Analysis of long-term (median 10.5 years) outcomes in children presenting with traumatic brain injury and an initial Glasgow Coma Scale score of 3 or 4

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OBJECT Patients with traumatic brain injury (TBI) with low presenting Glasgow Coma Scale (GCS) scores have very high morbidity and mortality rates. Neurosurgeons may be faced with difficult decisions in managing the most severely injured (GCS scores of 3 or 4) patients. The situation may be considered hopeless, with little chance of a functional recovery. Long-term data are limited regarding the clinical outcome of children with severe head injury. The authors evaluate predictor variables and the clinical outcomes at discharge, 1 year, and long term (median 10.5 years) in a cohort of children with TBI presenting with postresuscitation GCS scores of 3 and 4.

METHODS A review of a prospectively collected trauma database was performed. Patients treated at Riley Hospital for Children (Indianapolis, Indiana) from 1988 to 2004 were reviewed. All children with initial GCS (modified for pediatric patients) scores of 3 or 4 were identified. Patients with a GCS score of 3 were compared with those with a GCS score of 4. The outcomes of all patients at the time of death or discharge and at 1-year and long-term follow-up were measured with a modified Glasgow Outcome Scale (GOS) that included a "normal" outcome. Long-term outcomes were evaluated by contacting surviving patients. Statistical "classification trees" were formed for survival and outcome, based on predictor variables.

RESULTS Sixty-seven patients with a GCS score of 3 or 4 were identified in a database of 1636 patients (4.1%). Three of the presenting factors differed between the GCS 3 patients (n = 44) and the GCS 4 patients (n = 23): presence of hypoxia, single seizure, and open basilar cisterns on CT scan. The clinical outcomes were statistically similar between the 2 groups. In total, 48 (71.6%) of 67 patients died, remained vegetative, or were severely disabled by 1 year. Eight patients (11.9%) were normal at 1 year. Ten of the 22 patients with long-term follow-up were either normal or had a GOS score of 5.

Multiple clinical, historical, and radiological factors were analyzed for correlation with survival and clinical outcome. Classification trees were formed to stratify predictive factors. The pupillary response was the factor most predictive of both survival and outcome. Other factors that either positively or negatively correlated with survival included hypothermia, mechanism of injury (abuse), hypotension, major concurrent symptoms, and midline shift on CT scan. Other factors that either positively or negatively predicted long-term outcome included hypothermia, mechanism of injury, and the assessment of the fontanelle.

CONCLUSIONS In this cohort of 67 TBI patients with a presenting GCS score of 3 or 4, 56.6% died within 1 year. However, approximately 15% of patients had a good outcome at 10 or more years. Factors that correlated with survival and outcome included the pupillary response, hypothermia, and mechanism. The authors discuss factors that may help surgeons make critical decisions regarding their most serious pediatric trauma patients.

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KEY WORDS traumatic brain injury; pediatric; Glasgow Coma Scale; Glasgow Outcome Scale; trauma

ABBREVIATIONS GCS = Glasgow Coma Scale; GOS = Glasgow Outcome Scale; ICP = intracranial pressure; TBI = traumatic brain injury.

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TRAUMATIC brain injury (TBI) is a leading cause of death and morbidity in pediatric patients. Approximately 1.5 million people in the United States suffer TBI annually, resulting in an estimated 50,000 deaths and 500,000 patients with permanent disability.^{44,49} The Glasgow Coma Scale (GCS) score is a well-accepted measure of the severity of the injury.⁴⁷ There are modifications of the adult GCS for children.^{27,42,46} Adult patients with a GCS score of ≤ 8 are considered to have “severe” TBI. In children, a GCS score of 5 may be the critical level for “severe” TBI.¹⁰ In both adults and children, patients with a GCS score of 3 or 4 have the most severe injuries.

Clinicians may have a justifiably pessimistic view regarding these patients, because survival may be considered unlikely. Even if the patient survives the initial injury, the chance for meaningful neurological function may be poor. One may question the logic of committing significant resources to a patient if the outcome is likely to be death or vegetative survival. The difficulty of addressing these ethical concerns may be magnified in cases involving children, especially those who have suffered abuse.

To make decisions in the acute phase of treatment, we feel long-term data on the outcomes of these critically ill patients are crucial. There are very few studies that follow pediatric TBI patients for longer than 1 year. The neurosurgical service at Riley Hospital for Children (Indianapolis, Indiana) maintained a prospective database of all head-injured patients from 1988 to 2004. We evaluated all patients who presented with a GCS score of 3 or 4. Outcomes were evaluated at discharge, 1 year, and long term. Long-term (median 10.5 years, mean 11.04 ± 6.1 years) outcomes were evaluated by contacting survivors. Clinical, historical, and radiological factors were statistically correlated to survival and clinical outcome.

Methods

The neurosurgical service at Riley Hospital for Children, a Level 1 pediatric trauma center, maintained a database of all head-injured patients from 1988 to 2004. Scores were recorded for the modified pediatric GCS^{32,46} (also referred to simply as “GCS” in discussions of pediatric patients). All patients who presented with a GCS score of 3 or 4 were identified. The project began after local institutional review board approval.

The database was prospectively maintained by the neurosurgical service during the inclusive years. A neurosurgical research nurse recorded admission, hospital, and discharge information. Epidemiological data points included patient age at injury, sex, race, method of transport, mechanism of injury, and the possibility of abuse/nonaccidental trauma. Patients involved in a motor vehicle accident were subdivided according to accident characteristics: pedestrian, biker (fall, struck by vehicle, presence of helmet), and passenger (restrained vs not restrained). Clinical data points included presence of one or multiple seizures, responsiveness at the scene, and intubation at the scene versus in hospital. Physical examination findings included lowest systolic blood pressure, temperature, left and right pupil size, presence of retinal hemorrhages, and evaluation of the anterior fontanelle (if patent). “Hypother-

mia” was defined as a recorded initial temperature of less than 36°C . A patient was considered to be “hypotensive” if their lowest recorded systolic blood pressure was less than 2 standard deviations of the normal for age. The modified pediatric GCS score was recorded by the examining neurosurgeon (either the resident or attending physician). Every effort was made to record this score with the patient adequately resuscitated and free of sedating medications.

Radiological factors recorded from the initial CT scan included skull fracture (including size, length, open vs closed, depressed, basilar), hemorrhage/hematoma (intraventricular, intracerebral, subarachnoid, epidural, and subdural), patency or effacement of basilar cisterns, midline shift of > 1 cm, infarction, hydrocephalus, and pneumocephalus. Hospitalization data points included surgery, intracranial pressure (ICP) monitoring or external ventricular drain placement, and evaluation of the immediate outcome. Patient disposition was recorded. Outcomes were recorded at death, discharge, 1 year, and long term (> 1 year) using a modified version of the Glasgow Outcome Scale (GOS). We modified the GOS to include a category for “normal” as follows: “normal,” normal in every respect; 5, good recovery with minor cognitive or neurological problems; 4, disabled neurologically or cognitively; 3, severely disabled, possibly requiring institutional care; 2, vegetative survival; 1, death.

A normal patient outcome was defined as being neurologically intact, functioning at the appropriate grade level and/or able to graduate from high school, being gainfully employed, and/or living independently. Patients with a GOS score of 5 are able to attend school with minor problems and/or live independently. A score of 4 indicates a patient who is functional and ambulatory but has cognitive problems requiring special education and government assistance, and who is unable to function independently. A score of 3 indicates a patient who has severe neurological defects (such as spastic quadriplegia) and requires full-time care. A score of 2 includes patients with severe deficits who are unable to interact with their environment, requiring complete care.

We used statistical analysis to compare patients with a GCS score of 3 to those with a score of 4. While there were a few differences in presenting variables, the survival and outcomes at discharge were statistically similar. Therefore, all patients were grouped together to evaluate survival and clinical outcome at 1 year and long term. Long-term data were obtained either from current medical records or by telephone contact.

Statistical analysis was performed using R software, version 2.13.1. Data were analyzed using the t-test for continuous variables and Fisher exact test for the categorical variables. All of the above clinical, epidemiological, and radiological variables were included in the analysis. Statistical significance was set as $p \leq 0.05$.

Statistical “classification trees” were formed to predict membership in the class of a categorical dependent variable from 1 or more predictor variables.⁷ The classification tree is used to find the optimal way to split data into different classes on the basis of the characteristics of the variables of interest. The Gini rule⁷ was the default quality-of-split criterion used in the analysis. The Gini rule is applied

to determine the largest class in the database and isolate it from all others. It measures how well the “splitting rule” separates the classes contained in the parent node. The tree is built by first identifying the single variable that best splits the data into 2 groups according to the Gini rule. The first selected variable located at the top of the tree provides the split with maximal impurity reduction. Once the data are separated by the first variable, the same splitting process is applied to each subgroup. The process is repeated recursively until the subgroups either reach a minimum size or until no improvement can be made based on the Gini rule. We set the minimum size as 1.

Results

Sixty-seven (4.1%) of the 1636 patients in the database had a GCS score of 3 or 4. Of the 67 patients, 44 presented with an initial GCS score of 3, and 23 patients had a GCS score of 4. The demographic data are shown in Table 1. There were no statistically significant differences in the sex, race, age, or mechanism of injury between the patients with GCS 3 or 4.

The clinical presentations of patients with GCS scores of 3 and those with a score of 4 were compared. The analyzed variables between the 2 groups are shown in Table 2 and are comparable in most respects. However, there was a statistically significant difference in the percentage of presentation between groups for 3 of the variables: presence of hypoxia (65.9% of GCS 3 patients vs 39.1% of GCS 4 patients, $p = 0.046$); single seizure (2.3% of GCS 3 patients vs 17.4% of GCS 4 patients, $p = 0.044$); and patent (“open”) cisterns on CT scan (68.2% of GCS 3 patients vs 91.3% of GCS 4 patients, $p = 0.04$).

Survival and Outcomes at Discharge

The discharge outcomes are shown in Table 3. A total of 37 patients (55.2%) died, including 27 patients (61.4%) with a GCS score of 3 ($n = 44$) and 10 patients (43.5%) with a GCS score of 4 ($n = 23$). No patients were classified as normal at discharge. There was no statistically significant difference in survival between patients with GCS scores of 3 and those with GCS scores of 4 ($p = 0.2$). There was no statistically significant difference in discharge GOS scores ($p = 0.447$) between the 2 groups.

A statistical classification tree was created to predict survival or death (Fig. 1). The most predictive variable was pupillary reaction. If the pupillary reaction in both eyes was normal, the chance of survival was 87%. If the pupillary reaction was abnormal (in one or both eyes), the chance of survival dropped to 23%.

The classification tree was branched further. For those with a normal pupillary reaction, the next most important variable was whether abuse was the mechanism of injury. Patients with reactive pupils who did not suffer abuse had a 100% survival rate. Patients with reactive pupils and abuse had a 50% survival rate. For abused patients, the next variable was the presence of hypotension. Patients without hypotension had a 75% chance of survival, whereas those with hypotension had a 0% chance.

In patients with an abnormal pupillary response, the next most important variable was the presence of hypo-

TABLE 1. Demographic data of the study group ($n = 67$)

Patient Characteristics	GCS Score 3 ($n = 44$)	GCS Score 4 ($n = 23$)	p Value*
Sex, n (%)			0.792
M	27 (61.4)	13 (56.5)	
F	17 (38.6)	10 (43.5)	
Race, n (%)			0.076
Caucasian	34 (77.3)	11 (33.3)	
African-American	6 (13.6)	6 (18.2)	
Hispanic	1 (2.3)	2 (6.1)	
Other/unknown	3 (6.8)	4 (12.1)	
Age (mos)			0.2437
Mean $\pm$ SD	49.8 $\pm$ 51.8	66.9 $\pm$ 58.0	
Range	1 mo–15.1 yrs	2 mos–15.7 yrs	
Mechanism of injury, n (%)			0.275
Nonaccidental trauma	23 (52.3)	7 (30.4)	
Pedestrian struck	9 (20.5)	5 (21.7)	
Motor vehicle accident	7 (15.9)	4 (17.4)	
Fall from height	3 (6.8)	3 (13.0)	
Bicycle fall	1 (2.3)	3 (13.0)	
Struck by object	1 (2.3)	1 (4.3)	

* Fisher exact test.

thermia. A patient with an abnormal pupillary response and hypothermia had a probability of survival of 14%, whereas a patient without hypothermia had a probability of survival of 56%. The remainder of the variables are shown in Fig. 1. The lowest categories are terminal nodes. For example, a child without midline shift on CT, involved in a motor vehicle accident, with hypothermia, and with an abnormal pupillary response had a 0% chance of survival.

Outcomes at 1 Year and Long Term

There were 37 initial deaths. One patient died prior to 1 year of follow-up. Therefore, there were a total of 29 potential survivors. The outcomes of 5 patients were unknown or lost to follow-up at 1 year. The outcomes at 1 year are shown in Table 4. Ten patients (14.9%) had a “normal” or GOS Score 5 outcome. Ten patients (14.9%) were long-term survivors but had a GOS score of 2 or 3, indicating severe disability or vegetative state. In total, 48 (71.6%) of 67 died, remained vegetative, or were severely disabled.

We attempted to obtain clinical data on all patients known to have survived to 1 year. Two patients had follow-up data at 1 year, but no data past this time. We were able to obtain data past 1 year in 22 patients. In these patients, the mean follow-up duration was 11.04 ± 6.1 years (median 10.5 years). Table 5 shows the long-term data in greater detail. The GOS at 1 year correlated with the long-term GOS, although 1 patient improved. Therefore, 21 (95.5%) of 22 patients had the same GOS score long term as at 1 year, with 1 patient improving from a GOS score of 2 to 3 (by 7 years). Comments on the subjective quality of life are included in the table.

A classification tree was derived from predictor variables of outcome based on the long-term GOS (Fig. 2). Again, the most important variable was the pupillary reaction. Patients with a normal pupillary reaction had a 27%

TABLE 2. Analysis of presenting variables

Variable	GCS Score 3* (n = 44)	GCS Score 4* (n = 23)	p Value
Hypoxia			0.046
Yes	29 (65.9)	9 (39.1)	
No	8 (18.2)	4 (17.4)	
Unknown/not recorded	7 (15.9)	10 (43.5)	
Pupil asymmetry	9 (20.4)	3 (13.0)	0.523
Hypotension			0.131
Yes	22 (50)	8 (34.8)	
No	16 (36.4)	7 (30.4)	
Unknown/not recorded	6 (13.6)	8 (34.8)	
Hypothermia			0.101
Yes	22 (50)	7 (30.4)	
No	15 (34.1)	7 (30.4)	
Unknown/not recorded	7 (15.9)	9 (39.1)	
Secondary symptoms			
Abdominal injury	1 (2.3)	2 (8.7)	0.269
Chest trauma	6 (13.6)	0	0.087
Spinal cord injury	1 (2.3)	0	1.000
Long bone fractures	8 (18.2)	1 (4.3)	0.149
Respiratory distress	23 (52.3)	14 (60.9)	0.608
Seizure (single)	1 (2.3)	4 (17.4)	0.044
Seizures (multiple)	9 (20.5)	2 (8.7)	0.307
No additional symptoms	5 (11.4)	3 (13.0)	>0.99
Radiographic findings			
Skull fracture	15 (34.1)	8 (34.8)	>0.99
Basilar	3 (6.8)	2 (8.7)	>0.99
Open depressed	0	1 (4.3)	0.343
Hemorrhage			
Intraventricular	8 (18.2)	3 (13.0)	0.736
Intraparenchymal	7 (15.9)	5 (21.7)	0.738
Subarachnoid	31 (70.5)	15 (65.2)	0.783
Subdural	29 (65.9)	15 (65.2)	>0.99
Epidural	1 (2.3)	1 (4.3)	>0.99
Cisterns			0.04
Open	30 (68.2)	21 (91.3)	
Compressed	14 (31.8)	2 (8.7)	
Midline shift ≥10 mm	11 (25)	8 (34.8)	0.393
Hydrocephalus	1 (2.3)	0	>0.99
Hospital course			0.014
Surgical intervention	24 (54.6)	20 (87.0)	
ICP monitor/EVD	24 (54.6)	18 (78.3)	

EVD = external ventricular drain.

* Values are number of patients (%).

chance of eventually attaining a GOS score of 5 or normal. There was a 40% and 33% chance of attaining GOS scores of 4 and 1–3, respectively. The chance for patients with an abnormal pupillary response to attain GOS scores of 1–3, 4, or 5 were 92%, 8%, and 0%.

In patients with a normal pupillary response, the next classification branch point was based on the mechanism of injury. Patients injured in a fall did well, with 100% attaining a long-term outcome of normal or GOS score of 5. In patients with a different mechanism of injury, the evaluation of the fontanelle (if present) was the next variable.

TABLE 3. Outcomes at discharge using the modified GOS (n = 67)

GOS	GCS Score 3* (n = 44)	GCS Score 4* (n = 23)	p Value
Normal	0	0	0.447†
5	2 (4.6)	2 (8.7)	
4	7 (15.9)	3 (13.0)	
3	5 (11.4)	4 (17.4)	
2	3 (6.8)	4 (17.4)	
1	27 (61.4)	10 (43.5)	0.2‡

* Values are number of patients (%).

† No statistically significant difference in discharge GOS scores.

‡ No statistically significant difference in survival.

In patients with abnormal pupillary response, hypothermia was the next most predictive of outcome. One hundred percent of the patients with an abnormal pupillary response and hypothermia had a GOS score of 1–3.

Discussion

A physician may be faced with complex medical and ethical challenges in the care of the most severely injured TBI patients. Patients presenting with low postresuscitation GCS scores have extremely high morbidity and mortality rates.^{14,18,29,50}

Predictive Variables for Survival

In general, survival of critically ill patients has improved with advanced prehospital, emergency, and intensive care techniques.^{35,52} There are papers discussing survival in severely head-injured adults. Chamoun et al. reported survival in 50.8% of adult TBI patients presenting with a GCS score of 3 and good outcome at 6 months in 13.2%. The factors most predictive of outcome were age, ICP, and pupil reactivity at admission.⁸ Tien et al. reported an overall mortality rate of 76.8% in 173 patients with GCS score of 3; the mortality was 100% in patients with fixed, dilated pupils and 42% in patients with reactive pupils.⁵⁰ Other studies in adults show relatively consistent factors that correlate with survival and, conversely, death. Factors that are associated with poor survival include hypoxia, extremes of age, hypotension, hypercarbia, hyperglycemia, mechanism of injury, and hypothermia.^{6,21,25,28,36,39,43,51,53} Other factors that may be independent predictors of outcome in severe TBI patients include prehospital deterioration, duration of coma, time to “follow commands” duration of amnesia, time to resume oral feeding, and measurement of the efficacy of interventions designed to lower ICP.^{17,20,40,45}

As most of the published studies evaluated adults, we sought to examine a relatively large cohort of children presenting with a postresuscitation GCS (modified for pediatric patients) score of 3 or 4. We evaluated 67 children treated at a Level 1 trauma center. The demographics of the patient population are shown in Table 1. This table presents the comparison of 44 patients with a GCS score of 3 and 23 patients with a GCS score of 4. There were no statistically significant differences in the demographics between the 2 groups. There were minor differences in certain variables at presentation (Table 2). Patients with GCS score of 3 were more likely to be hypoxic (65.9% vs 39.1%; $p = 0.046$), less likely to have open basilar cist-

FIG. 1. Classification tree for predictive variables correlated with survival. MVA = motor vehicle accident; pt = patient.

terns (68.2% vs 91.3%; $p = 0.04$), and less likely to have single seizure (2.3% vs 17.4%; $p = 0.044$). Patients with GCS 4 were more likely to receive surgical intervention ($p = 0.014$). The outcomes at discharge, based on a modified GOS, are shown in Table 3. Overall, 37 patients (55.2%) died. The survival and clinical outcome at discharge were statistically similar between the GCS 3 and 4 patients. We therefore combined the patients to analyze predictive variables for survival and clinical outcome.

Figure 1 shows a statistical classification tree that stratifies the chance of survival based on predictor variables. The variable with the highest correlation to survival was the pupillary reaction. If the pupillary reaction was abnormal in one or both eyes, the probability of survival was 23%. Conversely, if the pupils were both normally reactive, the chance of survival was 87%. The next predictor in children with reactive pupils was the presence of abuse. Children with reactive pupils in whom the mechanism of injury was abuse had a 50% chance of survival. Children with reactive pupils and no history of abuse had 100% survival (17 survivors, 0 deaths).

In the patients with an abnormal pupillary examination, the next most important variable was the presence of hypothermia. Patients with an absent pupillary reflex and hypothermia had a 14% chance of survival, whereas those with an absent pupillary reflex and no hypothermia had a chance of survival of 56%. Each subsequent branch point gives the outcome of the sequence of variables. For example, a child with an absent pupillary reflex, with hypothermia, with a mechanism of action other than motor vehicle accident, and over 3 months of age had a 0% survival (23 deaths).

Predictive Variables for Clinical Outcome

Clinicians may justifiably argue that clinical outcomes are more relevant than survival. One may question the utility of therapy that allows survival but leaves the patient in a vegetative state. There are very few data regarding the long-term outcomes in severely injured children.

In our cohort, 29 (43.3%) of 67 patients survived to 1 year. We were able to obtain data regarding long-term clinical outcome in 22 of the survivors. The long-term GOS score was the same as the 1-year GOS score in 21 (95.5%) of 22 patients, with 1 patient improving from a score of 2 to a score of 3. Previously published papers indicate that the GOS score at discharge and at 3 months predict the outcomes at 1 year.^{26,30,31} There are few reported studies that have followed patients for longer than 1 year. For those studies that evaluated patients for longer

TABLE 4. Patient outcomes at 1 year (n = 67)

Outcome	No. of Patients (%)
Died	38 (56.7)*
Survivors	29 (43.3)
GOS score	
Normal	8 (11.9)
5, good	2 (3.0)
4, disabled	4 (6.0)
3, severely disabled	7 (10.4)
2, vegetative	3 (4.5)
Unknown (lost to follow-up)	5 (7.5)

* Includes 1 patient who survived to discharge but died prior to 1-year follow-up.

TABLE 5. Long-term follow-up in survivors with initial GCS scores of 3 or 4

GCS Score & Case No.	Age at Injury	Mechanism	GOS Score			Follow-Up Duration (yrs)	Long-Term Clinical Notes
			Discharge	1 Yr	Long Term		
GCS 3							
1	5 mos	Fall	5	Normal			No follow-up after 1 yr
2	4.6 yrs	MVA/pedestrian	5	Normal	Normal	23	Fully functional & lives independently
3	10.3 yrs	MVA/passenger	4	Normal	Normal	23	Gainfully employed, lives independently, fully functional
4	2.3 yrs	Fall	4	Unknown			
5	1 mo	NAT	2	2	2	3	Cortical blindness, spastic quadriparesis, vegetative
6	14.5 yrs	MVA/pedestrian	3	Normal	Normal		Neurologically intact
7	2 mos	NAT	3	3	3	16	Nonverbal, spastic quadriparesis
8	2.5 yrs	NAT	4	2	2	3	Vegetative
9	5.6 yrs	MVA/pedestrian	4	5	5	16	Required special education classes for delay, unemployed
10	1 mo	NAT	3	3	3	10	Nonverbal, spastic quadriparesis
11	3 mos	NAT	3	3	3	5	Seizures, severe developmental delay
12	1.4 yrs	NAT	4	Unknown			
13	2 mos	NAT	2	Normal	Normal	10	Neurologically normal
14	1.9 yrs	MVA/passenger	2	1			Survived to discharge, but died prior to 1 yr
15	15.1 yrs	MVA/passenger	3	3	3	13	Spasticity, mental retardation
16	3.3 yrs	NAT	4	Unknown			
17	13.6 yrs	MVA/bicycle struck	4	5	5	10	Graduated high school, some behavior problems, receives disability, memory problems, lives w/ family
GCS 4							
1	5.5 yrs	MVA/pedestrian	3	3	3	3	Spasticity, severe delay
2	1.8 yrs	MVA/pedestrian	3	3	3	4	Spasticity, severe delay
3	8.3 yrs	MVA/passenger	2	2	2	13	Eyes open, will look around, nonverbal, requires full-time care
4	2.5 yrs	MVA/pedestrian	4	4	4	20	Seizure disorder, moderate mental delay, lives w/ parents, not employed
5	5.9 yrs	Fall	5	Normal	Normal	5	Neurologically normal
6	14.2 yrs	MVA/bicycle struck	2	Unknown			
7	2 mos	NAT	2	2	3	7	Spastic quadriplegia, mental retardation
8	15.7 yrs	Struck by object	2	5	5	14	Graduated high school, on disability, lives independently
9	6.1 yrs	Fall	5	Normal	Normal	13	"A" student in honors classes, neurologically normal
10	8.4 yrs	MVA/passenger	3	Normal	Normal	11	Graduated high school, in college classes & employed in day care, chronic headaches
11	2.6 yrs	MVA/pedestrian	4	4	4	10	Special education classes, plays basketball, aggressive behavior in school
12	7.9 yrs	MVA/pedestrian	3	4	4	11	Attends high school & scheduled to graduate w/ a certificate at age 21, seizures, developmental delay
13	1.3 yrs	NAT	4	Unknown			

MVA = motor vehicle accident; NAT = nonaccidental trauma.

than 1 year, clinical improvement was frequently reported months after severe TBI in adult patients.^{9,26}

There are a number of differences between a pediatric and an adult TBI patient. Many abuse patients are injured

at a very early age, when the developing brain may be particularly vulnerable.³⁷ Children have changing needs as they grow and are dependent on their environment and social situation. Indeed, preinjury factors, such as education

FIG. 2. Classification tree for predictive variables correlated with outcome.

level and age, influence recovery after TBI.^{13,24,33,34,41} Pediatric TBI patients may have prolonged impairment, demonstrated by poor school performance, poor quality of life measures, need for special education services, and mental health problems.^{3,15–17} Rivara et al. compared a cohort of children with head injury with a control group of children with orthopedic injuries.³⁸ Children with head injury required higher levels of community resources than the control group despite a similar overall severity of injury. At 24 months, the health-related quality of life of patients with moderate or severe TBI continued to be worse than baseline. Notably, there was improvement over the first 2 years after injury.³⁶ Arnett et al. studied the educational outcome in children with mild, moderate, or severe TBI 1 year after brain injury.³ Outcome was correlated with postinjury executive functioning ability (including attention control, inhibition, organization, planning, and self-monitoring) independent of the severity of the initial injury.³ In one of the few studies following children longer than 1 year, An-

derson et al. evaluated predictors of cognitive function 10 years after TBI in a cohort of 40 children.² The preinjury function and family status was correlated with long-term outcomes. Environmental factors contributed to recovery and patients made progress up to 10 years after injury.² Access to rehabilitation facilities may improve long-term outcomes.⁴⁸

The clinical outcomes at 1 year in our patients are shown in Table 4. Ten patients (14.9%) were either “normal” or had a GOS score of 5 at 1 year. Long-term outcome data were obtained for 22 patients with a mean of 11.04 ± 6.1 years (median 10.5 years) of clinical follow-up. Ten of 22 patients with long-term data had a GOS score of 5 or “normal” outcome.

A second classification tree (Fig. 2) was generated based on the presenting variables and the long-term outcomes. As with survival, the pupillary response was the factor most correlated with outcome. This is consistent with other published studies.^{8,26,50} In patients with an absent pupil-

lary response, the next most correlative predictive variable in our study was the presence of hypothermia.

Note that we did not therapeutically induce hypothermia in any patient. In our cohort, hypothermia likely was caused by either prolonged extrication or a loss of cerebral autoregulation. Therapeutic hypothermia continues to generate interest as a potential treatment for head injury, despite multiple studies that do not demonstrate benefit.^{1,11,22} Our data argue against the concept of hypothermia as a protective element. Patients with an absent pupillary reflex and hypothermia had a 0% chance of an outcome of “normal,” GOS score of 5, or GOS score of 4.

Note that all variables (clinical, epidemiological, and radiological) were analyzed for creation of the classification trees. Prior to the analysis, we intuitively believed that certain variables would predict survival and good outcome. We thought that the presence of an operable epidural hematoma or a single seizure (with the postictal state clouding the initial examination) would predict a good outcome. Interestingly, neither of these factors were the most predictive of survival or outcome. “Midline shift” was correlated with survival but was low on the classification tree (Fig. 1).

Study Limitations

One of the difficulties in evaluating trauma patients is the heterogeneity of the population and treatments. Treatment of TBI patients at Riley is currently based on the accepted evidence-based guidelines.⁵ However, the initial data were largely obtained prior to publication of widely accepted pediatric trauma guidelines. We adhered to principles of preventing hypoxia, preventing hypotension, monitoring ICP in selected patients, and surgically evacuating mass lesions. Patients with presumed hypoxic injury from nonaccidental trauma were supported, but were generally not treated surgically. We did not actively cool patients for therapeutic hypothermia. Even with consensus trauma guidelines, there is a significant need for individual physician judgment and, by necessity, heterogeneity in care.

The database was initially created in 1988. Since its creation, a number of outcome scales have been developed that improve on the original GOS. There are now validated outcome scales specific for children, including the Glasgow Outcome Scale–Extended (GOS-E), the GOS-E Pediatric Revision, and the Pediatric Cerebral Performance Scale (PCPS).^{4,19,23} These scales account for pediatric-specific issues, such as needs at various stages of development. We acknowledge that the pediatric outcomes are better assessed by these tools than the rather broad GOS; however, we chose to remain consistent in our analysis of the original data. We did use a modified GCS for pediatric patients. A number of other evaluation scores have been developed that may be more specific to pediatric patients than the GCS.¹²

Conclusions

Children with severe TBI and a presenting GCS score of 3 or 4 have a high likelihood of death and morbidity. In our analysis, 48 (71.6%) of 67 patients either died, were severely disabled, or were vegetative. However, 14.9% of

patients had a good outcome. Factors that were associated with poor survival and poor outcome included an abnormal pupillary response, hypothermia, and the presence of abuse.

Our results provide some guidance for decision making in cases involving these critically injured children. The chances of meaningful survival in a patient with an abnormal pupillary response and hypothermia are extremely low. The clinician may decide that aggressive therapy in these patients is not warranted. Conversely, children with normal pupillary responses who were injured by a mechanism other than abuse may have a good or even normal outcome despite a GCS score of 3 or 4. While standard guidelines are necessary in the management of head-injured patients, critical decisions must be individualized.

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