Ultrasound Measurement of Optic Nerve Sheath Diameter for Detection of Increased Intracranial Pressure in Adult Patients with Traumatic Brain Injury in Emergency Department

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Abstract: Background: Increased intracranial pressure (ICP) is a common phenomenon in patients with traumatic brain injury (TBI). **Aim:** This study aims to assess the diagnostic accuracy of optic nerve sheath diameter (ONSD) measurement using ultrasound (US) to detect elevated ICP in adults with TBI in the Emergency Department (ED). **Patients and Methods:** This prospective cross-sectional study was conducted on 80 patients aged above 18 years, of both sexes, who had TBI and were referred to brain CT scanning from ED of Tanta University Hospitals. Bedside, bilateral ONSD measurements were obtained within 15 minutes after brain CT. Based on the CT findings, patients were divided into two groups; group A: 40 patients without findings of increased ICP and group B: 40 patients with findings of increased ICP on CT brain. Mechanism of injury, GCS, TBI classification, clinical features of increased ICP, mean ONSD of both eyes by USG and brain CT findings of increased ICP were recorded. **Results**: The present study found significant lower GCS in group B compared with group A. Mean ONSD was significantly higher in group B compared with group A. The cutoff value of ONSD for diagnosing increased ICP was >4.95 mm with sensitivity of 100 %, specificity of 95 %, PPV of 95.2%, NPV of 100% and accuracy of 99.6%. There was a significant strong inverse correlation between the mean ONSD and the GCS. **Conclusion:** ONSD measurement via bedside ocular US is a useful, non-invasive method for early diagnosis of elevated ICP with optimal cut-off point at>4.95 mm achieving 100% sensitivity and 95% specificity in adult patients with TBI in the ED.

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1. Introduction

Traumatic brain injury (TBI) is a critical public health problem throughout the world representing the leading cause of morbidity and mortality under the age of 45 years [(1)]. Following TBI, brain edema or space occupying lesions may decrease intracranial compliance resulting in high intracranial pressure (ICP) which leads to decrease in cerebral perfusion pressure (CPP) resulting in inadequate cerebral oxygen delivery and secondary cerebral ischemia which can cause severe disability or death [(2)].

Early diagnosis of high ICP allows for early management in TBI patients and improves outcomes. Invasive ICP monitoring is the gold standard but it may lead to complications (e.g. bleeding and bacterial colonization). In addition, it is not always possible owing to patient contraindication and ICP monitoring availability issues [(3)].

Therefore, searching for noninvasive techniques for detection of high ICP is essential; at the moment, computed tomography (CT) is the technique of choice. However, many drawbacks (e.g. transportation of the patient, being time-consuming and excessive radiation hazards) have urged the researchers to look for alternatives [(4)].

Fundoscopy is limited by the need for experienced observers and papilledema takes time to develop[(5)]. The Transcranial Doppler (TCD) pulsatility index reflects decline in CPP due to increases in ICP. However, TCD is not always easy to perform even in expert hands as unsatisfactory images are obtained in about 5% of patients when a temporal window is used [(6)].

Between the optic nerve and the sheath is situated the subarachnoid space which experiences the same pressure change as the intracranial compartment. Accordingly, the use of bedside ocular USG in measuring optic nerve sheath diameter (ONSD) may be a useful method for detecting raised ICP[(7)].

This study aims to assess the diagnostic accuracy of ONSD measurement using US as a quick, bedside,

and noninvasive tool to detect elevated ICP in adult patients with TBI in the Emergency Department (ED).

2. Patients and Methods

This prospective cross-sectional study was conducted on 80 patients aged above 18 years, of both sexes, who had TBI and were referred to brain CT scanning in a duration of one year from April 2017 to April 2018. They were selected from those presented to ED of Tanta University Hospitals. Informed written consent was taken from close relatives after explanation of benefits and risks. Privacy of all patient data was granted. There was code number for every patient file that includes all investigations. All patients underwent the standard procedures of the protocol.

Exclusion Criteria were: ocular trauma, history of ocular pathology or previous operation to the eye, treatment with medications affecting the ICP and critical cases whose enrolment was considered a hindrance to formal diagnostics or interventions.

Upon arrival to the ED, patients included in our study were resuscitated, and stabilized initially. All patients were subjected to: full history taking, general examination [blood pressure (BP), heart rate (HR), respiratory rate (RR), and body temperature] and neurological examination [Glasgow coma scale (GCS), pupils assessment (for size, light reflex, and asymmetry), motor evaluation (power and asymmetry) and clinical features of raised ICP (altered consciousness, headache, nausea, vomiting, Cushing's triad, and signs of herniation syndromes)].

After initial assessment and emergency treatment, brain CT scan was performed for all participants and the results were evaluated by a radiologist. The CT examination was considered to be positive for raised ICP if the findings matched those previously suggested in the literature, namely absence/compression of the basal cisterns and/or ventricles, midline shift of 3 mm or more, effacement of sulci, and loss of grey/white matter differentiation.

ONSD measurement by US:

Bedside, ONSD measurements were obtained within 15 minutes after brain CT. The operator was blind to brain CT to avoid bias.

The technique and patient safety considerations mirror those described in previous literature[8-10]. The acoustic output of the USG was adjusted according to the "as low as reasonably achievable" principle and the requirements for orbital sonography to avoid damaging the retina and lens [11].

Patients were examined in the supine position with head of bed elevated 30 degrees using a high-resolution linear array probe. The probe was placed lightly on the closed upper eyelid, which was covered with a thick layer of USG gel to prevent pressure from being exerted on the eye. The position of the probe was adjusted to clearly display the entry of the optic nerve into the globe[8-10].

Two measurements were performed for each optic nerve; one in the transverse plane and the second in the sagittal plane. The ONSD was measured bilaterally at 3 mm before entrance of the optic nerve to the globe and a binocular ONSD measurement was taken (by calculating the mean ONSD of both eyes).

Based on the CT findings of increased ICP, patients were divided into two groups; group A: 40 patients who had no findings of increased ICP and group B: 40 patients with findings of increased ICP on CT brain. Measures of the study were: age, gender, mechanism of injury, GCS, TBI classification, clinical features of increased ICP, mean ONSD of both eyes by USG and brain CT findings of increased ICP.

The sample size (N >30) was calculated MedCalc ® v18.2.1 software computer, based on the following criteria: 95% confidence limit, 95%power of study, area under the curve (AUC) of ONSD to predict high ICP was 0.75 according to the results of a previous study [12]. More cases were added to overcome patient dropout.

The statistical software was SPSS v25 (SPSS Inc., Chicago, IL, USA). Quantitative variables were presented as mean & SD and student's t test was used for comparison. Categorical variables were presented as patients' number and percentage (%) and were analyzed by the Chi-square test. Linear correlation coefficient was used for detection of correlation between two quantitative variables in one group. ROC (Receiver Operating Characteristic) curve analysis was used for diagnostic accuracy. P value < 0.05 was considered significant.

3. Results

Demographic data, mechanism of injury, GCS and severity of TBIare shown in [Table (1)]. GCS was lower in group B compared with group A. There was a significant difference regarding the classification of TBI as most of patients in group A (67.5%) had mild TBI while most of patients in group B (65%) had severe TBI [Table (1)]. CT findings of raised ICP in patients with group B are shown in [Table (2)]

Mean ONSD was significantly higher in group B compared with group A. The mean ONSD ranged from 2.48 to 5.76 mm with a mean value of 4.047 mm in patients of group A while in patients of group B, ONSD ranged from 5.25 to 7.72 mm with a mean value of 6.493 mm. The best cutoff value of ONSD for diagnosing increased ICP was >4.95 mm with sensitivity of 100 %, specificity of 95 %, PPV of 95.2%, NPV of 100% and accuracy of 99.6% [Figure (1)]. Moreover, there was a significant strong inverse correlation between the mean ONSD and the GCS of patients [Figure (2)].

Table (1): Demographic data, mechanism of injury, GCS and severity of TBI

Demographic data			Group A (n = 40)	Group B (n = 40)	Test	P value
Age (y)	**Range**		19 – 84	19 – 82	t = -0.482	0.631
	Mean ± SD		36.7 ± 15.4	38.5 ± 17.8		
Gender	**Male**	**N**	26	28	$X^2 = 0.228$	0.633
		%	65	70		
	Female	**N**	14	12		
		%	35			
Mechanism of injury	**MVCs**	**N**	24	22	$X^2 = 3.776$	0.582
		%	60	55		
	Falls	**N**	8	10		
		%	20	25		
	Blunt assault	**N**	4	2		
		%	10	5		
	Struck by/against injuries	**N**	2	2		
		%	5	5		
	Penetrating injuries	**N**	1	4		
		%	2.5	10		
	Sports- related injuries	**N**	1	0		
		%	2.5	0		
GCS	**Range**		6 – 15	3 – 13	t = 10.04	<0.001*
	Mean ± SD		13.1 ± 2.38	7.28 ± 2.77		
TBI severity	**Mild**	**N**	27	1	$X^2 = 42.77$	<0.001*
		%	67.5%	2.5%		
	Moderate	**N**	10	13		
		%	25%	32.5%		
	Severe	**N**	3	26		
		%	7.5	65		
Clinical features of raised ICP		**N**	11	12	$X^2 = 0.061$	0.805
		%	27.5	30		

MVCs: Motor Vehicle Collisions, TBI: Traumatic Brain Injury, GCS: Glasgow Coma Scale, ICP: Intracranial Pressure, N: Number.

Table (2): CT findings of raised ICP in group B patients

CT findings of raised ICP	N	%
Cisterns compression/absence	26	65.00
Ventricles compression/absence	24	60.00
Sulci effacement	31	77.50
Midline shift	26	65.00
Loss of G/W matter differentiation	32	80.00

N: Number.

Table (3): ONSD of patients in the studied groups

		Groups						T-Test	
		Group A			Group B			t	P-value
Right ONSD	Range	2.45	-	5.8	5.3	-	7.62	-17.086	<0.001*
	Mean ±SD	4.051	±	0.691	6.489	±	0.580		
Left ONSD	Range	2.51	-	5.72	5.2	-	7.82	-17.432	<0.001*
	Mean ±SD	4.043	±	0.667	6.502	±	0.592		
Mean ONSD	Range	2.48	-	5.76	5.25	-	7.72	-17.275	<0.001*
	Mean ±SD	4.047	±	0.677	6.493	±	0.586		

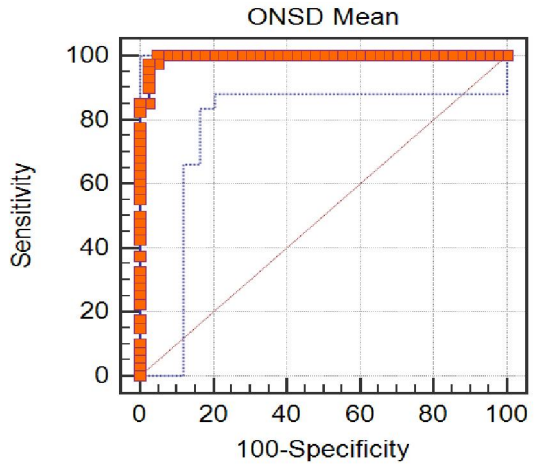

Figure (1): ROC curve of ONSD

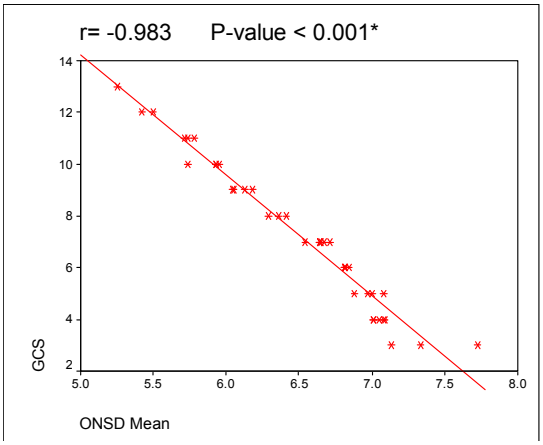

Figure (2): Correlation between mean ONSD and GCS

4. Discussion

Cranial CT has been used in our study as the reference standard for detecting increased ICP, as there is a considerable literature reporting that CT has been found a highly accurate technique in this regard and it is the most common method used in suspected cases with increased ICP[9, 13-16].

Direct ICP monitoring perhaps would be more sensitive in detecting raised ICP, but it is invasive procedure with many complications and is not recommended in cases of mild and moderate head injury. Also, placement of a measurement catheter may not always be possible due to lack of appropriate facilities especially in the ED [13, 17].

Therefore, comparison between ONSD US and other non-invasive tests such as CT or MRI is more practical in daily practice. Considering test time and cost-effectiveness in emergency situations, CT might be more appropriate than MRI for comparative studies to determine the diagnostic accuracy of US ONSD [18].

Our study revealed that clinical features of raised ICP have a low sensitivity and specificity for diagnosis of increased ICP (30% and 72.5 % respectively). These findings agree with Goel RS, et al. [19], and Tayal VS, et al. [16] who found that clinical assessment alone was not a reliable indicator of elevated ICP.

As regard ONSD measurement in the present study, mean ONSD was significantly higher in patients with increased ICP (group B) compared with patients with normal ICP (group A). The cutoff value of ONSD for diagnosing increased ICP was >4.95 mm with sensitivity of 100%, specificity of 95 %, PPV of 95.2%, NPV of 100% and accuracy of 99.6%.

Several studies have investigated the diagnostic accuracy of ONSD sonography for detecting increased ICP in adults using CT brain as the gold standard and in agreement with our results, they demonstrated a strong association between distension of the ONSD and an increase in ICP [8, 9, 12, 18, 20, 21].

Tayal VS, et al. [16]conducted a prospective blinded observational study on 55 adult head injury patients in an ED and found that an ONSD of 5.0 mm or more correlated with CT findings suggestive of raised ICP with a sensitivity of 100% and specificity of 63%. In a similar study done by Goel RS, et al. [19], a mean binocular ONSD > 5 mm had a sensitivity of 98.6% and specificity 92.8% for detection of raised ICP.

In another study correlating ONSD with CT features of raised ICP, Aduayi OS, et al. [20] demonstrated that ata cut-off value of 5.2 mm, the sensitivity was 81.2% and specificity was 100%. Similarly, a study of 24 adult patients by Qayyum H, et al. [22] compared ONSD by ocular US to CT findings and using a cutoff of 5.0 mm, they achieved a sensitivity of 100 %, specificity of 75 %, PPV of 95.4 %, and NPV of 100%.

Shirodkar CG, et al. [23] found ONSD cutoffs (4.6 mm for females; 4.8 mm for males) that had a sensitivity between 84.6 % (females) and 75 % (males) and a specificity of 100 % (both genders) for the detection of MRI signs of elevated ICP.

Amini A, et al. [15]showed that the cut off for detection of elevated ICP was 4.85 with a sensitivity and specificity 96.4 % and 95.3% respectively in head trauma or cerebrovascular accident. In a study by Tarzamni MK, et al [9], the mean binocular ONSD at cut-off point = 4.53 mm had sensitivity and specificity of 100% for prediction elevated ICP.

A prospective multicenter study by Lee SU, et al. [24] was performed for Korean adult patients with brain lesions. ONSD by US in patients with increased ICP diagnosed by radiological tests such as CT and MRI were significantly higher than those with normal ICP (5.9mm and 5.2mm respectively). ONSD >5.5mm

yielded a sensitivity of 98.77% and a specificity of 85.19%.

In a 3-month prospective observational study by Major R, et al. [25] that included 26 adult patients who required CT from the ED, a mean ONSD greater than 5mm was 100% specific and 86% sensitive for identification of raised ICP on CT brain. Kazdal H, et al. [26] evaluated the correlation between ONSD and intracranial midline shift seen on CT and reported that the midline shift correlated well with ONSD (Spearman's rank correlation coefficient 0.761; P<0.0005).

ONSD measurement by ultrasound have been also compared to invasive methods of ICP monitoring in many studies. Rajajee V and colleagues [27] showed that optimal ONSD as no less than 4.8 mm for detection of high ICP (>20 mmHg) had a sensitivity of 96% and a specificity of 94%. Frumin E, et al. [28] concluded that the ONSD ≥ 5.2mm was a good predictor of the ICP> 20 mmHg with a sensitivity of 83.3% and specificity of 100%.

A prospective study by Jeon JP, et al. [29] suggested a diameter of 5.6 mm as the optimal cut-off for diagnosing elevated ICP with a sensitivity of 93.75% and a specificity 86.67%.

Recently, Soliman I, et al. [30] have used new sonographic quality criteria to optimize ONSD measurements and investigated the correlation between ONSD measurements and simultaneous invasive ICP measurements in severe TBI. They found that ONSD measurements were strongly correlated to ICP values (p < 0.0001). ROC curve analysis revealed that the ONSD cutoff value for predicting elevated ICP was 6.4mm when using the mean of both eyes with a sensitivity of 85.3% and specificity of 82.6%.

Another recent prospective, single-cohort study by Robba C, et al. [31] was conducted on patients with TBI requiring invasive ICP monitoring and they found that the ability to detect intracranial hypertension (ICP ≥20 mmHg) was high for ONSD (area under the curve 0.91, 95% CI 0.88±0.95).

Dubourg J and colleagues [32] did a systematic review and meta-analysis composed of 231 patients from 6 studies and concluded that US ONSD shows a good level of diagnostic accuracy for detecting increased ICP as compared to invasive monitoring. The pooled sensitivity and specificity in this study was determined to be 90% and 85% respectively. They emphasized on the enormous potential this diagnostic method has in clinical decision□making, whether it be the triage of patients requiring transfer to specialized centers or the need to place an invasive device in situations where there is a lack of specific recommendations for their placement.

Recently, authors have increasingly compared US OSND and opening LP pressure. Amini A, et al. [15] reported that mean ONSD values in the increased ICP (defined as opening pressure>20 cmH2O) and normal ICP groups were 6.7±0.6 and 4.6±0.4 mm, respectively, with US ONSD>5.5mm showing a sensitivity and specificity of 100% for increased ICP detection.

A similar study by Wang L, et al. [33]concluded that the optimal cut-off point for increased ICP was 4.1mm, which yielded a 95% sensitivity an 92% specificity. However, defining increased ICP based on lumbar puncture was a concern to the interpretation of the results. Also, they revealed that the ONSD and ICP values were strongly correlated.

All these studies suggested that the ONSD measurement may be an effective method to assess ICP. However, we noticed that there has been a substantial variability around the ideal ONSD cut-off value that best predicts elevated ICP [18, 30, 34].

The wide range could be due to multiple reasons including the variations in the technique used, variations in the machine and probe used, experience of the observer and the population from various ethnicities. In addition, not all studies attempted to stratify results by gender or ventilatory status, both factors which may affect results. Lastly, the 'confirmation' of raised ICP was done with a variety of different methods – MRI, CT, invasive ICP monitors, and CSF opening pressure. This makes comparison between studies difficult.

We therefore, suggest standardizing the procedure in each institution and conclude a significant ONSD value after studying the normal range. This is in consensus of Rajajee V, et al. [27] who highlighted the importance of internal, institutional validation of sonographic ONSD criteria, prior to the routine clinical use.

Although a wide range of optimal OSND cut-offs have been reported, a cut-off ≥ 5.0 mm has been validated for detecting increased ICP (ICP > 20 mmHg) by several authors in their studies [18, 35] which comes in agreement with our results that revealed a cut-off value of >4.95 mm.

In contrast to our results, Strumwasser A, et al. [10]who concluded that US ONSD measurements were not reliable to monitor ICP due to poor accuracy and correlation on the basis of 36% sensitivity and 38% specificity. These differences may be methodological. They measured the ONSD in the linear transverse orientation only in contrast to our study where ONSD was measured at vertical and transverse orientation and then the mean value was recorded. ONSD measurements in that study were performed by 3 operators and varied significantly from one operator to the next as US imaging is operator-dependent

where in our study only one operator performed all measurements.

The present study found a significant lower GCS (a mean value of 7.275) in patients with increased ICP compared with patients with normal ICP (a mean value of 13.075). These findings agree with Çanakçi Y, et al. [36] who performed a study to investigate the value of the measurement of ONSD in patients presenting to the ED with headache and a significant drop in GCS was seen in patients with increased ICP. Moreover, there was a significant inverse correlation between the mean ONSD and the GCS of patients. This agree with and Çanakçi Y, et al, [36] who also observed similar results in their studies.

Limitations to the study:

Although this study showed that ONSD measurement by US may be a potentially useful and noninvasive tool in detecting the elevated ICP, it is limited by: the criterion standard used for comparison with the ONSD ultrasonography, the CT scan, is not a direct measurement of ICP. While a single physician measuring ONSD keeps the study consistent, the inter- and intra-observer variability of the method could not be assessed in this study. No correlation was performed between ONSD and neurological outcomes.

Conclusion:

ONSD measurement via bedside ocular US is a useful, non-invasive method for early diagnosis of elevated ICP with optimal cut-off point at >4.95 mm achieving 100% sensitivity and 95% specificity in adult patients with TBI in the ED.

Conflicts of interest: Nil.

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