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Research Article

ONSD Ultrasound for Rapid Triage and Severity Grading in Traumatic Brain Injury

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Abstract: ***Introduction****:* Traumatic brain injury is a significant cause of death and illness in neurocritically ill patients. An early diagnosis of raised ICP and accurate severity grading is necessary for timely neuroprotection. The ultrasound of the optic nerve sheath diameter (ONSD) at the bedside or ONSD ultrasound is a rapid, non-invasive method for assessing intracranial compliance.**Methods:** A prospective observational study was conducted over a 6-month period in the ESIC Medical College, Kalaburagi. A total of 35 adult TBI patients were evaluated upon admission. Point-of-care ultrasound (POCUS) using a 7–13 MHz high-frequency linear transducer was performed to measure ONSD 3 mm posterior to the globe. ONSD values were correlated with admission Glasgow Coma Scale (GCS) severity grading and computed tomography (CT) findings of raised ICP.**Results**: Among the 35 patients, 12 had mild TBI (GCS 13–15), 13 had moderate TBI (GCS 9–12), and 10 had severe TBI (GCS 3–8). Mean ONSD increased progressively with clinical severity: 4.62 ± 0.38 mm in mild TBI, 5.38 ± 0.42 mm in moderate TBI, and 6.15 ± 0.48 mm in severe TBI (ANOVA $p < 0.001$). Patients with radiological or invasive evidence of raised ICP (n = 15) exhibited significantly larger ONSD compared to those with normal ICP (6.08 ± 0.41 mm vs. 4.71 ± 0.35 mm, $p < 0.001$). Receiver operating characteristic (ROC) analysis demonstrated that an ONSD threshold of ≥ 5.70 mm predicted raised ICP with a sensitivity of 86.7%, specificity of 90.0%, and an area under the curve (AUC) of 0.93.**Conclusion:** Point-of-care ONSD ultrasound is a reliable, rapid, and non-invasive triage tool that strongly correlates with clinical TBI severity and effectively identifies intracranial hypertension. Routine integration of ONSD measurement into emergency neurotrauma protocols is highly recommended.

Keywords: Traumatic Brain Injury; Optic Nerve Sheath Diameter; Point-of-Care Ultrasound; Intracranial Pressure; Glasgow Coma Scale.

INTRODUCTION

Traumatic brain injury or TBI has been characterized as a public health issues of great concern and is a leading cause of death and long-term disability worldwide, particularly in young adults and traumatized patients [1,2]. In neurotrauma, the secondary brain injury caused by cerebral edema and leading to an increase in intracranial pressure (ICP) is the main cause of adverse clinical outcomes [2,3]. Recognizing and treating intracranial hypertension in a timely manner (defined as ICP > 20 mmHg in general) can prevent cerebral hypoperfusion, brainstem compression, and ultimately irreversible cerebral ischemia [3, 4].At present, invasive intracranial pressure monitoring through an intraventricular catheter or an intraparenchymal sensor remains the clinical gold standard to quantify ICP [3,4]. Despite the aforementioned, one must note that in resource-limited emergency room settings, invasive monitoring often becomes restricted, carries a risk of hemorrhage and central nervous system infection, and requires neurosurgical expertise that may cause delay in diagnosis [4,5]. Brain aNCCT is the established procedure for neuro-imaging triage, however, transferring unstable mechanically ventilated TBI patients to the CT suite has significant logistical and clinical disadvantages. ANCCT signs of raised ICP in patients include basal cistern compression, midline shift, and sulcal effacement which are often late findings in the pathophysiological cascade [5,6].As the three meningeal layers (dura, arachnoid, and pia mater) surround the optic nerve's intraorbital segment, its subarachnoid space is directly continuous with the subarachnoid compartment intrusion [6,7]. An immediate increase in intracranial cerebrospinal fluid (CSF) pressure is transmitted along this channel and results within minutes in measurable distention of the optic nerve sheath [7,8].The measurement of optic nerve sheath diameter (ONSD) using point-of-care ultrasound (POCUS) has become an accessible, rapid and non-invasive bedside technique to estimate intracranial compliance [7,8].

International studies have looked at ONSD in heterogeneous critical care populations. However, aside from a few existing ones, little empirical documentation has prospectively validated cross-linked serial POCUS ONSD thresholds with standardized clinical severity grading in regional Indian tertiary emergency settings [6, 8]. Hence this study aimed to evaluate the diagnostic accuracy and clinical utility of bedside ONSD ultrasonography for rapid triaging, severity grading and diagnosis of intracranial hypertension in acute traumatic brain injury patients presenting to ESIC Medical College, Kalaburagi.

MATERIALS AND METHODS

Study Design and Setting

This prospective observational study was conducted over a 6-month period in the ESIC Medical College, Kalaburagi. The institutional research and ethics committee approved the study protocol, and written informed consent was obtained from the patients or their legally authorized representatives prior to enrollment.

Patient Selection and Eligibility Criteria

A total of N = 35 adult patients (aged ≥ 18 years) presenting with acute traumatic brain injury within 12 hours of trauma were enrolled sequentially upon arrival.

Inclusion Criteria: Patients aged 18 to 65 years with acute closed head injury confirmed by clinical examination and scheduled for emergency brain CT imaging.

Exclusion Criteria: Patients with penetrating ocular trauma, open globe injuries, severe orbital fractures, preexisting glaucoma, cataract or optic nerve pathology, history of neurosurgical intervention, or hemodynamic instability requiring immediate operating room transfer prior to baseline ultrasound assessment.

Ultrasound ONSD Measurement Protocol

Bedside ocular ultrasonography was performed by trained emergency medical physicians and radiologists blinded to the patient's CT brain reports and invasive ICP readings. Scans were executed within 30 minutes of emergency department admission using a high-resolution color Doppler ultrasound system equipped with a 7–13 MHz linear-array transducer.

With the patient in a supine position and the head elevated at 20–30 degrees (when cervical spine injury was ruled out or stabilized), a thick layer of acoustic coupling gel was applied over the closed upper eyelids. The transducer was applied gently over the lateral aspect of the upper eyelid without exerting mechanical pressure on the globe, avoiding vagal stimulation or artificial IOP elevation [6, 7]. The optic nerve was visualized as a hypoechoic linear structure extending posteriorly from the hyperechoic globe.

In accordance with standardized international neurosonology protocols, an electronic caliper was placed along the axis of the optic nerve to mark a point exactly 3 mm posterior to the retinal disc surface [7, 8]. At this depth—where anatomical elasticity is maximum—the transverse diameter of the optic nerve sheath was measured from the outer hyperechoic dural border on one side to the outer border on the contralateral side. For each eye, two measurements in the transverse and sagittal planes were captured, and the average of all four readings (both eyes) was recorded as the mean ONSD in millimeters (mm).

Clinical Severity Grading and ICP Assessment

Clinical severity was stratified upon admission using the post-resuscitation Glasgow Coma Scale (GCS) score: Mild TBI (GCS 13–15), Moderate TBI (GCS 9–12), and Severe TBI (GCS 3–8). Concurrently, raised intracranial pressure was identified based on invasive ICP monitoring (when clinically indicated and placed in severe TBI, defined as sustained ICP ≥ 20 mmHg) or unequivocal CT radiological criteria (midline shift > 5 mm, compression or obliteration of the third ventricle and basal cisterns, or significant mass effect from intracranial hematoma) [4, 5].

Statistical Analysis

All statistical computations were performed using standard statistical software. Continuous data with normal distribution were presented as mean ± standard deviation (SD). Comparisons of continuous variables across the three GCS severity groups were analyzed using one-way analysis of variance (ANOVA) followed by Tukey's post-hoc test. An independent two-tailed t-test was utilized to compare ONSD values between patients with and without raised ICP. Receiver operating characteristic (ROC) curves were constructed to determine the optimal ONSD cutoff threshold, sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and area under the curve (AUC). A p-value < 0.05 was considered statistically significant.

RESULTS

Over the 6-month study duration at ESIC Medical College Kalaburagi, 35 adult TBI patients meeting the inclusion criteria completed the ultrasound and neuroimaging protocol. The cohort comprised 25 males (71.4%) and 10 females (28.6%), with a mean age of 38.4 ± 12.6 years. Road traffic accidents accounted for the majority of injuries (68.6%), followed by falls from height (20.0%) and assault (11.4%). Based on admission GCS severity grading, 12 patients (34.3%) presented with mild TBI, 13 patients (37.1%) with moderate TBI, and 10 patients (28.6%) with severe TBI (Table 1).

Table 1: Baseline Demographic and Clinical Characteristics by TBI Severity

Clinical / Demographic Variable	Mild TBI (n=12)	Moderate TBI (n=13)	Severe TBI (n=10)	Total Cohort (N=35)
Age (years), Mean ± SD	36.2 ± 11.4	39.5 ± 13.1	39.8 ± 13.8	38.4 ± 12.6
Male Sex, n (%)	8 (66.7%)	9 (69.2%)	8 (80.0%)	25 (71.4%)
Mechanism of Injury, n (%)				
Road Traffic Accident	7 (58.3%)	9 (69.2%)	8 (80.0%)	24 (68.6%)
Fall from Height	3 (25.0%)	3 (23.1%)	1 (10.0%)	7 (20.0%)
Assault / Blunt Trauma	2 (16.7%)	1 (7.7%)	1 (10.0%)	4 (11.4%)
Admission GCS Score, Mean ± SD	14.2 ± 0.8	10.6 ± 1.1	5.4 ± 1.6	10.3 ± 3.8
CT Evidence of Raised ICP, n (%)	1 (8.3%)	5 (38.5%)	9 (90.0%)	15 (42.9%)
Neurosurgical Intervention Required, n (%)	0 (0.0%)	3 (23.1%)	7 (70.0%)	10 (28.6%)

Point-of-care ultrasound measurements demonstrated a statistically significant progressive expansion of the optic nerve sheath diameter that mirrored clinical TBI severity (Table 2). The mean ONSD across the entire cohort was 5.34 ± 0.76 mm. Patients presenting with mild TBI exhibited a normal mean ONSD of 4.62 ± 0.38 mm. In contrast, patients with moderate TBI showed moderate sheath expansion with a mean ONSD of 5.38 ± 0.42 mm, while those with severe TBI manifested marked expansion with a mean ONSD of 6.15 ± 0.48 mm.

One-way ANOVA confirmed a highly significant intergroup variance across GCS severity classifications ($F = 38.6$, $p < 0.001$). Post-hoc pairwise comparisons revealed that severe TBI patients had significantly larger ONSD than both moderate ($p < 0.001$) and mild TBI cohorts ($p < 0.001$), establishing ONSD as a reliable anatomical biomarker for injury severity.

Table 2: Optic Nerve Sheath Diameter Across TBI Severity Groups

TBI Severity Group	GCS Range	No. of Patients (n)	Mean ONSD ± SD (mm)	95% Confidence Interval	ANOVA p-value
Mild TBI	13–15	12	4.62 ± 0.38	4.38 to 4.86	**< 0.001**
Moderate TBI	9–12	13	5.38 ± 0.42	5.13 to 5.63	**< 0.001**
Severe TBI	3–8	10	6.15 ± 0.48	5.81 to 6.49	**< 0.001**
Total Cohort	3–15	35	5.34 ± 0.76	5.08 to 5.60	N/A

Of the 35 patients evaluated, 15 patients (42.9%) were diagnosed with elevated intracranial pressure based on neuroimaging criteria or invasive monitoring. The mean ONSD in the raised ICP subgroup was dramatically elevated compared to the normal ICP subgroup (6.08 ± 0.41 mm vs. 4.71 ± 0.35 mm, $p < 0.001$).Receiver operating characteristic (ROC) curve analysis was performed to determine the diagnostic accuracy of bedside ONSD for detecting intracranial hypertension (Table 3). An optimal cutoff threshold of ONSD ≥ 5.70 mm yielded an outstanding discriminatory performance with an area under the curve (AUC) of 0.93 (95% CI: 0.85–0.99). At this threshold, bedside ultrasound identified raised ICP with a sensitivity of 86.7%, specificity of 90.0%, positive predictive value (PPV) of 86.7%, and negative predictive value (NPV) of 90.0%, confirming its robust triage capability.

Table 3: Diagnostic Performance of Bedside ONSD for Detecting Raised Intracranial Pressure

Diagnostic Statistic	Calculated Value	95% Confidence Interval
Optimal ONSD Cutoff Threshold	≥ 5.70 mm	N/A
Area Under ROC Curve (AUC)	0.93	0.85 to 0.99
Sensitivity (%)	**86.7%**	61.3% to 97.8%
Specificity (%)	**90.0%**	69.9% to 98.2%
Positive Predictive Value (PPV, %)	**86.7%**	61.3% to 97.8%
Negative Predictive Value (NPV, %)	**90.0%**	69.9% to 98.2%
Overall Diagnostic Accuracy (%)	88.6%	73.3% to 96.8%

DISCUSSION

The prospective clinical study done at ESIC Medical College Kalaburagi demonstrates that the point-of-care ultrasound measurement of optic nerve sheath diameter is a remarkably reliable, rapid, and non-invasive adjunct for emergency triage and severity grading in acute traumatic brain injury. Our study shows that GCS score has strong negative correlation with ONSD expansion. The mean ONSD increased significantly from mild 4.62 ± 0.38 mm to moderate 5.38 ± 0.42 mm and severe TBI groups with 6.15 ± 0.48 mm [6, 8]. In addition, the authors' ONSD threshold of ≥ 5.70 mm had 86.7% sensitivity and 90.0% specificity (AUC = 0.93) for detecting intracranial hypertension.

Our observations are consistent with literature on neurotrauma. The optic nerve was the focus of early seminal studies by Soldatos et al. [1] and Geeraerts et al. [2], which first demonstrated the high diagnostic accuracy of sonography to monitor ICP changes. Robba et al. [3] performed a large-scale meta-analysis involving 38 studies with over 1,900 critical care patients. In this study, the pooled sensitivity and specificity of sonographic ONSD for detecting intracranial hypertension were around 90% and 85%, respectively, which is encompassed in our reported AUC performance. Koziarz et al. [4] also confirmed in a systematic review that ocular ultrasonography at the bedside is a useful emergency room triage tool when invasive ventriculostomy is not yet possible or is delayed. Recent prospective cohort data corroborated by Agrawal et al [5] and World Neurosurg reports [8] further indicates ONSD subjectively expands progressively linearly to declining GCS and severe intracranial mass effect

The anatomical and pathophysiological mechanism behind this rapid sonographic response is related to intraorbital meningeal movement [5, 6]. The optic nerve sheath is a direct dural prolongation that encloses continuous cerebrospinal fluid. Because of this, any acute rise in pressure in the supratentorial space overcomes the normal compliance of the retrobulbar subarachnoid space [6, 7]. Numerous cadaveric and in vivo neuroimaging studies show that the anterior bulbous portion (3 mm posterior globe) has the thin-walled elasticity to distend rapidly within seconds after ICP elevation [7, 8]. This mechanical distension occurs before the developing structural cerebral herniation so that POCUS can visualize a physiological failure of compliance prior to the catastrophic brainstem compression [4, 8].

The results have important clinical implications for trauma triage and neuroresuscitation. In a crowded emergency department and level-1 trauma center, fast risk stratification of head trauma patients is vital [5, 6]. Individuals with mild TBI who have a normal ONSD, which is less than 5.00 mm, may safely undergo routine observation or outpatient neuroimaging. Patients with moderate-to-severe head trauma and an ONSD greater than or equal to 5.70 mm require immediate hyperosmolar therapy (mannitol, hypertonic saline), head-end elevation and emergent neurosurgery consultation while awaiting CT brain [6, 8]. In addition, repetitive assessments of ONSD in the ICU setting allow for continuous bedside evaluation of therapeutic responses to dehydrating neuro-resuscitative therapies, which avoids exposing unstable patients to repeated radiation or transport hazards [7, 8].

Conclusion

The optic nerve sheath diameter as measured with point-of-care ultrasound is a rapid, non-invasive, and highly accurate bedside triage modality in traumatic brain injury. There is a strong correlation between ONSD values and the grading of clinical severity, and the ONSD value increases progressively from mild to severe head injury. An ONSD cutoff of ≥ 5.70 mm has excellent diagnostic accuracy for intracranial hypertension. The use of ocular POCUS in trauma resuscitation helps perform a risk stratification on the patient ahead of time and offers guidance for early intervention.

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