permanent, might change over time, and might be mild or severe. In this article, we report on quality of life, adaptive functioning, and participation in social and community activities, adjusted for age, gender, and functioning before the injury. Findings regarding educational/academic functioning will be presented in a separate report.

METHODS

Patient Population

All study procedures were approved by the human subject committees of participating institutions. We sought to identify all children younger than 18 years treated either in the emergency department (ED) or as inpatients in a study hospital and discharged alive for either a TBI or an arm injury. All 18 hospitals in King County, Washington, with EDs serving children were classified into 3 strata: the regional children's hospital and the only level 1 trauma center; the 7 level 3 and level 4 trauma centers; and the 9 other nontrauma centers. Both hospitals in the first stratum were included; 4 and 3 hospitals were randomly sampled from the second and third strata, respectively. Not all hospitals were sampled, because the projected number of mild TBI cases needed did not require all possible patients to be included. In addition, inpatients with TBI treated at the Children's Hospital of Philadelphia were included to increase the number of more severely injured, younger children. As described previously,[27] study participants were selected by computer-generated random number from the list of all eligible children who were treated between March 1, 2007, and September 30, 2008, and contacted. Different proportions of children were sampled depending on age group, gender, TBI versus arm injury, and whether hospitalized within the TBI group. This was done to ensure that there was representation across age and gender groups in the study participants.

Definition and Severity of TBI

The definition of TBI used was from a 2002 Centers for Disease Control and Prevention (CDC) report[28]: an injury to the head with decreased level of consciousness, amnesia, and/or neurologic or neuropsychological abnormality or diagnosed intracranial lesion. We used CDC[29] and World Health Organization[30] definitions to define mild TBI: (1) any period of transient confusion, disorientation, or impaired consciousness as recorded in the medical record or (2) any period of amnesia that lasted $<$24 hours or (3) signs of other neurologic or other neuropsychological dysfunction and (4) worst Glasgow Coma Scale (GCS) score of 13 to 15 at

the time of the first medical evaluation and a GCS score of 15 at discharge from the ED or 24 hours after injury if hospitalized. Mild TBI was further subdivided into 3 subcategories: mild I, no abnormalities on computed tomography (CT) or no CT was performed; mild II, skull fracture without intracranial hemorrhage; and mild III, intracranial hemorrhage but case still met criteria for mild TBI. Moderate TBI was defined by a best motor GCS score 24 hours after injury of 4 or 5 or a score of 6 for cases that did not meet the criteria for mild TBI.[29] Severe TBI was defined as a best motor GCS score 24 hours after injury of 1 to 3. Abbreviated Injury Scale (AIS) coding of head injuries was performed manually by 1 investigator (Dr Rivara) using the 2008 AIS.[31]

Definition of Control Patients

We used as controls patients with isolated arm injury who were treated in the same King County study hospitals as those with TBI, consistent with CDC recommendations[32] and our previous studies.[33–35] Fifty controls were sought from each of the 4 age groups (0–4, 5–9, 10–14, and 15–17 years), and they were frequency matched on gender to patients with mild TBI. Sampling of controls proceeded concurrently with TBI case recruitment.

Procedures

A baseline survey was administered to 1 parent and to adolescents aged 14 years or older, if cognitively able, as soon as possible after injury (median: 37.0 days). Follow-up surveys were conducted 3, 12, and 24 months after the date of the index injury with parents and with those adolescents aged 14 years or older who were able to complete the survey. In addition to obtaining information on the standard measures described below, we also obtained self-report data on the potential confounders of race/ethnicity, insurance, household income, and respondent education.

Measures

The Pediatric Quality of Life Inventory (PedsQL)[36] is a measure of health-related quality of life that assesses physical, emotional, social, and school functioning of children aged 24 months and older. The PedsQL has been shown to be reliable and valid and has been used previously for children with trauma including TBI.[37–40] Six additional items from the cognitive functioning scales of the PedsQL multidimensional fatigue scale that assess memory, attention, and processing speed were also included, in keeping with previous studies of pediatric TBI.[41] Total PedsQL scores range from 0 to 100; higher scores indicate higher quality of life. A 4.5-point change in the PedsQL total score for parent proxy report has been judged to represent a clinically meaningful difference.[36] Per the designers of the PedsQL, separate forms were used for those aged 24 months to younger than 5 years and those aged 5 years or older.

The Adaptive Behavior Assessment System-Second Edition (ABAS-II) is a comprehensive, norm-referenced assessment of adaptive skills with excellent reliability and validity.[42] It is widely used to evaluate people with neurologic disorders including TBI. There are 9 subscales in the ABAS-II; we used the communication and the self-care subscales, for which the mean score among healthy people is 10 (SD: 3); higher scores indicate better functioning, and scores below 8 represent below-average functioning. Separate forms are used for those younger than 2, 2 to 5, and 5 years or older.

The Child and Adolescent Scale of Participation (CASP) is a 20-item measure that assesses the involvement of children aged 5 years and older in various activities at home, at school, and in the community, including play, interaction with friends, structured activities, and educational activities.[43] Total summary scores range from 0 to 100; higher scores indicate better participation.

Previous studies have shown that preinjury family functioning is an important predictor of a child's function after injury, including TBI.[44] We used the self-report McMaster Family Assessment Device to measure family functioning and emotional relationships within the family. We used the 12-item general functioning scale, which assesses overall health and psychopathology within the family system.[45] Scores range from 11 to 41; higher scores indicate worse family functioning.

Medical Record Data

Charts were abstracted by the principal investigator (Dr Rivara) or a trained research nurse using an online standardized abstraction form; they were blinded to the baseline and outcome measures. CT scans of the head were reviewed by pediatric neuroradiologists blinded to the baseline and outcome data. These data were used in the assignment of the head AIS score and in further stratifying patients with mild TBI.

Data Analysis

Multiple imputation was used to account for missing medical record variables. Data were missing for $<5\%$ of the patients on most of the variables. Ten imputed data sets were created, and age, hospital, and ED disposition were used as predictors.

Linear mixed models were used to assess the change of outcome scores from baseline to 3, 12, and 24 months after TBI compared with controls, adjusting for patient age (as a continuous variable), gender, race/ethnicity, insurance, household income, and respondent education. To account for

clustering within hospitals, robust SEs were computed.

We performed predictive modeling on the outcome of the PedsQL 3, 12, and 24 months after injury separately. The potential independent variables included age, gender, TBI-severity group, household income, respondent education, lowest motor GCS score in the ED, McMaster Family Assessment Device score at baseline, and PedsQL score at baseline. Injury type and baseline PedsQL scores were forced into the model, and the other potential independent variables listed previously were added if they changed the point estimate by >10%.

Because the demographic characteristics of the children from the Philadelphia hospital differed from those of the King County hospitals, analyses were conducted with and without the Philadelphia patients. These characteristics were similar, so only the results with all patients are shown.

RESULTS

Study Patients

There were 2940 patients with a diagnosis of TBI and 2371 patients with arm injuries treated at the study hospitals during the recruitment period. We randomly selected 2179 potential patients with TBI and 694 patients with arm injury (74.1% and 29.3% of those treated, respectively); the probability of selection varied according to age, gender, and hospital admission. Of these patients, 1519 with TBI and 381 with arm injury were contacted; 660 and 313, respectively, were not able to consent because of missing or incorrect contact information, passive refusals, or expiration of the time window for participation in the study. Of those contacted, 347 and 44 children, respectively, were found in a screening telephone interview with the parent or after subsequent medical record review not to have had the injury in question. Parents of 443 children with TBI and 140 children with arm injury refused participation. Thus, 729 patients with TBI (62.2% of contacted patients later determined to be eligible) and 197 with arm injury (58.5% of contacted patients determined to be eligible) were enrolled in the study, and all of them completed the baseline interview. Follow-up interviews were completed for 96.8% of the patients with TBI and 96.4% of the patients with arm injury at 3 months, 90.5% and 92.4%, respectively, at 12 months, and 87.1% and 90.9%, respectively, at 24 months. Enrollees were of similar age (109.7 vs 106.3 months; $P = .41$) and gender (34.3% vs 35.0% female; $P = .83$) but more likely to have moderate or severe TBI (13.5% vs 2.5%; $P = .001$) and less likely to have been seen at lower-level trauma centers (20.6% vs 36.7%; $P < .0001$) than those selected but not enrolled.

Most (84.5%) of the study patients with TBI had mild TBI, 13.2% had moderate TBI, and only 2.3% had severe injuries (Table 1). Children in the mild I TBI group were less likely to be older teens than those in the other TBI-severity groups. The age range of participants at the time of injury was 2 months to 17 years (with the exception of 1 patient who had just turned 18). Nonwhite race/ethnicity, Medicaid insurance, lower education, and lower household income were overrepresented among those with severe injuries, in part because of the larger proportion of minority patients cared for at the Children's Hospital of Philadelphia (which only enrolled patients with moderate or severe TBI) compared with Seattle-area hospitals.

Injury Characteristics

Falls accounted for 56.6% of those with mild TBI but only 34.1% of those with moderate TBI and 23.1% of those with severe TBI (Table 2). Motor vehicle occupant injuries were the most common cause of injury in those with moderate or severe TBI. Among those children with mild TBI, 76.9% either did not have a CT scan (38.3% of all mild TBI) or had no abnormalities on CT (mild I TBI group), 5.2% had mild TBI complicated by skull fracture (mild II TBI group), and 17.9% were found to have intracranial hemorrhage (mild III TBI group). Relatively few children with moderate or severe TBI had an isolated TBI, defined as no other injury with an AIS score of ≥1. In contrast, the majority of those with mild TBI had an isolated TBI.

Activities and Adaptive Skills

Tables 3 and 4 list the main disability results at 3, 12, and 24 months. The columns labeled "mean at month" list the mean score for all children assessed at each time point. Thus, the month-zero average includes some children who did not participate in the follow-up outcome assessment. The change (Δ) columns are based on the slightly smaller subset of children who were assessed at both baseline and the follow-up time in question. The "adjusted net difference" lists the estimated change for each TBI subgroup, above and beyond the change observed in children with arm injury, adjusting for confounders. The adjusted net difference estimate is from the mixed-model analysis, in which data from all study children were used.

The patients with arm injury had almost completely returned to baseline levels on the ABAS-II and CASP by 3 months. In contrast, the patients with TBI consistently had residual impairments in direct relation to the severity of their TBI. Communication abilities in children with moderate and severe TBI were lower at 3 months than at baseline and did not improve by 24 months (Table 3). Children in the mild III TBI group also had lower communication skills at 3 months, but these differences

TABLE 1 Characteristics of the Study Population ($N = 926$)

	TBI						Arm Injury ($n = 197$)
	Mild I ($n = 479$)	Mild II ($n = 31$)	Mild III ($n = 106$)	Mild, All ($n = 616$)	Moderate ($n = 96$)	Severe ($n = 17$)	
Age at injury, %							
0–4 y	28.7	12.9	28.3	28.6	38.5	29.4	32.0
5–9 y	23.5	38.7	20.8	23.5	11.5	17.7	21.3
10–14 y	28.5	22.6	23.6	27.1	24.0	23.5	27.9
15–17 y	19.3	25.8	27.4	20.8	26.0	29.4	18.8
Gender, %							
Male	61.8	77.4	74.5	64.6	68.8	70.6	61.9
Female	38.2	22.6	25.5	35.4	31.2	29.4	38.1
King County hospitals, %							
HMC	18.0	71.0	80.2	30.7	71.9	41.2	5.1
Seattle Children's	54.2	16.1	5.7	45.6	3.1	35.3	56.4
Other trauma centers	26.4	9.7	3.8	20.7	1.0	0.0	32.4
Other nontrauma centers	1.3	3.2	0.0	1.1	0.0	0.0	6.1
Pennsylvania hospital: Children's Hospital of Philadelphia, %	0.2	0.0	10.4	2.0	24.0	23.5	0.0
Race/ethnicity, %							
White, non-Hispanic	66.7	80.7	65.1	65.9	49.0	23.5	65.5
Black, non-Hispanic	2.2	0.0	7.6	3.3	11.5	23.5	2.5
Hispanic	8.1	6.5	10.4	9.1	15.6	17.7	12.2
Asian	1.8	0.0	4.7	2.1	2.1	5.9	3.1
Other or multiple	21.1	9.7	12.3	19.2	21.9	29.4	16.8
Unknown	0.2	3.2	0.0	0.5	0.0	0.0	0.0
Health insurance, %							
None	1.8	6.5	6.6	2.9	11.5	5.9	2.0
Medicaid	25.2	25.8	18.9	25.0	36.5	64.7	25.9
Private	70.8	67.7	68.9	69.3	50.0	11.8	71.1
Tricare/CHAMPUS	0.2	0.0	5.7	1.1	2.1	11.8	0.0
Basic health	2.0	0.0	0.0	1.5	0.0	5.9	1.0
Unknown	0.0	0.0	0.0	0.2	0.0	0.0	0.0
Household income, %							
Less than $30 000	20.4	25.8	21.7	21.6	30.2	41.2	16.8
$30 000–$60 000	17.1	16.1	19.8	17.4	27.1	35.3	15.7
$60 000–$100 000	19.1	29.0	28.3	20.9	21.9	5.9	25.4
More than $100 000	39.3	22.6	24.5	35.4	14.6	0	37.6
Unknown	4.2	6.5	5.7	4.7	6.3	17.7	4.6
Respondent parent's education, %							
Less than high school	7.0	6.5	11.3	8.0	18.8	23.5	9.1
High school/GED	12.1	16.1	17.9	13.6	29.2	29.4	11.2
Some college	27.6	35.5	34.0	29.1	29.2	35.3	25.4
College graduate	30.0	32.3	19.8	28.1	15.6	0.0	33.0
Post-college	23.3	9.7	16.0	20.9	7.3	5.9	20.8
Unknown	0.0	0.0	0.9	0.3	0.0	5.9	0.5
Family Assessment Device baseline score, mean (SD)	18.2 (5.0)	17.8 (4.9)	17.5 (4.7)	18.0 (4.9)	18.8 (5.3)	21.5 (5.4)	17.5 (4.9)

HMC indicates Harborview Medical Center; GED, general equivalency diploma.

diminished and were not significant by 12 months after injury. Self-care scores were also lower than those at baseline in the moderate and severe TBI groups at 3 months and did not improve by 24 months (Table 3). The small differences in self-care among those in the mild TBI I group were not significant after considering the changes in the controls with arm injury.

Three months after injury, there was a substantial decrease in the level of social and community activities in which children with moderate and severe TBI were able to participate, as measured by the CASP (Table 3). These activities improved by 12 months but were still significantly impaired. There was another small improvement at 24 months.

Health-Related Quality of Life

In all groups, the PedsQL score was lower at 3 months than at baseline; children in the moderate and severe TBI groups scored 17.6 and 30.9 points lower, respectively (Table 4). Children in the mild III group had lower scores at 3 months than those in the other 2 mild TBI groups. Although there

TABLE 2 Injury Characteristics From Chart Abstraction

	TBI						Arm Injury ($n = 194$)
	Mild I ($n = 456$)	Mild II ($n = 31$)	Mild III ($n = 106$)	Mild, All ($n = 593$)	Moderate ($n = 96$)	Severe ($n = 17$)	
Mechanism of injury, %							
Motor vehicle occupant	6.8	16.1	16.4	9.0	35.1	38.4	3.2
Pedestrian or bicycle	6.2	12.9	11.5	7.4	17.6	7.7	2.7
Fall	57.4	54.8	53.9	56.6	34.1	23.1	83.1
Struck by/against	29.6	16.2	17.2	26.8	8.8	15.4	10.5
Other	0.0	0.0	1.0	0.2	4.4	15.4	0.5
Intent, %							
Intentional	3.5	0.0	7.6	4.1	12.5	23.5	3.6
Unintentional	96.5	100.0	92.4	95.9	87.5	76.5	96.4
Emergency medical services level, %							
Advanced Life Support	9.8	25.0	35.7	15.0	72.1	75.0	2.6
Basic Life Support	12.8	25.0	16.3	14.0	8.1	0.0	5.8
Not transported by emergency medical services	77.4	50.0	48.0	71.0	19.8	25.0	91.6
Isolated TBI, %	62.5	48.4	50.0	59.5	21.9	23.5	0.0
Injury severity score, mean (SD)	2.9 (4.1)	7.3 (2.9)	12.3 (8.0)	4.8 (6.1)	23.8 (11.4)	33.0 (9.1)	4.5 (3.0)
Maximum AIS score, %							
1	71.3	0.0	0.0	54.8	0.0	0.0	3.1
2	23.7	64.5	37.7	28.3	8.3	0.0	88.7
3	3.7	35.5	34.9	11.0	24.0	0.0	7.7
4	1.1	0.0	13.2	3.2	10.4	0.0	0.5
5	0.2	0.0	14.2	2.7	57.3	100.0	0.0
Head maximum AIS score, %							
0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
1	75.0	0.0	0.0	57.7	0.0	0.0	0.0
2	24.6	67.7	45.3	30.5	15.6	0.0	0.0
3	0.4	32.3	29.3	7.3	18.8	0.0	0.0
4	0.0	0.0	11.3	2.0	8.3	0.0	0.0
5	0.0	0.0	14.1	2.5	57.3	100.0	0.0
Lowest motor GCS score in ED, %							
6	98.9	100.0	74.5	94.6	22.1	6.7	99.5
4/5	0.4	0.0	16.0	3.2	29.5	0.0	0.0
2/3	0.0	0.0	0.0	0.0	1.1	20.0	0.0
1, not paralyzed	0.0	0.0	0.0	0.0	17.9	26.7	0.0
1, paralyzed	0.7	0.0	9.4	2.2	29.4	46.7	0.5
Had CT, %	50.2	100.0	100.0	61.7	100.0	100.0	1.6
Preinjury comorbidities, %[a]							
None	36.5	38.7	40.6	37.3	45.8	58.8	35.0
1	24.1	9.7	28.3	24.0	18.7	23.5	31.5
2	14.8	29.0	10.4	14.8	11.5	0.0	15.7
≥3	24.6	22.6	20.7	23.9	24.0	17.7	17.8

Medical records were not available from 26 patients.

[a] Preinjury comorbidities assessed included developmental delay, seizures, previous TBI with loss of consciousness, hemiplegia or paraplegia, lung disease, diabetes, attention-deficit/hyperactivity disorder, depression, other mental health or behavioral problems, learning problems, previous fractures, and previous surgery.

was some improvement by 12 months and another small improvement by 24 months, PedsQL scores remained significantly lower than those at baseline for children with moderate and severe TBI. By 12 months, those in the mild III TBI group had scores that were not significantly different from those at baseline. The changes from baseline in the PedsQL scores in the other mild TBI groups were small and not significant after adjusting for the changes in the controls with arm injury.

Multivariate Predictors

At 3 months, children with moderate or severe TBI had a significantly lower quality of life than those in the arm-injury group (Table 5). These differences were still substantial for those in the moderate and severe TBI groups at both 12 and 24 months. Among children in the mild TBI I group, quality-of-life scores were lower at all follow-up times and were statistically, but not clinically, significant at the 12- and 24-month follow-up times. Generally, older children had larger decrements in their quality of life than did younger children, although none of these differences were significant.

Quality of life was higher in those with higher or not-reported house-

TABLE 3 Adaptive Skills and Activities 3, 12 and 24 Months After Injury

	Mean at Month[a]				Change 0 to 3 mo[b]				Change 0 to 12 mo[b]				Change 0 to 24 mo[b]			
	0	3	12	24	Δ	95% CI	Adjusted Net Difference[c]	95% CI	Δ	95% CI	Adjusted Net Difference[c]	95% CI	Δ	95% CI	Adjusted Net Difference[c]	95% CI
ABAS-II communication																
Arm injury	10.7	10.9	10.9	10.8	0.3	−0.1 to 0.6	Reference	—	0.3	−0.1 to 0.6	Reference	—	0.1	−0.2 to 0.5	Reference	—
Mild TBI																
I	10.3	10.4	10.7	10.6	0.1	−0.1 to 0.3	−01	−0.6 to 0.3	0.3	0.1 to 0.6	0.1	−0.4 to 0.6	0.2	−0.1 to 0.4	0.1	−0.5 to 0.6
II	11.1	11.3	10.9	11.0	0.2	−0.6 to 1.0	−0.1	−1.0 to 0.9	−0.3	−1.1 to 0.5	−0.5	−1.5 to 0.6	0.0	−0.8 to 0.8	−0.1	−1.3 to 1.1
III	10.8	10.4	10.5	10.9	−0.5[d]	−1.0 to −0.1[d]	−0.7[d]	−1.3 to −0.1[d]	−0.2	−0.8 to 0.3	−0.5	−1.1 to 0.2	0.0	−0.6 to 0.6	−0.1	−0.8 to 0.7
Moderate TBI	10.6	9.6	9.2	9.2	−1.1[d]	−1.7 to −0.4[d]	−1.3[d]	−1.9 to −0.6[d]	−1.5[d]	−2.2 to −0.8[d]	−1.8[d]	−2.5 to −1.1[d]	−1.5[d]	−2.2 to −0.8[d]	−1.6[d]	−2.4 to −0.8[d]
Severe TBI	11.2	8.3	8.3	6.9	−2.8[d]	−5.0 to −0.7[d]	−3.1[d]	−4.4 to −1.7[d]	−3.0[d]	−5.2 to −0.8[d]	−3.2[d]	−4.6 to −1.8[d]	−4.3[d]	−6.6 to −2.0[d]	−4.4[d]	−6.0 to −2.8[d]
ABAS-II self-care																
Arm injury	9.1	9.2	9.9	10.2	0.1	−0.2 to 0.5	Reference	—	0.8	0.4 to 1.1	Reference	—	1.1	0.7 to 1.5	Reference	—
Mild TBI																
I	8.8	9.1	9.3	9.4	0.4	−0.1 to 0.6	0.2	−0.2 to 0.7	0.5[d]	0.2 to 0.7[d]	−0.3	−0.8 to 0.2	0.6[d]	0.3 to 0.8[d]	−0.5	−1.0 to 0.1
II	10.2	10.3	10.0	10.6	0.1	−1.0 to 1.2	−0.1	−1.2 to 1.1	−0.2	−1.3 to 0.9	−1.0	−2.2 to 0.1	0.4	−0.6 to 1.5	−0.7	−2.0 to 0.5
III	10.1	10.2	9.9	10.4	0.1	−0.4 to 0.7	0.0	−0.7 to 0.7	−0.1	−0.7 to 0.5	−0.9[d]	−1.6 to −0.2[d]	0.3	−0.4 to 0.9	−0.8	−1.6 to 0.04
Moderate TBI	10.1	8.3	8.6	8.8	−1.9[d]	−2.6 to −1.1[d]	−2.0[d]	−2.7 to −1.3[d]	−1.6[d]	−2.3 to −0.8[d]	−2.5[d]	−3.2 to −1.7[d]	−1.3[d]	−2.1 to −0.6[d]	−2.5[d]	−3.3 to −1.6[d]
Severe TBI	10.9	7.0	6.7	6.1	−3.9[d]	−6.4 to −1.4[d]	−4.2[d]	−5.7 to −2.7[d]	−4.4[d]	−6.9 to −1.9[d]	−5.3[d]	−6.8 to −3.7[d]	−4.8[d]	−7.3 to −2.3[d]	−6.0[d]	−7.7 to −4.2[d]
CASP[e]																
Arm injury	95.6	95.4	96.8	96.6	−0.2	−1.7 to 1.3	Reference	—	1.1	−0.4 to 2.6	Reference	—	1.2	−0.3 to 2.6	Reference	—
Mild TBI																
I	94.0	93.3	94.8	94.5	−0.7	−1.6 to 0.2	−0.5	−2.3 to 1.3	0.6	−0.2 to 1.5	−0.5	−2.2 to 1.3	0.3	−0.6 to 1.2	−0.9	−2.8 to 0.7
II	94.9	96.5	96.7	96.2	1.6	−1.0 to 4.2	1.9	−1.8 to 5.5	1.5	−1.1 to 4.2	0.3	−3.4 to 4.0	1.0	−1.9 to 3.8	−0.3	−4.1 to 3.2
III	96.1	94.3	94.4	96.3	−1.5	−3.2 to 0.3	−1.3	−3.8 to 1.3	−1.3	−3.2 to 0.5	−2.5	−5.1 to 0.1	0.4	−1.6 to 2.3	−0.9	−3.5 to 1.6
Moderate TBI	96.2	89.9	91.8	93.3	−6.2	−9.2 to −3.2[d]	−6.0[d]	−8.7 to −3.2[d]	−4.0[d]	−7.0 to −1.0[d]	−4.8[d]	−7.6 to −2.1[d]	−2.8	−5.7 to 0.1	−3.6[d]	−6.8 to −1.1[d]
Severe TBI	93.2	73.0	82.7	83.9	−20.0	−34.3 to −5.7[d]	−19.4[d]	−25.0 to −13.9[d]	−10.6[d]	−24.5 to 3.2[d]	−11.7[d]	−17.1 to −6.3[d]	−8.9	−22.3 to 4.5	−10.6[d]	−15.2 to −4.4[d]

[a] On the basis of all children with data at each time point.
[b] On the basis of children with data at both time points.
[c] Net change compared to arm-injury controls, adjusted for age, gender, race, insurance, parent income, and parent education, on the basis of all children.
[d] Significant result.
[e] Measured only on children ≥60.

hold incomes but was not significantly related to baseline family functioning or parent-respondent education.

DISCUSSION

This study of a large cohort of children younger than 18 years has revealed the significant impact of TBI on a wide variety of domains of functioning during the 2 years after injury. Children with moderate or severe TBI and children with mild TBI who had intracranial hemorrhage had substantial reduction in their quality of life, participation in activities, and ability to communicate and care for themselves.

Certain limitations should be considered. Measures of functional outcome were reported by a parent and might not have fully reflected the child's own perceptions of their limitations. However, parents' report of their child's health-related quality of life using the PedsQL has been shown to be reliable and valid.[46] The ABAS-II is only administered as a parent or teacher report of adaptive functioning at the ages of the study participants. The median time between injury and baseline interview was 37 days, which might have created recall biases on the part of the parents; the amount and direction of this bias is unknown. Not all children with mild TBI received a head CT scan at the initial assessment, which leaves the possibility that some children in the mild TBI I group might have had undetected abnormalities that would have placed them in a different mild TBI subgroup. We believe that such misclassification is likely to be minor given the liberal use of CT scans in our study institutions and nationally.

Children aged 2 years and older with moderate and severe TBI had large decrements in their quality of life. In studies of other children, a 4.5-point difference on the PedsQL is clinically meaningful,[36] and a 5-point difference

TABLE 4 Health-Related Quality of Life 3 and 12 Months After Injury

PedsQL	Mean at Month[a]				Change 0 to 3 mo[b]				Change 0 to 12 mo[b]				Change 0 to 24 mo[b]			
	0	3	12	24	Δ	95% CI	Adjusted Net Difference[c]	95% CI	Δ	95% CI	Adjusted Net Difference[c]	95% CI	Δ	95% CI	Adjusted Net Difference[c]	95% CI
Arm injury	89.3	86.1	86.7	86.0	−3.2[d]	−4.7 to −1.7[d]	Reference	—	−2.6[d]	−4.1 to −1.1[d]	Reference	—	−3.5[d]	−5.1 to −2.0[d]	Reference	—
Mild TBI																
I	85.6	81.1	82.1	82.0	−4.7[d]	−5.9 to −3.4[d]	−1.4	−3.7 to 0.8	−4.1[d]	−5.4 to −2.9[d]	−1.4	−3.7 to 0.9	−4.6[d]	−5.8 to −3.4[d]	−0.7	−3.0 to 1.6
II	87.6	83.1	82.7	83.9	−4.5[d]	−8.2 to −0.7[d]	−1.3	−6.2 to 3.7	−4.6[d]	−8.4 to −0.8[d]	−1.7	−6.9 to 3.4	−2.7	−6.9 to 1.5	0.7	−4.4 to 5.9
III	86.9	80.4	81.7	85.2	−6.6[d]	−9.2 to −3.9[d]	−3.3	−6.6 to 0.0	−4.9[d]	−7.6 to −2.1[d]	−2.4	−5.9 to 1.2	−3.1[d]	−5.8 to −0.4[d]	0.9	−2.5 to 4.3
Moderate TBI	91.4	74.0	75.6	76.2	−17.6[d]	−21.6 to −13.5[d]	−14.0[d]	−17.5 to −10.5[d]	−15.3[d]	−19.3 to −11.2[d]	−12.5[d]	−16.1 to −8.8[d]	−14.6[d]	−18.5 to −10.7[d]	−10.7[d]	−14.4 to −7.1[d]
Severe TBI	88.6	56.6	66.4	68.1	−30.9[d]	−42.1 to −19.7[d]	−27.8[d]	−35.4 to −20.2[d]	−22.1[d]	−33.0 to −11.2[d]	−19.4[d]	−27.0 to −11.7[d]	−19.1[d]	−29.6 to −8.6[d]	−16.0[d]	−23.6 to −8.3[d]

[a] On the basis of all children with data at each time point.
[b] On the basis of children with data at both time points.
[c] Net change compared to arm-injury controls, adjusted for age, gender, race, insurance, parent income, and parent education, on the basis of all children.
[d] Significant result.

TABLE 5 Prediction Model of PedsQL at 3 and 12 Months for Children Aged 24 Months and Older

	PedsQL 3 mo, Coefficient (95% CI)	PedsQL 12 mo, Coefficient (95% CI)	PedsQL 24 mo, Coefficient (95% CI)
Injury group			
Arm injury	Reference	Reference	Reference
Mild I	−2.2 (−4.7 to 0.3)	−2.4 (−4.4 to −0.3)[a]	−1.8 (−3.2 to −0.4)[a]
Mild II	−0.7 (−4.1 to 2.7)	−1.2 (−3.5 to 1.2)	1.3 (−2.8 to 5.5)
Mild III	−3.0 (−6.6 to 0.6)	−2.3 (−6.7 to 2.2)	−0.6 (−2.0 to 0.7)
Moderate TBI	−11.6 (−14.6 to −8.6)[a]	−9.7 (−14.0 to −5.3)[a]	−7.9 (−9.6 to −6.2)[a]
Severe TBI	−24.8 (−36.9 to −12.7)[a]	−18.0 (−33.1 to −2.9)[a]	−13.2 (−27.6 to 1.2)
Age group			
2–4	Reference	Reference	Reference
5–9	−1.0 (−2.6 to 0.6)	−0.7 (−2.7 to 1.4)	0.1 (−1.9 to 2.0)
10–14	−2.7 (−5.5 to 0.1)	−1.5 (−5.5 to 2.5)	0.7 (−2.7 to 4.0)
15–17	−4.3 (−9.1 to 0.5)	−2.5 (−5.7 to 0.8)	2.0 (−2.4 to 6.5)
Household income			
Less than \$30 000	Reference	Reference	Reference
\$30 000–\$60 000	1.8 (−1.0 to 4.6)	3.0 (−1.1 to 7.0)	3.0 (0.2 to 5.9)[a]
\$60 000–\$100 000	3.5 (0.9 to 6.1)	4.9 (−0.6 to 10.4)	2.9 (−0.3 to 6.1)
More than \$100 000	4.9 (1.9 to 7.9)	6.8 (2.5 to 11.1)	6.3 (2.8 to 9.8)[a]
Refused/unknown	6.0 (3.9 to 8.1)	5.9 (2.1 to 9.7)	5.5 (2.8 to 8.2)[a]
Respondent parent's education			
Less than high school/high school/GED	Reference	Reference	Reference
Some college	−1.0 (−3.2 to 1.3)	−2.5 (−5.2 to 0.2)	−0.9 (−3.3 to 1.5)
College or higher	0.7 (−1.7 to 3.1)	−0.9 (−3.4 to 1.5)	−0.6 (−3.1 to 1.8)
Baseline PedsQL score	0.7 (0.6 to 0.8)[a]	0.7 (0.6 to 0.8)[a]	0.75 (0.68 to 0.81)[a]
Any comorbidities	[b]	[b]	−0.4 (−2.3 to 1.6)
Baseline FAD score	[b]	[b]	−0.09 (−0.21 to 0.04)

FAD indicates McMaster Family Assessment Device; GED, general equivalency diploma.
[a] Significant result.
[b] Not confounders at 3 and 12 months.

on the PedsQL distinguishes chronically ill from healthy children.[37] In our study, the quality of life of children with moderate and severe TBI was lower than that of children undergoing active treatment for cancer.[47]

The lower quality of life in older children after TBI is supported by findings on other measures used in this study. Participation in life situations and events was impaired in children with moderate and severe TBI. The CASP reflects disability participating in movement-related activities and in communication and social activities at school.[48] Measurement of these dimensions was supplemented by the ABAS-II, which examined the effect of TBI on adaptive skills that are necessary for daily living. Studies of adults with childhood TBI have found that few survivors have impaired self-care skills for activities of daily living but that impaired communication leads to lower quality of life for work and leisure.[49]

Children with mild TBI are not a homogeneous group. We categorized those with mild TBI into 3 groups on the basis of their CT findings, as previously suggested but not commonly done with children.[50–55] Those with intracranial hemorrhage (mild TBI III) have been labeled as having "complicated mild TBI" by others.[56,57] The lower quality of life in this group 3 months after injury that seemed to resolve by 12 months suggests short-term adverse consequences of mild TBI with intracranial pathology and warrants further exploration.

Children with mild TBI without any intracranial hemorrhage on CT scan, or for whom imaging was not performed, constituted the majority of children in

our study. These children also had somewhat lower quality of life both 3 and 12 months after injury. However, after adjusting for changes in the controls with arm injury, these differences were small and not believed to be clinically significant. Nevertheless, given the large size of this group of children, further efforts to understand the reasons for persistent symptoms and to develop effective treatments might be needed.

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