Intracranial Pressure Monitoring in Severe Isolated Pediatric Blunt Head Trauma

ALI SALIM, M.D.,* MATTHEW HANNON, M.D.,† CARLOS BROWN, M.D.,‡ PANTELIS HADJIZACHARIA, M.D.,† LEAH BACKHUS, M.D.,† PEDRO G.R. TEIXEIRA, M.D.,† LINDA S. CHAN, PH.D.,† HENRI FORD, M.D.§

*From the *Department of Surgery, Division of Trauma and Critical Care, Cedars-Sinai Medical Center, Los Angeles, California; †Los Angeles County+University of Southern California Medical Center, Los Angeles, California; ‡Division of Trauma, Brackenridge Hospital, Austin, Texas; and the §Department of Surgery, Childrens Hospital Los Angeles, Los Angeles, California*

Very little research regarding standard treatments for pediatric traumatic brain injury (PTBI) exists. The objective of this study was to examine the use of intracranial pressure (ICP) monitoring devices in PTBI and to determine if its use was associated with any outcome benefit. Data were collected from the Trauma Registry over an 11-year period (1996–2006) on all blunt trauma pediatric patients (age < 14 years) with an initial Glasgow Coma Scale score ≤ 8. Data collected included: demographics, admission Glasgow Coma Scale score, mechanism of injury, Injury Severity Score, Abbreviated Injury Score, and use of an ICP monitor. Outcome measures included: mortality, complications, discharge location, and capacity. Thirty-three (25%) of 129 blunt PTBI patients had ICP monitors placed. Patients with monitors were more severely injured overall (Injury Severity Score: 25 *vs* 18, $P = 0.001$) and had more severe head injury (81% head Abbreviated Injury Score > 3 *vs* 55%, $P = 0.01$) than patients without monitors. However, there was no difference in mortality (28% *vs* 35%, $P = 0.52$), discharge location ($P = 0.10$), and discharge capacity ($P = 0.84$). After multivariable analysis to adjust for the differences between the two study groups, the use of ICP monitor provided no survival benefit (adjusted odds ratio: 1.1; 95% confidence interval [CI]: 0.3–4.1; adjusted P value = 0.85). The use of ICP monitor was, however, independently associated with a higher risk of developing extracranial complications (adjusted odds ratio: 4.3; 95% CI: 1.2–16.4; adjusted P value = 0.025). In conclusion, the use of ICP monitors in pediatric patients with severe isolated head injury provided no survival benefit and was associated with an increased risk of complications.

MORBIDITY AND MORTALITY remain high for blunt traumatic brain injury (TBI) in pediatric patients. The principle strategy for managing patients with TBI is to limit the secondary brain injury. This strategy is best accomplished with the use of intracranial pressure monitoring guiding the treatment of elevated intracranial pressures. Very little research exists to support standard treatment protocols for TBI in pediatric patients. Treatment recommendations are often extrapolated from the adult trauma literature. The Brain Trauma Foundation recommends, as an option, performing ICP monitoring in infants and children with a Glasgow Coma Scale (GCS) score of 8 or less. ICP monitoring may also be indicated in patients with less severe head injuries who will be under anesthesia or sedation which would preclude serial examinations.[1] These recommendations are based upon the observations that increased ICP is associated with poor outcome and that treatment of intracranial hypertension is associated with the best clinical outcomes in pediatric patients.[1]

Despite these observations there is still a lack of consensus on the management of TBI and the use of ICP monitoring in the pediatric population. Current literature is limited by several considerations. Many studies analyze data from severe head injured patients secondary to both traumatic and nontraumatic encephalopathies and combine data from several institutions and clinical settings with varying therapies or management protocols. This lack of strict criteria for ICP monitoring in pediatric blunt TBI in combination with the potential risk of procedural complications may serve to limit its application and thus hinder efforts to establish true benefit and treatment standards.

The purpose of our study is to examine the use of intracranial pressure monitoring and outcome vari-

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Address correspondence and reprint requests to Ali Salim, M.D., Cedars-Sinai Medical Center, Department of Surgery, 8700 Beverly Boulevard, Suite 8215N, Los Angeles, CA 90048. E-mail: ali.salim@cshs.org.

ables in pediatric patients with severe TBI in a single institution over an 11-year period.

Methods

Clinical Management

All pediatric blunt trauma patients presenting to our institution with a GCS of 8 or less were seen initially by the Trauma Surgery Service and managed by a multidisciplinary team involving the Trauma and Neurosurgical Services, as well as Pediatric Intensivists. Most patients were intubated in the Emergency Room and, unless precluded by immediately life-threatening injuries, a computed tomography scan of the head was immediately obtained. CT scans were interpreted by a board certified Neuroradiologist. The initial GCS was recorded after appropriate resuscitation. Sedatives and mild hyperventilation were used routinely. Normothermia was maintained with cooling blankets and antipyretics if necessary. ICP monitors were placed as deemed necessary by the attending Neurosurgeon. When an ICP monitor was used, an ICP greater than 20 mm Hg was treated with hypertonic saline, mannitol, or cerebral spinal fluid (CSF) drainage as appropriate.

Data Collection

This study was approved by the Institutional Review Board and the need for informed consent was waived. Data were collected from the Los Angeles County+University of Southern California Medical Center Trauma Registry on all blunt head trauma pediatric patients 14 years of age or less admitted with an initial GCS $\leq$ 8 over an 11-year period (1996–2006). Data were inserted into a computerized spreadsheet using Microsoft Excel 2003 (Microsoft Corporation, Redmond, WA). Patients who died within 48 hours were excluded from analysis as were patients with significant injuries to other anatomic regions [defined by Abbreviated Injury Score (AIS) > 3 for other anatomic regions]. Admission data included: age, gender, ethnicity, admission GCS, mechanism of injury, Injury Severity Score, AIS, and use of an ICP monitoring device. Outcome measures included hospital length of stay, intensive care unit (ICU) length of stay, complications, procedures performed, mortality, discharge location, and functional status. Functional status was characterized as permanent disability, temporary disability, preinjury, or unknown.

Statistical Analysis

All data analysis was performed using SAS System, version 8.2 (SAS Institute Inc., Cary, NC). To examine the variation of ICP monitoring utilization over time during the study period, a Mantel-Haenszel χ^2 test for trend was used.

Patients undergoing ICP monitoring were compared with patients that did not receive an ICP monitor to identify differences in baseline characteristics using χ^2 or Fisher's exact test for proportions and Wilcoxon two-sample test for means. Factors that on bivariate analysis were different between the two study groups at $P < 0.2$ were included as covariates into the multivariable analysis performed to assess the differences in outcomes. For dichotomous outcomes including death and complications, logistic regression was used to adjust for the confounders. Adjusted odds ratio with 95 per cent confidence interval, and adjusted P value were derived. For continuous variables including length of stay in ICU or hospital, analysis of covariance was used to derive the adjusted mean differences with 95 per cent confidence interval, and adjusted P value. Due to the significant skewness of the length of stay, the P value based on the nonparametric analysis of covariance was also given.

Results

One hundred and forty-one blunt TBI pediatric patients were admitted over the 11-year period. One hundred and twenty-nine of these had complete data available and comprise the study group. Overall, 32 patients, or 25 per cent, had ICP monitors placed. There was no significant trend in ICP monitor use over this time period ($P = 0.36$) (Table 1). Demographic characteristics were similar in the two groups as seen in Table 2. The majority of patients in both groups sustained injury secondary to being struck by a motor vehicle. This was followed by falls and motor vehicle accidents. Admission vital signs were not different with the exception of diastolic blood pressure. The most common type of intracranial pathology was subarachnoid hemorrhage, followed by subdural hematomas and epidural hematomas. There was no difference in the type of intracranial injury between the two groups.

Associated spine fractures and need for craniotomy, thoracotomy, or laparotomy were not different between the two groups (Table 2). Those patients with monitors were more severely injured compared with those without as reflected by the Injury Severity Score (25 ± 9 *vs* 18 ± 11, $P = 0.001$) and had more severe head injury, as shown by the percentage with head AIS > 3 (81% *vs* 55%, $P = 0.01$). Other significant differences between the ICP and nonICP monitored patients were the need for mechanical ventilation and the presence of a central line (Table 3).

On bivariate analysis, no significant difference was identified between the two groups of patients with

TABLE 1. *ICP Monitor Use Over Time*

Year of Admission	Blunt Pediatric Trauma Patients (n)	Patients with ICP Monitors (n)	ICP Monitors (%)
1996	10	3	30%
1997	7	0	0%
1998	12	2	17%
1999	13	5	38%
2000	11	1	9%
2001	15	3	20%
2002	12	4	33%
2003	9	3	33%
2004	22	5	23%
2005	11	5	45%
2006 (6 months)	7	1	14%
Total	129	32	25%

Mantel-Haenszel χ^2 test for trend showed no significant trend, $P = 0.41$.

TABLE 2. *Comparison of Clinical and Demographic Characteristics According to ICP Monitor Utilization*

	ICP Group (n = 32)	NonICP Group (n = 97)	*P* value
Age (year), mean ± SD [median]	7.0 ± 3.8 [6]	7.2 ± 4.2 [7]	*0.80*
Male	72% (23)	68% (70)	*1.00*
Ethnicity			
Hispanic	69% (22)	74% (72)	*0.88*
Black	13% (4)	11% (11)	
White	9% (3)	6% (6)	
Asian	9% (3)	7% (7)	
Other	0% (0)	1% (1)	
Mechanism of Injury			
AvP	62% (20)	56% (54)	*0.66*
Fall	16% (5)	20% (19)	
MVA	12% (4)	18% (17)	
MCA	0% (0)	3% (3)	
Sports	3% (1)	2% (2)	
Unknown	6% (2)	2% (2)	
SBP on admission (mean ± SD)	128 ± 39	111 ± 47	0.34
DBP on admission (mean ± SD)	77 ± 28	67 ± 31	0.04
HR on admission (mean ± SD)	104 ± 32	101 ± 45	0.56
RR on admission (mean ± SD)	13 ± 11	16 ± 14	0.20
GCS (mean ± SD)	4.7 ± 1.8	5.1 ± 2.0	0.47
ISS (mean ± SD)	25 ± 9	18 ± 11	0.001
ISS ≥ 16	88% (28)	60% (58)	0.005
Head AIS > 3	81% (26)	55% (53)	0.01
Associated injuries			
Skull vault fracture	22% (7)	31% (30)	0.38
Basilar skull fracture	28% (9)	26% (25)	0.82
SAH	22% (7)	26% (27)	0.65
SDH	16% (5)	10% (10)	0.52
EDH	6% (2)	8% (8)	1.00
Cervical spine fracture	9% (3)	7% (7)	0.71
Thoracic spine fracture	0% (0)	1% (1)	1.00
Lumbar spine fracture	0% (0)	0% (0)	—

The statistics in the table are per cent (number of cases) unless stated otherwise. The *P* values for proportions were derived from the χ^2 test or 2-sided Fisher's exact test; *P* values for means were derived from Wilcoxon two sample test.

SD, standard deviation; AvP, auto *versus* pedestrian; MVA, motor vehicle accident; MCA, motorcycle accident; SBP, systolic blood pressure; DBP, diastolic blood pressure; HR, heart rate; ISS, Injury Severity Score; SAH, subarachnoid hemorrhage; SDH, subdural hematoma; EDH, epidural hematoma; RR, respiratory rate.

respect to overall survival (72% with ICP *vs* 66% without ICP, $P = 0.52$) (Table 4). There was also no difference in discharge location ($P = 0.38$) and discharge capacity ($P = 0.10$) between groups. Most patients were able to be discharged to home (28% with ICP monitors and 38% without ICP monitors) without permanent disability (59% and 53% respectively).

Extracranial complications occurred significantly more frequently in the ICP monitored patients (38% *vs* 9%, $P < 0.001$). The most common complications

TABLE 3. *Management Differences According to ICP Monitor Group*

	ICP Group (n = 32)	NonICP Group (n = 97)	*P* value
Interventions			
PA catheter	16% (5)	6% (6)	0.14
Central venous catheter	44% (14)	14% (14)	0.001
Mechanical ventilation	97% (31)	60% (58)	<0.0001
Surgical Procedures			
Craniotomy	6% (2)	7% (7)	1.00
Craniectomy	0% (0)	2% (2)	1.00
Thoracotomy	0% (0)	1% (1)	1.00
Laparotomy	6% (2)	2% (2)	0.26

The statistics in the table are per cent (number of cases). The *P* values for proportions were derived from the χ^2 test or 2-sided Fisher's exact test.
PA, pulmonary artery.

TABLE 4. *Crude Outcomes (Comparison of Hospital Outcomes Between ICP and NonICP)*

Outcome	ICP Group (n = 32)	NonICP Group (n = 97)	*P* value
Survival	72% (23)	65% (62/95)	0.52
Complications			
Any complication	38% (12)	9% (9)	<0.001
Pneumonia	31% (10)	8% (8)	0.003
Pulmonary insufficiency	3% (1)	0% (0)	0.25
Acute renal failure	0% (0)	1% (1)	1.00
Acute respiratory failure	9% (3)	1% (1)	0.05
Sepsis	6% (2)	1% (1)	0.15
UTI	0% (0)	1% (1)	1.00
Discharge To			
Home	28% (9)	38% (36)	0.10
Rehabilitation center	16% (5)	18% (17)	
Other hospital	28% (9)	9% (9)	
Morgue	28% (9)	35% (33)	
Functional status			
Permanent	9% (3)	8% (8)	0.84
Temporary	50% (16)	47% (46)	
Pre-injury	9% (3)	6% (6)	
Unknown	31% (10)	38% (37)	
	Mean ± SD [Median] (n)	Mean ± SD [Median] (n)	*P* value
ICU stay	15 ± 16 [9]	8 ± 9 [4]	0.002
ICU stay (excluding deaths)	19 ± 17 [13] (23)	9 ± 10 [6] (62)	0.002
Hospital stay	26 ± 22 [17]	10 ± 15 [4]	<.0001
Hospital stay (excluding deaths)	33 ± 21 [24] (23)	15 ± 17 [12] (62)	<.0001
Charges	234,856 ± 241,859 [133,407]	78,976 ± 113,382 [25,613]	<.0001
Charges (excluding deaths)	306,430 ± 250,635 [217,595] (23)	115,261 ± 125,812 [72,302] (62)	<.0001

The statistics in the table are per cent (number of cases) unless stated otherwise. The *P* values for proportions were derived from the χ^2 test or 2-sided Fisher's exact test; *P* values for means were derived from Wilcoxon two sample test.
UTI, urinary tract infection; SD, standard deviation.

were pneumonia and respiratory failure. Intensive care unit length of stay and hospital length of stay were significantly longer in patients managed with ICP monitors. As expected, the hospital charges were significantly greater in the ICP monitored patient group ($P < 0.001$).

After multivariable analysis to adjust for the differences between the two study groups, the use of ICP monitor provided no survival benefit, with an adjusted odds ratio for survival of 1.1 (95% CI: 0.3–4.1) and an adjusted *P* value of 0.85 (Table 5). The use of ICP monitor was, however, independently associated with a higher risk of developing extracranial complications with an adjusted odds ratio of 4.3 (95% CI: 1.2–16.4) and an adjusted *P* value of 0.025. After adjustment for the confounders, the differences in ICU and hospital length of stay between the two study groups were no longer significant.

Discussion

Severe traumatic brain injury remains a leading cause of mortality and disability among injured children. To minimize mortality and disability, strategies aimed at limiting secondary brain injury have evolved over the years. The Brain Trauma Foundation guide-

TABLE 5. *Adjusted Outcomes (ICP vs NonICP)*

Dichotomous Outcomes	Adjusted Odds Ratio (95% CI)	Adjusted *P* Value	
Survival	1.1 (0.3, 4.1)	*0.85*	
Any Complication	4.3 (1.2, 16.4)	*0.025*	
Continuous Outcomes	**Adjusted Mean Difference (95% CI)**	**Adjusted *P* Value**	**Nonparametric *P* Value**
ICU days	−5.2 (−11.5; 1.1)	*0.10*	*0.15*
Hospital days	−7.4 (−15.7; 0.8)	*0.07*	*0.09*
Hospital days (excluding deaths)	−8.5 (−19.2; 2.1)	*0.11*	*0.17*
Hospital charges	107,175 (44,306; 170,045)	*0.001*	*0.002*

Multivariable analysis adjusting for head AIS, Injury Severity Score, admission diastolic blood pressure and respiratory rate, central line, pulmonary artery catheter, and ventilatory support.

lines include the use of ICP monitoring as one of the adjuncts to the management of patients with severe brain injury and the recommendation for its use is based on the best evidence presently available.[2] The efficacy of ICP monitoring in terms of outcomes improvement, however, has not been validated.

Since Marshall et al.[3] first described outcomes in a large group of patients with severe TBI managed with ICP monitoring, their data have been used as a benchmark. Mortality in these patients was 36 per cent with only 7 per cent having a good outcome at hospital discharge. Elevated ICP has been associated with poor outcomes in severe TBI, therefore interventions aimed at lowering ICP or maintaining cerebral perfusion pressure (CPP) have become the mainstay of therapy for TBI. Rosner et al.[4] used a protocol designed to maintain CPP greater than 70 mm Hg and reported mortality of 29 per cent and a Glasgow Outcome Score of 4 or 5, indicating a good recovery or moderate disability in 59 per cent of patients. Stocchetti et al.[5] used a regimen designed to keep ICP less than 20 to 25 mm Hg. They reported mortality of 13.7 per cent and good recovery or moderate disability in 59.4 per cent. Both of these strategies require monitoring of ICP and interventions based on this measurement. Data are less abundant in the pediatric population but Kumar et al.[6] had 35 per cent mortality and 51 per cent of patients with a good recovery or moderate disability in a group of children managed with a goal of keeping ICP less than 20 mm Hg. They also found that patients with a GCS of 3 or 4 who were managed aggressively with ICP monitors had a mortality of 44 per cent compared with a mortality of 80 per cent in patients managed conservatively. Kasoff et al.[7] reported slightly better results. A mortality of 20 per cent was attained in 25 children with severe head trauma that they managed with ICP monitors and invasive hemodynamic monitoring. These studies provide some of the evidence available for the management of pediatric patients with severe TBI and suggest that aggressive management with the use of ICP monitoring may result in improved outcomes. In contrast to these reports, in our patients managed with ICP monitors, mortality was 28 per cent, with 59 per cent of patients determined to have temporary disability or to be at their preinjury level of functioning at discharge; but these figures were not significantly different from the 35 per cent mortality and 53 per cent temporary disability or return to preinjury function observed in the group of patients managed without an ICP monitor. Shafi et al.[8] analyzed the association between the use of ICP monitors and survival in the adult population using the National Trauma Data Bank of the American College of Surgeons (1994–2001) and found that the use of ICP monitors was associated with worsening of survival in traumatic brain injury patients that fulfilled the Brain Trauma Foundation criteria for ICP monitor placement. In the present study, the use of an ICP monitor provided no survival benefit and was associated with an increased risk for the development of extracranial complications. Patients in the ICP group were 4.3 times more likely to develop these complications compared with the patients that did not undergo ICP monitoring.

The use of ICP monitors as part of the management of pediatric patients with severe TBI varies widely. In our study only 25 per cent of patients were managed with ICP monitors. ICP monitoring is used in anywhere from 19 to 68 per cent of pediatric patients with severe TBI.[9–12] Bulger et al.[13] compared 11 centers that aggressively managed patients with TBI, including ICP monitoring, with 20 centers that did not and found mortality was 27 per cent in the former compared with 45 per cent in the latter.

The perception that using ICP monitors prolongs hospital stays was not confirmed by the present study. The hospital stay and ICU stay seen for patients managed with ICP monitors were not significantly different from those in the nonICP group after adjustment for confounding factors. This suggests that the duration of hospital and ICU stay was mostly associated with the severity of injury and not the ICP monitor utilization itself. On the other hand, the higher hospital charges identified for patients undergoing ICP moni-

toring remained statistically significant after adjustment for the differences between the two study groups. Patients with an ICP monitor had hospital charges that were on average $107,175 more expensive after adjustment.

This study has several limitations that need to be pointed out. Due to the retrospective nature of the study, we were unable to assess the reasons patients were or were not monitored. Although we have protocols in place regarding ICP management, the exact ICP guided intervention for each patient was not recorded. Variables such as fluid requirement, use of pressors, sedative agents used, and response to ICP lowering measures were not captured. We also did not have long-term functional outcome. Without this data, our conclusions are unfortunately limited. Unmeasured variables associated with the ICP monitor utilization, which were not controlled for on the multivariable analysis performed, may be the reason why a survival benefit with the use of ICP monitors was not identified and may also explain the increased rate of extracranial complications associated with the use of ICP monitors.

In conclusion, the use of ICP monitors in pediatric patients with severe isolated head injury provided no survival benefit and was associated with an increased risk of extracranial complications. The use of ICP monitoring and directed therapy in pediatric patients with severe traumatic brain injury warrants further investigation in a prospective randomized controlled trial to identify its role in outcome improvement.

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