Evaluation of Bedside Sonographic Measurement of Optic Nerve Sheath Diameter for Assessment of Raised Intracranial Pressure in Adult Head Trauma Patients

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Abstract

Aim: The aim was to evaluate the use of bedside sonographic measurement of the optic nerve sheath diameter (ONSD) in the assessment of elevated intracranial pressure in patients with head injury coming to the emergency department (ED). Methods: A prospective study of ED patients presenting with a history of acute head injury, an ocular ultrasound was performed for ONSD measurement, followed by a computed tomography (CT) of the brain. Three measurements were taken for each eye, then, the mean binocular ONSD measurement for each patient was obtained to ensure accuracy. A mean bipolar ONSD >5 mm was considered abnormal. Results: A total of 175 patients were considered for the study. Of 175 patients, only 56 (32%) had intracranial pathology detected on CT brain with mean ONSD of 5.7 mm (standard deviation [SD]: 0.59). The mean ONSD for 119 (68%) patients, who had normal CT brain, was 4.5 mm (SD: 0.42). The mean ONSD measured for the right eye was 4.86 mm with SD 0.88, and the mean ONSD for the left eye was 4.90 mm with SD 0.85. When comparing ONSD measurement with CT findings of raised intracranial pressure, the ONSD sensitivity was 87.5% (95% confidence interval [CI]: 85%–96%) and specificity was 94.1% (95% CI: 85%–96%), with a positive predictive value of 87.5% and a negative predictive value of 94.1%. The area under the receiver operator characteristic curve obtained was 0.90 (95% CI: 0.85–0.96). Conclusion: The study has shown a bedside measurement of ONSD through sonography as an efficient tool to assess elevations in intracranial pressure in head injury patients.

Keywords: Bedside assessment, emergency department, head trauma, intracranial pressure, intracranial pressure, optic nerve sheath diameter, sonographic measurement, trauma, ultrasonography

Introduction

Traumatic brain injuries are one of the major causes of mortality in many developing countries including India and pose severe socioeconomic losses. In India, around 1.5–2 million people get injured in a year, mostly from road traffic injuries, falls, alcohol influence, and violence.[1] Among the injured, many present to the emergency department (ED) with a head injury but with diverse severity depending on the mechanism of injury. One common feature associated with different intracranial pathologies is the elevation of intracranial pressure. The elevation in intracranial pressure might lead to life-threatening conditions such as brainstem herniation and compromises cerebral perfusion. Early detection of raised intracranial pressure (RICP) is considered a better strategy to prevent secondary brain insults. The best method still in practice for measuring RICP is invasive and has a risk of hemorrhage and infection.[2] Imaging methods such as cranial computed tomography (CT) and magnetic resonance imaging can also be used but require the transport of trauma patients to the facility and can be cumbersome.[3] Intracranial pressure (ICP) is measured using a CT brain. Brain CT findings suggesting of RICP are midline shift, mass effect, cerebral edema, and compression of third ventricle/cisterns.

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Optic nerve is enclosed by a perineural space filled with cerebrospinal fluid (CSF) and the dural sheath. Increased intracranial pressure caused by the displacement of CSF, causes further increase in the amount of CSF within perineural space, which leads to the expansion of the dural sheath around the optic nerve. Several studies have reported the measurement of optic nerve sheath diameter (ONSD) as an indicator of and for effective management of RICP. Ultrasound is considered as one of the most important adjunct imaging in trauma resuscitation guidelines, and the potential uses of bedside ED ultrasound are increasing. The use of ocular ultrasonography in cadavers for assessing elevated intracranial pressure has been demonstrated recently. This could well be extended to patients presenting with a variety of traumatic injuries and altered consciousness.

The measurement of intracranial pressure through ocular ultrasonogram holds potential applications for patients in ED, who have limitations to undergo physical examinations due to loss of consciousness, intubations, or paralysis. Early detection of elevations in RICP could help delay papilledema. Yet, the use of ocular ultrasonography for ONSD measurement has certain limitations owing to hyperechoic artifacts, interexamination variability, small-sized structure and measurements, variation in ONSD cutoff values, and varying patient population. Despite these limitations, ONSD measurements have been described as a very useful screening method in the early detection of RICP in head injury patients presenting to the ED. Hence, we evaluate the use of bedside sonographic measurement of ONSD in the assessment of elevated intracranial pressure in patients with head injury coming to the ED.

**Methods**

**Study design**

This study was conducted as an observational, prospective clinical study followed by the approval from institutional ethics committee (IEC) and consent obtained from the patient or a legally acceptable representative in both English and local languages in the ED of a tertiary care hospital with an annual input of about 25,000–30,000 patients. This study was conducted from October 2015 to August 2017.

All consecutive patients aged above 18 years of age presenting to the ED with a history of acute head injury, loss of consciousness, and retrograde amnesia; Glasgow Coma Scale (GCS) <13 on initial assessment in the ED and GCS <15 at 2 h postinjury; and showing signs of skull fracture, posttraumatic seizure, and focal neurological deficit; and more than one episode of vomiting, from October 2015 to August 2017; were included in the study.

Patients of age <18 years; pregnant women; patients with bilateral ocular trauma, penetrating eye injury, or other ocular pathologies such as glaucoma, optic neuritis, central retinal vein/artery occlusion, retrobulbar hematoma or orbital cellulitis; patients allergic to gel; and those who are not willing to consent were excluded from the study. For enrolled patients, complete medical history and clinical examination records were collected; ocular ultrasound for ONSD measurement and CT brain was performed.

**Study methodology**

Ocular ultrasound image acquisition was done by the emergency physician. ONSD measurements were performed with patients in the supine position, head centrally placed and elevated at 30°. A clear film protective dressing was placed over both eyes, and a layer of coupling gel was applied over closed eyelids. A 10 MHz ultrasonographic linear array probe was used on closed eyelids with careful positioning to ensure that pressure was not exerted on the globe. The probe was placed on the temporal area of the upper eyelid for optimal visualization of the optic nerve head. The eye was examined in the axial or transverse plane with the probe oriented in horizontal, left to right direction. The imaging was performed on both the eyes.

The intensity was adjusted lower than the values recommended by the US FDA Center for Devices and Radiological Health (mechanical index <0.23 and thermal index <1) for the eye to limit the amount of energy absorbed by the eye. The output power of the ultrasound was kept low to reduce the risk of thermal and nonthermal effects. The acoustic energy used for diagnostic purposes has no described adverse effects.

The mean binocular ONSD was measured at an angle perpendicular to the optic nerve at 3 mm depth behind the lamina cribrosa of the sclera in both eyes. Three measurements were taken for each eye, then, the mean binocular ONSD measurement for each patient was obtained to ensure accuracy. A mean bipolar ONSD >5 mm was considered abnormal.

The time of measurement of ONSD was important to avoid major confounding factors. ONSD was measured using sonography immediately on arrival in the ED in patients with suspected head injuries before the patient was sent for CT scan of the brain. Intravenous fluid administration and osmotic diuretics were not given until the ONSD was measured. ONSD was done before the patient was sent for CT scan of the brain. This way the investigator who is performing the ONSD is blinded to the CT scan results and prevents bias. The investigator had no clue what kind of brain injury the patient has while measuring ONSD in the ED.

Cranial CT findings suggesting RICP such as midline shift, mass effect, cerebral edema, and compression of third ventricle/cisterns were used to evaluate the ONSD. The emergency physician performing the ocular ultrasound image and assessing the outcomes has access to the clinical information, CT image findings.

**Statistical analysis**

IBM, SPSS software (v23.0, Armonk, NY, USA: IBM Corp.) was used for all statistical analyses. A sample size was calculated with 95% confidence level (CI) and 7.5% margin of error. Mean and standard deviation (SD) were
computed for continuous variables, while descriptive statistics, frequency analysis, and percentage analysis were done for categorical variables. The use of USG in the measurement of ONSD to assess RICP is going to be measured using the sensitivity, specificity, and correlation with CT imaging findings suggestive of RICP. The sensitivity and specificity of ONSD measurement and correlation with CT imaging findings were assessed by receiver operator characteristic (ROC) curve analysis. A significance was assessed by Chi-square and Fisher’s exact test (CI 95%). $P = 0.05$ was considered statistically significant.

RESULTS

A total of 175 patients were considered for the study with a median age of 44 years (range: 19–86 years). The flow of patients is illustrated in Figure 1. In the present study, of 175 patients, 36 (20.5%) were elderly (aged ≥65 years), with mean ONSD 5.1 mm (SD: 0.56). Fourteen (38.9%) out of the 36 patients had ONSD measured ≥5 mm on ocular ultrasound. Among 139 (79.4%) patients belonging to the younger age group, with mean ONSD of 4.9 mm (SD: 0.78), 43 (30.2%) patients had widened ONSD. Almost every patient presented to the ED with a history of loss of consciousness (100%), and most of them had experienced vomiting post-injury (48.6%) and posttraumatic seizures (16.6%). Only 45 (25.7%) of patients require intubation.

Of the 175 patients, 56 (32%) of patients had a positive finding on CT head suggestive of intracranial pathology, and 119 (68%) patients had a normal CT scan. CT examination identified cerebral contusion (34.3%), parenchymal hemorrhage (14.9%), extradural hemorrhage (EDH) (7.4%), subdural hemorrhage (29.7%), subarachnoid hemorrhage (15.4%), diffuse axonal injury (DAI) (4%), and depressed skull fracture (1.1%).

GCS score was used as a measure of the neurological deficit in patients with a head injury, where a score of 13–15 is mild, 9–12 is moderate, and 3–8 marks severe cases. Of the patients included in the current study, 36 (21%) patients were elderly with age above 65 years, and 139 (79%) were younger. Only 4 (11%) of these elderly patients had a severe GCS score of 3–8, while 33 (23.7%) of younger patients had a severe GCS score. Moderate GCS score (9–12) was seen in 7 (19.4%) elderly and 11 (7.9%) younger patients. Twenty-five (69.4%) elderly patients presented with a GCS score between 13 and 15, whereas 95 (68.3%) younger patients presented with GCS between 13 and 15, with the $P = 0.001$.

AVPU scale has been used for rapid neurological assessment in trauma, critically ill, and poisoned patients.[13] In the present study, of 175 patients, 99 (56.6%) patients were alert (A), 30 (17.1%) patients were responsive to verbal stimuli (V), 25 (14.3%) were responsive to painful stimuli (P), and 21 (12%) were unresponsive (U).

A statistically significant correlation was observed between the GCS and alert, verbal, painful, unresponsiveness (AVPU) scale of the patients. Among 175 patients, 99 (56.6%) patients who were “alert” by the AVPU scale were having GCS score 13–15. Out of 17% of patients responsive to “verbal” stimuli, 21 (12%) had GCS 13–15, and 9 (5.1%) had GCS 9–12. Furthermore, 16 (9.1%) and 9 (5.1%) of patients responsive to painful stimuli were having GCS <8 and 9–12, respectively. Twelve percent of patients who were “unresponsive” had a GCS score <8 with a $P < 0.000$ which is statistically significant. Of 56 patients, who had widened ONSD on ocular ultrasound, 9 (16%) had a GCS score between 13 and 15, 14 (25%) had a score between 9 and 12, and 33 (58.9%) had a score <8.

CT imaging found cerebral edema in 53 patients (30.3%) with head injury, which is highly suggestive of RICP [Table 1]. Effacement of sulci 35 (20%), collapse of third ventricle 31 (17.7%), and compression of cisterns 32 (18.3%) were

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**Figure 1:** Illustration of the flow of patients in the study
observed in the CT suggestive of RICP. Mass effect was seen in 34 (19.4%) patients, and midline shift was detected in 34 (19.4%) of them [Table 1].

Out of 36 (20.5%) elderly patients who presented to the ED with the head injury, only 13 (36.1%) had CT imaging patterns associated with elevated ICP, whereas 43 (30.9%) out of 139 younger patients had signs of RICP on CT imaging.

Out of 175 patients, positive intracranial pathology identified on CT brain includes subdural hematoma in 52 (29.7%) patients, EDH in 13 (7.4%) patients, subarachnoid hemorrhage in 27 (15.4%) patients, DAI in 7 (4%) patients, and cerebral contusion in 60 (34.3%) patients [Table 2].

When comparing ONSD measurement with CT findings of RICP, the ONSD sensitivity was 87.5% (95% CI: 85%–96%) and specificity was 94.1% (95% CI: 85%–96%). The resulting positive predictive value was 87.5%, with the negative predictive value being 94.1%. The area under the ROC curve was 0.90 (95% CI: 0.85–0.96) [Figure 2].

**Discussion**

Head injury patients presenting to the ED usually have multiple injuries, which require rapid detection and management. Recognition of RICP in traumatic brain injury remains the diagnostic challenge for emergency physicians in a busy ED setup. RICP remains a significant prognostic factor for poor outcome following traumatic brain insult. [14] Helmke and Hansen proposed that optic nerve that is a part of the brain, is surrounded by subarachnoid CSF and dural mater; variation in CSF pressure was associated with ONSD, which was widened in patients with RICP. [15] The aim was to determine whether bedside evaluation of ONSD could accurately correlate with CT findings suggestive of RICP in traumatic brain injury patients in the emergency medicine department.

| CT brain findings         | Number of patient, n (%) | Normal ONSD (<5 mm), n (%) | Raised ONSD (>5 mm), n (%) |
|---------------------------|--------------------------|----------------------------|---------------------------|
| Cerebral edema            | 53 (30.3)                | 6 (11)                     | 47 (88.6)                 |
| Midline shift             | 34 (19.4)                | 3 (8.8)                    | 31 (91.1)                 |
| Effacement of the sulci   | 35 (20)                  | 1 (2.85)                   | 34 (97.14)                |
| Collapse of the third ventricle | 31 (17.7)                | 0                          | 31 (100)                  |
| Collapse of the cisterns  | 32 (18.3)                | 0                          | 32 (100)                  |
| Mass effect               | 34 (19.4)                |                            | 34 (100)                  |
| Total                     | 219 (95.45)              | 10 (4.56)                  | 209 (100)                 |

ONSD: Optic nerve sheath diameter

| CT brain findings         | Number of patient (n=175), n (%) | Normal ONSD (<5 mm) | Raised ONSD (>5 mm) |
|---------------------------|-----------------------------------|---------------------|---------------------|
| Extradural hemorrhage     | 13 (7.4)                          | 2                   | 11                  |
| Subdural hemorrhage       | 52 (29.7)                         | 17                  | 35                  |
| Sub arachnoid hemorrhage  | 27 (15.4)                         | 7                   | 20                  |
| Diffuse axonal injury     | 7 (4)                             | 0                   | 7                   |
| Cerebral contusion        | 60 (34.3)                         | 25                  | 35                  |

CT: Computed tomography, ONSD: Optic nerve sheath diameter
Most of our patients were involved in road traffic accidents 142 (81.1%), followed by fall from height 26 (15%), and 7 (4%) with a history of assault. The open head injury was seen only in 1%, whereas 99% of patients sustained a closed head injury. In a prospective study by Tayal et al., of 59 patients, 76% of patients were involved in motor vehicle crash, 12% had fallen from height, and 9% had assault.[17]

In our study, among 175 patients who presented to our ED, only 56 (32%) had intracranial pathology detected on CT brain [Table 1] with mean ONSD of 5.7 mm (SD: 0.59). Forty-nine (87.5%) out of 56 patients with CT findings suggestive of RICP had widened ONSD. Only 7 (12.5%) out of 56 patients had normal ONSD with CT findings of RICP.

The mean ONSD for 119 (68%) patients, who had a healthy CT brain was 4.5 mm (SD 0.42). The mean ONSD measured for the right eye was 4.86 mm with SD 0.88, and the mean ONSD for the left eye was 4.90 mm with SD 0.85. When comparing ONSD measurement with CT findings of RICP, the ONSD sensitivity was 87.5% (95% CI: 85%–96%) and specificity was 94.1% (95% CI: 85%–96%). The resulting positive predictive value was 87.5%, with the negative predictive value being 94.1%. The area under the ROC curve was 0.90 (95% CI: 0.85–0.96) [Figure 2].

In Nash et al.’s study, 9 (45%) out of 20 patients, had signs of RICP and their ONSD ranged from approximately 5.2–6.2 mm with a mean of 5.8 mm (SD: 0.62). Right versus left eyes again did not show significant variability in these patients. Eleven (55%) patients were determined to have normal ICP with mean ONSD in this group averaged 4.9 mm (SD: 0.49).[18]

In Blaivas et al.’s study, out of 35 patients, 14 had CT results consistent with elevated intracranial pressure. In 14 patients with RICP, the mean ONSD was 6.27 mm (95% CI: 5.6–6.89). In patients with normal ICP on the CT brain, the mean ONSD was 4.42 (95% CI: 4.15–4.72). The difference in mean ONSD between normal and RICP was 1.85 mm (95% CI: 1.23–2.39) which was statistically significant with a $P = 0.001$, sensitivity of 100% and specificity of 95%. The positive predictive value was 93%, and the negative predictive value was 100%.[19]

In the present study, out of 175 head injury patients who underwent bedside sonographic measurement of ONSD, 56 (32%) patients had widened ONSD (>5 mm).

The data from our study show a strong relationship between signs of RICP on CT brain and dilated optic nerve sheath on ocular ultrasound in adult head injury patients in the ED. Other than head trauma, some rare etiologies can cause dilation of the optic nerve sheath, which can lead to false-positive findings. These include optic neuritis, arachnoid cyst of the optic nerve, and optic nerve trauma. This noninvasive test for detecting RICP can also be done when CT imaging is not available. The measurement of ONSD in this manner is easy to learn, precise, and inexpensive. A cutoff value of 5 mm can be used to screen for RICP.

**Limitation**

Despite a clear description of a strong relationship between ONSD and increasing ICP, the optimism surrounding this technique is blurred by the lack of consensus regarding optimal cutoff values. The second limitation was the ONSD measurement which was performed only by a single investigator who is certified in point-of-care ultrasound. In future, conducting a multicenter, multi-investigator study to rule out possible bias and validate our study findings is recommended. The third limitation is the comparison of ICP was done with a CT scan and not with the gold standard, as ICP is not directly measured in the ER by inserting a catheter into the brain.

**Conclusion**

Bedside ocular sonography for measuring ONSD can be used as an early test for diagnosing RICP in head injury patients, as it is a noninvasive, cost-effective bedside test, which can be repeated for reevaluation. The study did show the bedside evaluation of ONSD accurately predicts RICP in traumatic brain injury patients in the emergency medicine department, as they accurately correlate with CT findings of RICP.

**Research quality and ethics statement**

The authors of this manuscript declare that this scientific work complies with reporting quality, formatting, and reproducibility guidelines set forth by the EQUATOR network. The authors also attest that this clinical investigation was determined to require the IEC review, and the corresponding IEC approval reference number is CSP-MED/15/AUG/24/34. We also certify that we have not plagiarized the contents in this submission and have done a plagiarism check.

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Nil.

**Conflicts of interest**

There are no conflicts of interest.

**References**

1. Gururaj G. Epidemiology of traumatic brain injuries: Indian scenario. Neurol Res 2002;24:24-8.
2. The Brain Trauma Foundation. The American Association of Neurological Surgeons. The Joint Section on Neurotrauma and Critical Care. Recommendations for intracranial pressure monitoring technology. J Neurotrauma 2000;17:497-506.
3. Hiler M, Czosnyka M, Hutchinson P, Balesreeti M, Smielewski P, Matta B, et al. Predictive value of initial computerized tomography scan, intracranial pressure, and state of autoregulation in patients with traumatic brain injury. J Neurosurg 2006;104:731-7.
4. Rosenberg JB, Shiloh AL, Savel RH, Eisen LA. Non-invasive methods of estimating intracranial pressure. Neurocrit Care 2011;15:599-608.
5. Geeraerts T, Duranteau J, Benhamou D. Ocular sonography in patients with raised intracranial pressure: The papilloedema revisited. Crit Care 2008;12:150.
6. London A, Benhar I, Schwartz M. The retina as a window to the brain-from eye research to CNS disorders. Nat Rev Neuro 2013;9:44-53.
7. Ramji FG, Slovis TL, Baker JD. Orbital sonography in children. Pediatr Radiol 1996;26:245-58.
8. Fielding JA. Ocular ultrasound. Clin Radiol 1996;51:533-44.
9. United States Department of Health and Human Services, Food and Drug Administration, Center for Devices and Radiological Health. Information for Manufacturers Seeking Marketing Clearance of Diagnostic Ultrasound Systems and Transducers. Washington, DC: United States Department of Health and Human Services, Food and Drug Administration, Center for Devices and Radiological Health; 2008. Available from: http://www.fda.gov/cdrh/ode/guidance/560.pdf. [Last Accessed on 2017 Apr 15].

10. Rott H. Clinical safety statement for diagnostic ultrasound. European Committee for Medical Ultrasound Safety, Tours, France, March 1998. Eur J Ultrasound 1998;8:67-8.

11. Toms DA. The mechanical index, ultrasound practices, and the ALARA principle. J Ultrasound Med 2006;25:560-1.

12. Lizzi FL, Mortimer AJ. Bioeffects considerations for the safety of diagnostic ultrasound – Preface. J Ultrasound in Med 1988;7:S1-38.

13. Kuday C, Uzan M, Hanci M. Statistical analysis of the factors affecting the outcome of extradural haematomas: 115 cases. Acta Neurochir (Wien) 1994;131:203-6.

14. Becker DP, Miller JD, Ward JD, Greenberg RP, Young HF, Sakalas R. The outcome from severe head injury with early diagnosis and intensive management. J Neurosurg 1977;47:491-502.

15. Helmke K, Hansen HC. Fundamentals of transorbital sonographic evaluation of optic nerve sheath expansion under intracranial hypertension II. Patient study. Pediatr Radiol 1996;26:706-10.

16. Goel RS, Goyal NK, Dharap SB, Kumar M, Gore MA. Utility of optic nerve ultrasonography in head injury. Injury 2008;39:519-24.

17. Tayal V, Neulander M, Norton H, Foster T, Saimters T, Blaivas M. Emergency department sonographic measurement of optic nerve sheath diameter to detect findings of increased intracranial pressure in adult head injury patients. Ann Emerg Med 2007;49:508-14.

18. Nash JE, O'Rourke C, Moorman ML. Transocular ultrasound measurement of the optic nerve sheath diameter can identify elevated intracranial pressure in trauma patients. Trauma 2016;18:28-34.

19. Blaivas M, Theodoro D, Sierzenski PR. Elevated intracranial pressure detected by bed-side emergency ultrasonography of the optic nerve sheath. Acad Emerg Med 2003;10:376-81.