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Original Article

Intracranial pressure monitoring for severe traumatic brain injury: A retrospective study of 273 consecutive patients

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ABSTRACT

Background: Intracranial pressure (ICP) monitoring is essential in severe traumatic brain injury (sTBI) cases; yet, the frequency of high ICP occurrences remains debated. This study presents a 9-year analysis of ICP monitoring using intraventricular catheters among sTBI patients.

Methods: A retrospective review of 1760 sTBI patients (Glasgow Coma Score <9) admitted between January 2011 and December 2019 was conducted. Of these, 280 patients meeting monitoring criteria were included based on Brain Trauma Foundation (BTF) Guidelines. ICP was monitored using intraventricular catheters through right frontal burr holes. Initial ICP readings were recorded intraoperatively, followed by continuous monitoring. Patients with ICP >20 mmHg for 10–15 min during 72 h were categorized with high ICP. Data collected included demographics, computed tomography (CT) findings, intra- and post-operative ICP, and complications.

Results: Of 273 patients, 228 were male and 45 females, aged 18–80 (71.30% aged 18–45). Traffic accidents were the primary cause (90.48%). Fifty-two-point seventy-five percent experienced high ICP, correlating significantly with subdural hematoma ($P < 0.001$), intraventricular hemorrhage ($P < 0.013$), and compressed basal cisterns ($P = 0.046$) on initial CT. Twenty patients (7.3%) developed meningitis. Lower mortality rates and improved outcomes were observed in the low ICP group across discharge 3-and 6-month follow-ups.

Conclusion: Adherence to BTF guidelines yielded a 52.75% high ICP rate. Significant correlations were found between high ICP and specific CT abnormalities. This study underscores the benefits of ICP monitoring in selected sTBI cases, suggesting a need to review criteria for initiating monitoring protocols.

Keywords: Functional outcome, Intracranial pressure monitoring, Severe traumatic brain injury

INTRODUCTION

Traumatic brain injury (TBI) is one of the leading causes of death and severe disability globally, especially in most developing countries. Morbidity and mortality remain high even considering the major improvements in medical, surgical, and intensive care in the last couple of decades. Improved intensive care and several monitoring techniques among patients with severe TBI (sTBI) may prolong life and decrease mortality rates, but long-term morbidity and functional

outcome have remained questionable.[11,14,15] Intracranial pressure (ICP) monitoring has become a standard of care for managing sTBI in many developed countries.[1,12] Brain Trauma Foundation (BTF) guidelines for managing sTBI, 4th edition (BTF guidelines 2016) recommended ICP monitoring among all salvageable patients with sTBI harboring abnormal computed tomography (CT) findings. ICP monitoring is thought to constitute an essential tool in managing sTBI for guiding ICP management to prevent secondary brain injury and early detecting secondary intracranial expanding lesions.[14] Many earlier studies reported the benefits of the procedure, but a solid indication for ICP monitoring remains unavailable and needs more extensive studies to produce conclusive evidence.[4,11] Current indications recommended BTF guidelines resulting in low yields of detected high ICP, meaning some patients in this group do not need ICP monitoring. Moreover, the adherence rate, according to the guideline, was approximately 11.5–46.4%.[7,9] In this study, we aim to enhance the clarity and focus of our research questions concerning the indication for ICP monitoring in patients with sTBI. By aligning our research questions with the BTF guidelines and addressing the controversies surrounding ICP monitoring outcomes, we seek to provide valuable insights into identifying the most appropriate situations for ICP monitoring in sTBI patients. Specifically, we will investigate the relationship between each type of initial abnormal CT findings and ICP to refine the criteria for ICP monitoring in line with the recommended guidelines.

MATERIALS AND METHODS

The Ethics Committee approved our study in our institute before data collection, and informed consent was waived as a retrospective design (IRB225/2014). We retrospectively studied patients with sTBI admitted to our hospital between January 2011 and December 2019. Our inclusion criteria comprised patients with sTBI (Glasgow coma scale [GCS] <9) exhibiting abnormal CT findings and lacking indications for emergency hematoma evacuation surgery. Patients with multiple injuries, loss of follow-up, or insufficient medical records during the follow-up period were excluded from the study.

After cranial CT scanning verified the indication for ICP monitoring, all patients were operated on for a ventricular catheter insertion through the right frontal burr hole. The ICP was recorded at the intraoperative period and continuously monitored for 48–72 hours postoperation. Patients having ICP >20 mmHg for 10–15 min during monitoring were grouped as the high ICP group and the rest were grouped as the low ICP group. Patient's demographic data, GCS, and ICP parameters were recorded at the first insertion of external ventricular drainage (EVD) and were continuously monitored for 48–72 h. During the postoperation period, Glasgow outcome scale (GOS) and complications were recorded at discharge and 3 and 6 months after discharge. All intracranial lesions were calculated in volume using the modified ellipsoid method.

RESULTS

One thousand seven hundred and sixty patients with sTBI were admitted to our hospital between January 2011 and December 2019. Exactly 1224 patients harboring intracranial lesions, indicating emergency surgical evacuation, were excluded from the study.

All totaled, 536 patients presented salvageable sTBI (GCS <9) with abnormal CT findings on admission and age ≥18 years old. Of those recommended by BTF guidelines for ICP monitoring, 276 patients proceeded to ICP monitoring, and the remaining 260 were managed without ICP monitoring, affirmed by the attending neurosurgeon's opinion, surgical procedure refused by the patient's relatives or the patients who die in the emergency department. Three patients failed ICP measurement after surgery.

Among 273 patients with TBI, 228 (83.5%) were male and 45 (16.5%) were female. Age ranged from 18 to 80 years old. In all, 71.3% of patients were 18–45 years old. The most common cause of injury was traffic accidents (90.48%), while falling and assault were minor causes, as shown in Table 1. The demographics appearing between high and low ICP did not differ significantly, as shown in Table 2.

In total, 144 (52.75%) patients experienced high ICP (>20 mmHg) for 10 ~ 15 min during ICP monitoring, and 129 (47.25%) patients never had high ICP during the monitoring period. No statistically significant demographics differed between the two groups, as shown in Table 2.

Present of subdural hemorrhage (SDH), intraventricular hemorrhage (IVH), and compressed basal cisterns on cranial CT on admission were significantly related to high ICP during admission ($P < 0.001$, $P < 0.013$, and $P < 0.046$, respectively), as shown in Table 3.

Among the intracranial lesions found on the initial cranial CT scan, intraparenchymal lesions, including cerebral contusion and intracerebral hematoma size of >5 mL, compared with volume <5 mL, were significantly related to high ICP ($P < 0.012$ and $P < 0.001$, respectively) while size of other lesions was not significantly related to high intracranial pressure, as shown in Table 4.

Overall, the mortality rate was 8.06% at discharge and 8.42% at 3 and 6 months after discharge. About 47.25% had poor outcomes (vegetative state and severe disability) at discharge and decreased to 26.38% and 22.72% at 3 and 6 months after

Table 1: Demographic data.

Parameters	*n*=273
Gender, *n* (%)	
Male	228 (83.52)
Female	45 (16.48)
Age, *n* (%)	
18–30 years	156 (51.15)
31–45 years	55 (20.15)
46–60 years	43 (15.75)
>60 years	19 (6.96)
Mechanism, *n* (%)	
Traffic accident	247 (90.48)
Falling	13 (4.76)
Assault	13 (4.76)
Admit Glasgow coma score, *n* (%)	
3	7 (2.56)
4	20 (7.33)
5	14 (5.13)
6	55 (20.15)
7	143 (52.38)
8	34 (12.45)
Ventriculostomy (day)	
Mean (SD)	3.30 (2.74)
Median	3
Length of hospital stay (day)	
Mean (SD)	18.33 (21.67)
Median	13

SD: Standard deviation

Table 2: Comparison of patients' characteristics of low and high ICP.

Parameters	ICP (mmHg)		*P*-value
	≤20 (mmHg) (*n*=129)	>20 (mmHg) (*n*=144)	
Gender, *n* (%)			
Male	114 (88.37)	114 (79.17)	0.050
Female	15 (11.63)	30 (20.83)	
Age, *n* (%)			
≤15 years	5 (3.88)	7 (4.86)	0.411
16–30 years	64 (49.61)	80 (55.56)	
31–45 years	32 (24.81)	23 (15.97)	
46–60 years	18 (13.95)	25 (17.36)	
>60 years	10 (7.75)	9 (6.25)	
Mechanism, *n* (%)			
Traffic accident	122 (94.57)	125 (86.81)	0.097
Falling	4 (3.10)	9 (6.25)	
Assault	3 (2.33)	10 (6.94)	
Admit Glasgow coma scale, *n* (%)			
3	4 (3.10)	3 (2.08)	0.539
4	10 (7.75)	10 (6.94)	
5	4 (3.10)	10 (6.94)	
6	29 (22.48)	26 (18.06)	
7	69 (53.49)	74 (51.39)	
8	13 (10.08)	21 (14.58)	
Ventriculostomy (day)			
Mean (SD)	3.23 (2.56)	3.37 (2.90)	0.673
Median	3	3	
Length of stay (day)			
Mean (SD)	16.67 (18.79)	19.82 (23.93)	0.231
Median	13	14	

ICP: Intracranial pressure, SD: Standard deviation

discharge, while 44.69% had good outcomes (Good recovery and moderate disability) at discharge and increased to 65.20% and 68.87% at 3 and 6 months after discharge. Meningitis is the only procedural-related complication found in 7.33%, as shown in Table 5.

The mortality rate was significantly high in the high intracranial pressure group ($P < 0.001$), while meningitis was not significantly different between the two groups. GOS at discharge, 3 and 6 months were all significantly better in the low intracranial pressure group ($P < 0.001$), as shown in Table 6.

DISCUSSION

This study examined the role of ICP monitoring in sTBI according to BTF recommendations.[3] In total, 52.75% of patients experienced high ICP (>20 mmHg) for at least 10–15 min. The presence of SDH, IVH, and compressed basal cisterns on cranial CT on admission was significantly related to high ICP during admission. Among the intracranial lesions found on the initial cranial CT scan, intraparenchymal lesions, including cerebral contusion and intracerebral hematoma >5 mL, were significantly related to experiencing high ICP. The mortality rate was significantly high in the high ICP group, while meningitis did not significantly differ between the two groups. GOS at discharge, 3 and 6 months, was all significantly better in the low ICP group.

The principal management of TBI is to avoid intracranial hypertension to maintain cerebral perfusion pressure and minimal secondary brain injury. This is important to maintain ICP <20 mmHg for the management strategy of sTBI. The current trend in ICP monitoring, as recommended by the BTF, suggests that ICP should be monitored in all cases of severe TBI with abnormal CT findings, such as hematoma, contusion, swelling, brain herniation, or cistern compression. It also advises considering ICP monitoring in cases where the CT scan is negative but meets two or more of the following criteria: age over 40 years, unilateral or bilateral motor posturing, or systolic blood pressure below 90 mmHg.[3] Despite the guideline recommendations, the ICP monitor among patients with sTBI meeting the criteria exhibited low compliance rates, 11.5–46.4% suspected

Table 3: Specific intracranial lesions and ICP.

Primary lesion	ICP (mmHg)		*P*-value	Total (cases)
	≤20 (mmHg) (*n*=129)	>20 (mmHg) (*n*=144)		
EDH, *n* (%)				
Yes	19 (14.73)	23 (15.97)	0.867	42 (15.38)
No	110 (85.27)	121 (84.03)		231 (84.62)
SDH, *n* (%)				
Yes	37 (28.68)	73 (50.69)	<0.001	110 (40.29)
No	92 (71.32)	71 (49.31)		163 (59.71)
SAH, *n* (%)				
Yes	69 (53.49)	65 (45.14)	0.183	134 (49.08)
No	60 (46.51)	79 (54.86)		139 (50.92)
Contusion, *n* (%)				
Yes	45 (34.88)	67 (46.53)	0.064	112 (41.03)
No	84 (65.12)	77 (53.47)		161 (58.97)
ICH, *n* (%)				
Yes	22 (17.05)	31 (21.53)	0.363	53 (19.41)
No	107 (82.95)	113 (78.47)		220 (80.59)
IVH, *n* (%)				
Yes	8 (6.20)	23 (15.97)	0.013	31 (11.36)
No	121 (93.80)	121 (84.03)		244 (88.64)
Isolate brain swelling, *n* (%)				
Yes	1 (0.78)	4 (2.78)	0.374	5 (1.83)
No	128 (99.22)	140 (97.22)		268 (98.17)
Compressed basal cisterns, *n* (%)				
Yes	18 (13.95)	34 (23.61)	0.046	52 (19.05)
No	111 (86.05)	110 (76.39)		221 (80.95)

EDH: Epidural hemorrhage, ICH: Intracerebral hemorrhage, IVH: Intraventricular hemorrhage, SAH: Subarachnoid hemorrhage, SDH: Subdural hemorrhage, ICP: Intracranial pressure

Table 4: Size of intracranial lesion and ICP.

Lesion	ICP (mmHg)		Total	*P*-value
	≤20 (mmHg)	>20 (mmHg)		
Size of contusion (*n*=112)				
≤5 (mL)	30 (66.67)	28 (41.79)	58 (51.79)	**0.012**
>5 (mL)	15 (33.33)	39 (58.21)	54 (48.21)	
Size of ICH (*n*=53)				
≤5 (mL)	19 (86.36)	11 (35.48)	30 (56.60)	**<0.001**
>5 (mL)	3 (13.64)	20 (64.52)	23 (43.40)	
Size of SDH (*n*=110)				
≤5 (mm)	15 (40.54)	25 (34.25)	40 (36.36)	0.536
>5 (mm)	22 (59.46)	48 (65.75)	70 (63.64)	
Size of EDH (*n*=42)				
≤5 (mm)	8 (42.11)	3 (23.08)	13 (30.95)	0.192
>5 (mm)	11 (57.89)	18 (78.26)	29 (69.05)	

EDH: Epidural hemorrhage, ICH: Intracerebral hemorrhage, SAH: Subarachnoid hemorrhage, SDH: Subdural hemorrhage, ICP: Intracranial pressure, Bold value (P-value<0.05) consider statistically significant

from controversies involving limited resources and clinical benefits.[2,9] Many studies showed that ICP monitoring for TBI decreased mortality.[5,16] However, some studies reported that ICP monitoring in sTBI was associated with increased mortality rate and length of stay.[9,13] In 2012, Chesnut *et al.* published a trial of ICP monitoring in TBI comprising a multicenter randomized trial that showed no clinical benefits (mortality rate, survival time, 6-month functional, and neuropsychological status) of ICP monitoring compared with imaging and clinical examination.[4]

The two different types of ICP monitoring in TBI included intraventricular and intraparenchymal, with their benefits and drawbacks.[8] Aiolfi *et al.* compare the outcomes between intraventricular and intraparenchymal devices among patients with sTBI. The study demonstrated that the type of ICP monitoring device did not affect mortality, systemic complications, or functional outcomes.[1] Our center considers intraventricular ICP due to its cost-effectiveness and ability to release cerebrospinal fluid to treat intracranial hypertension. However, in some cases, due to high increased ICP with slit ventricle and brain herniation, intraventricular ICP monitoring is technically difficult to perform. The most common intraventricular ICP monitoring with EVD is infection associated with increased mortality, morbidity, and length of stay.[10] The rate of infection, according to the literature, is between 7.3% and 10.4%.[6] Our study showed an

Table 5: Overall outcome and complication.

Parameters	*n*=273
GOS at discharge, *n* (%)	
Death	22 (8.06)
Vegetative	35 (12.82)
Severe disability	94 (34.43)
Moderate disability	60 (21.98)
Good recovery	62 (22.71)
GOS at 3-month, *n* (%)	
Death	23 (8.42)
Vegetative	14 (5.13)
Severe disability	58 (21.25)
Moderate disability	35 (12.82)
Good recovery	143 (52.38)
GOS at 6-month, *n* (%)	
Death	23 (8.42)
Vegetative	12 (4.40)
Severe disability	50 (18.32)
Moderate disability	28 (10.26)
Good recovery	160 (58.61)
Death, *n* (%)	
Yes	22 (8.06)
No	251 (91.94)
Meningitis, *n* (%)	
Yes	20 (7.33)
No	253 (92.67)

GOS: Glasgow outcome scale

Table 6: Clinical outcomes between low and high ICP.

Parameters	ICP (mmHg)		*P*-value
	≤20 (mmHg) (*n*=129)	>20 (mmHg) (*n*=144)	
Meningitis, *n* (%)			
Yes	5 (3.88)	15 (10.42)	0.060
No	124 (96.12)	129 (89.58)	
Meningitis day, *n* (%)			
≤5 days	3 (60.00)	6 (40.00)	0.617
>5 days	2 (40.00)	9 (60.00)	
Death, *n* (%)			
Yes	2 (1.55)	20 (13.89)	<0.001
No	127 (98.45)	124 (86.11)	
GOS at discharge, *n* (%)			
Death	2 (1.55)	20 (13.89)	<0.001
Vegetative	14 (10.85)	21 (14.58)	
Severe disability	43 (33.33)	51 (35.42)	
Moderate disability	33 (25.58)	27 (18.75)	
Good recovery	37 (28.68)	25 (17.36)	
GOS at 3-month, *n* (%)			
Death	2 (1.55)	21 (14.58)	<0.001
Vegetative	4 (3.10)	10 (6.94)	
Severe disability	26 (20.16)	32 (22.22)	
Moderate disability	14 (10.85)	21 (14.58)	
Good recovery	83 (63.34)	60 (41.67)	
GOS at 6-month, *n* (%)			
Death	2 (1.55)	21 (14.58)	<0.001
Vegetative	4 (3.10)	8 (5.56)	
Severe disability	21 (16.28)	29 (20.14)	
Moderate disability	12 (9.30)	16 (11.11)	
Good recovery	90 (69.77)	70 (48.61)	

GOS: Glasgow outcome scale, ICP: Intracranial pressure

overall infection rate of 7.3%, with 3.9 and 10.4% in the low and high ICP groups, respectively.

Due to different study designs, low rate of ICP monitoring, different types of ICP monitoring, and various management practices, that is, increased ICP protocol and limited randomized trials, the result of ICP monitoring with the clinical benefit in sTBI remains difficult to conclude. Our study confirms that increased ICP (ICP >20 mmHg) was associated with high mortality and poor outcome among patients with sTBI. However, the rate of patients with high ICP was only 50% in our study, following BTF guidelines. Abnormal CT findings on admissions, including SDH, IVH, and compressed basal cistern, were significantly associated with high ICP. These findings should inform guideline modifications to enable more precise patient selection for ICP monitoring, leading to cost-effective benefits and reduced complication rates from unnecessary monitoring. Therefore, further studies are warranted to assess the long-term and cost-effective benefits of these modifications.

Our study encountered limitations due to the retrospective study nature and prospective design using a single institute. In addition, our center monitored only ICP with an intraventricular catheter. Other intracranial monitoring techniques such as brain tissue oxygenation or jugular bulb oxygen saturation, may provide more details affecting treatment outcome.

CONCLUSION

ICP monitoring in TBI remains beneficial for selected patients in reducing mortality and improving functional outcomes. However, the current yield of high ICP following BTF guidelines for monitoring is relatively low (52.75%). Modifications are needed to identify more specific candidates, particularly those with subdural hematoma, IVH, and compressed basal cisterns, which were significantly associated with high ICP. Future studies must provide clear conclusions about the current state of ICP monitoring in alignment with BTF guidelines, emphasizing both its limitations and potential benefits for patient management.

Ethical approval

The Ethics Committee approved our study in our institute before data collection, (IRB225/2014).

Declaration of patient consent

Patient's consent was not required as there are no patients in this study.

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Nil.

Conflicts of interest

There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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