ORIGINAL ARTICLE

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The Correlation of Optic Nerve Sheath Diameter with Radiological Classifications and Outcome in Pediatric Head Trauma

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Abstract

Objective: To demonstrate the correlation of optic nerve sheath diameter (ONSD) on initial computed tomography (CT) with outcome and radiological classification systems in pediatric intensive care unit (PICU) patients with head trauma.

Methods: Patients who were admitted to the PICU due to head trauma between June 2018-December 2022 were retrospectively analyzed. Both side ONSD and eye transverse diameters (ETD) were measured from head CTs at admission. CT findings were scored according to the Marshall and Rotterdam classifications of traumatic brain injury (TBI). Traumatic injury mechanisms, Glasgow coma scores, and outcomes were recorded from the hospital database.

Results: Mean ONSD differed significantly with age ($p<0.001$) and poor outcome ($p=0.005$). ONSD was also significantly higher in 0-2 and >10-year-old groups with severe TBI according to Rotterdam classification. The mean ONSD/ETD ratio was also significantly correlated with age, outcome, and Rotterdam classifications ($p<0.001$, $r2=0.583$; $p=0.031$, $r2=0.207$; $p=0.008$, $r2=252$, respectively.).

Conclusion: ONSD and ONSD/ETD ratio are feasible measurements that clearly correlate with prognosis and severe TBI in pediatric patients.

Keywords: Optic nerve sheath diameter, CT, pediatric, traumatic brain injury, intensive care

INTRODUCTION

Head trauma is the most frequent presentation to pediatric emergency departments, and traumatic brain injury (TBI) is the leading cause of mortality and morbidity in children (1). Increased intracranial pressure (ICP), hypotension, and hypoxia are known factors that increase mortality in these patients (1). ICP monitoring is recommended in the current guidelines for severe TBI Glasgow coma scores [(GCS ≤8)]. Although invasive methods are the gold standard, non-invasive monitoring has been increasingly studied and used in clinical practice because of the complications of surgery such as intracranial hemorrhage and infection (1).

The optic nerve sheath is a direct continuation of the dura mater and subarachnoid space. Hence, any increase in the cerebrospinal fluid (CSF) pressure may result in the expansion of the nerve sheath. Unlike papilledema, the change in optic nerve sheath diameter (ONSD) occurs in seconds, whereas papilledema may take days (2). Even though its non-ionizing nature makes ultrasound the preferred method for optic nerve sheath evaluation, it may not always be feasible, and the fact that the technique depends on the experience of the performer is a major disadvantage. Computerized tomography (CT), however, is widely used in trauma patients and enables objective interpretation and measurement. It also provides the opportunity to evaluate retrospectively (3,4).

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CT is the method of choice for the initial examination of head trauma patients, particularly in high-energy traumas, which may easily demonstrate fractures and hemorrhages. Marshall and Rotterdam classifications are CT scan-derived metrics that predict the outcome in patients with TBI (5,6). Both systems use the presence of hemorrhages, edema, and midline shift to indicate prognosis in TBI. On the other hand, CT may not show every injury, especially injuries in minor traumas (7).

In this study, we aimed to investigate the correlation of ONSD on thin-slice CT scans with Marshall and Rotterdam classification scores and outcomes in head trauma patients admitted to the pediatric intensive care unit (PICU).

METHODS

Patient Selection

This is a single-centered retrospective study that was approved by the Regional Ethics Committee (date: 07/03/2023, decision number: 810). Informed consent was obtained from each patient's parent or guardian before CT. Because this study is retrospective and does not risk the patients' anonymity, a second informed consent was waived for the study.

Patients who were admitted to the PICU due to head trauma from June 2018 to December 2022 were retrospectively analyzed. Patients with known neurological diseases, intracranial mass lesions (e.g., arachnoid cysts, tumors), and hydrocephalus were excluded. Age, gender, traumatic injury mechanisms, GCS at admission, and outcomes were recorded from the hospital database.

Patients were further classified according to age groups asfollows: 0-2 years (2-year-old included), 2-4 years (4-year-old included), 4-10 years and older than 10 years. Trauma injury mechanisms were classified as low-energy traumas (ground level fall, running into a stationary object) and high-energy traumas (car accidents, fall from height, pedestrian hit by a vehicle, motorcycle accidents, assault). GCS scale at admission were also subgroup as 3-8, 9-13, and 14-15.

Radiological Imaging and Measurement

Head CT was performed using 256-row dual-core multidetector system (Siemens SOMATOM Definition Flash, Siemens Medical Solutions, Germany) with an initial thickness of 3 mm. Axial non-enhanced 1.5-mm-thick processed images were co-interpreted by two radiologists (GT and MB) who were blinded to the patients' age, traumatic injury mechanism, GCS, and outcome. If there was a discrepancy, a consensus was reached. The presence of fractures, pneumocephalus, epidural-subdural-subrachnoid and intraventricular hemorrhages, paraenchymal contusions, compression of basal cistern edema, and herniation/midline shift were recorded. Patients were scored according to the Rotterdam and Marshall classifications. Additional traumatic pathologies in the body were also recorded.

For measurements of ONSD and ETD, all images were displayed at a standardized window level with WW: 60, WL: 400. All measurements were performed using the same window, contrast, and brightness. Right and left ONSD were measured at a distance of 3 mm from the posterior wall of the bulbus on 1.5-mm thick slices, as described previously in the literature (8). All measurements were performed by a single radiologist. To make the measurements more practicable, routine axial slices without any reformatting were used. Then, the mean value was calculated. ETD (retina to retina) of the right and left eyes were also measured from the same images, and the mean value was calculated. The mean ONSD/ETD ratio was then calculated for each patient (Figure 1).

Statistical Analysis

The SPSS 22 statistical package program was used for statistical analysis. The distribution of the variables was assessed by the Kolmogorov-Smirnov test, and continuous variables were presented as mean ± standard deviation or median (with interquartile range) accordingly. Categorical variables are given as numbers and percentages. Comparison between the two groups for data with normal distribution was performed using Student's t-test. Comparison between groups for data that did not show a normal distribution was performed using the Mann-Whitney U test. Categorical variables were compared using the chi-square test. Kruskall-Wallis test was used for multiple group comparisons. Pearson correlation was used for numerical data, and Spearman correlation was used for ordinal data. Univariate analysis was used to determine the factors related to poor outcome separately, and the variables with statistical difference ($p<0.2$) were included in binary logistic regression analysis to predict the odds of being a case (poor outcome) based on the values of the independent variables. $P<0.05$ was accepted as the level of significance.

RESULTS

Patients who were admitted to the pediatric ICU between June 2018 and December 2022 because of head trauma were collected from the hospital database, and their images were retrospectively analyzed. Eighteen patients were excluded because of imaging artifacts, and 109 patients were included in the study. Sixty patients were male and 49 were female.

The median age was 4.5 years (0-17). The basic features of the patients are given in Table 1.

Mortality rate was 4.5% (n=5). Twelve patients (11%) were discharged with severe sequelae, 6 of which demonstrated diffuse axonal injury on follow-up magnetic resonance imaging (MRI) (5.5%). Forty-one patients (37.6%) manifested additional traumatic pathologies; 17 (15.6%) in the abdomen, 23 (21.1%) in the thorax, and 22 (20.2%) in the extremities.

Table 1. Characteristics of the patients and CT findings

		n	%
Age	0-2	34	31.2
	2-4	15	13.8
	4-10	31	28.4
	>10	29	26.6
Gender	Female	49	45
	Male	60	55
Traumatic injury mechanism	Low energy	32	29.3
	High energy	77	70.7
GCS at admission	3-8	16	14.7
	9-13	21	19.3
	14-15	72	66.1
Pathologies on head CT	Fractures	40	36.7
	Pneumocephalus	26	23.8
	Subarachnoid hemorrhage	22	20.2
	Subdural hemorrhage	18	16.5
	Epidural hemorrhage	16	14.7
	Contusion	13	11.9
	Brain edema	8	7.3
	Midline shift more than 5 mm	6	5.5

GCS: Glasgow coma scale, CT: Computed tomography

Forty-four patients' CTs were interpreted as normal. Head CT at admission demonstrated trauma-related pathologies in 65 patients (59.6%). The most common pathology was fractures (n=40, 36.7%). Fifty-one patients showed one-sided pathology on CT (78.4%). In addition, head CTs were scored according to the Marshall and Rotterdam classification systems for traumatic brain injury. CT pathologies and scores are listed in Tables 1 and 2, respectively. The presence of intracranial pathologies did not show a significant difference according to the trauma injury mechanisms (Table 3).

GCS was significantly negatively correlated with both the Marshall ($p<0.001$, r^2:-0.44) and Rotterdam classifications (p.0.001, r^2:-0.59). On the other hand, the classification systems showed no significant difference according to the injury mechanisms (p=0.64 for Marshall and p=0.17 for Rotterdam).

Table 2. Patient distribution according to the Marshall and Rotterdam classifications

Marshall classification			Rotterdam classification		
	n	%		n	%
1	47	43.1	**1**	64	58.7
2	44	40.4	**2**	27	24.8
3	9	8.3	**3**	7	6.4
4	2	1.8	**4**	7	6.4
5	2	1.8	**5**	3	2.8
6	5	4.6	**6**	1	0.9

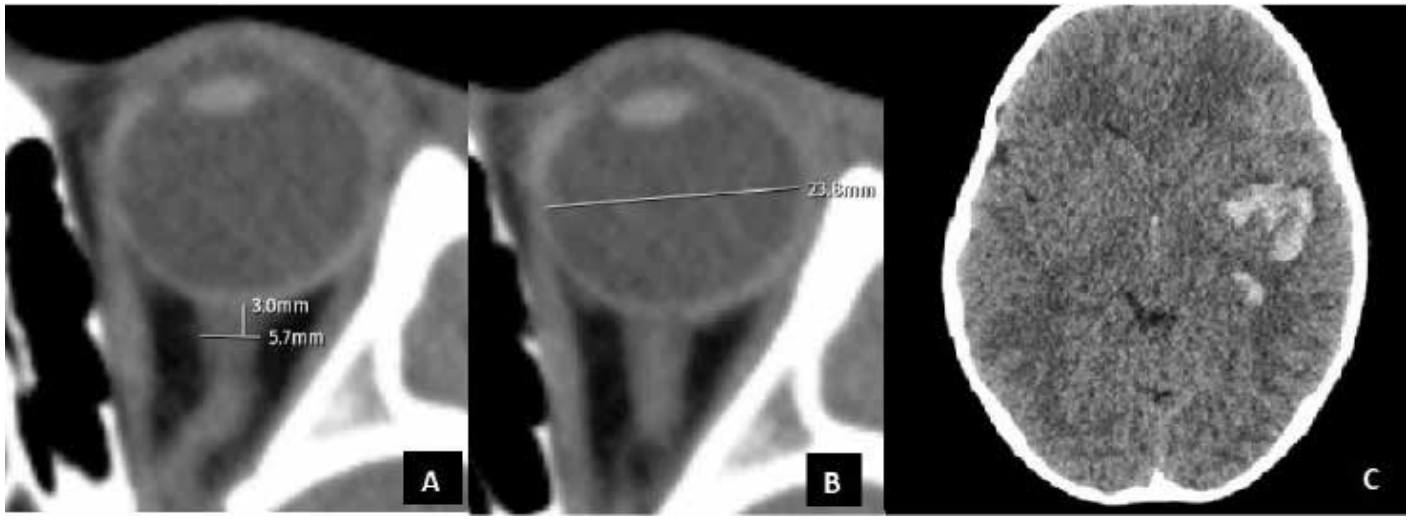

Figure 1. ONSD measurement (A), ETD measurement (B), and head CT scan images (C) of a 6-year-old boy who was hit by a car. (A) At a standardized window level, left ONSD is measured 3 mm behind the posterior wall of the bulbus. (B) ETD is measured from the retina to the retina. (C) Unenhanced CT scan shows left-sided parenchymal hematoma and blood in the left temporal horn

ONSD: Optic nerve sheath diameter, CT: Computer tomography, ETD: Eye transverse diameter

Right, left, and mean ONSD, ETD, and ONSD/ETD values according to age groups are given in Table 4. Mean ONSD values significantly increased with age (p<0.001). When the age subgroups were compared, significant differences were present in 0-2 vs 4-10 years (2.64±0.47 vs 3.8±0.8, p<0.001); 0–2 vs more than 10 years (2.64±0.47 vs 4.11±0.66, p<0.001); and 2-4 vs more than 10 years (3.28±0.61 vs 4.11±0.66, p=0.008).

Although not significant, the mean ONSD was higher in males (p=0.055).

No significant correlations were observed between ONSD and the Marshall and Rotterdam classifications. However, when Rotterdam scores were subgrouped into two as mild TBI (Rotterdam 1-2-3) and severe TBI (Rotterdam 4-5-6), ONSD was significantly higher in 0-2 and >10-year-old groups (2.642.64±0,48 vs 3.67±0,53, p=0.006 and 4.11±0.66 vs 5.07±0.95, p=0.017, respectively). Comparison could not be made for the 2–4-year group because there were no severe TBI patients (Table 5).

ONSD was significantly higher in patients with poor outcome (severe sequela or death) (3.40±0.89 vs 4.06±0.8, p=0.005). Subgroup analysis according to age groups was significant in 0-2 age group (2.62±0.46 vs 3.60±0.4, p=0.001). The difference was not significant in the other age groups (p=0.73 for 2-4 years, p=0.52 for 4-10 years and p=0.35 for more than 10 years).

Patients with one-sided intracranial pathology on CT were separately analyzed. In patients with left-sided pathologies, ONSD was significantly higher on the left (4.05±0.88 vs 3.5±0.93, p=0.037). However, the difference was not significant in patients with right-sided pathologies (3.56±0.99 vs 3.8±0.84, p=0.38).

ONSD/ETD ratios were significantly correlated with age (p<0.001, r^2=0.583). The correlation was also significant with Rotterdam classification (p=0.008, r^2=0.252). For further analysis, ONSD/ETD ratios were subgroup into two as (0.07-0.14) and (0.15-0.27). According to univariate analysis, age (p=0.191, F=2.69 [95% confidence interval (CI): 0.609-11.927)]; Rotterdam subgroup [p<0.01 F=50.63 (95% CI: 9.302-275.525)], and ONSD/ETD ratio subgroups [p=0.017 F=12.31 (95% CI: 1.566-96.750)] were significant predictors of poor outcome. Binary logistic regression analysis identified only Rotterdam subgroups as independent predictors of poor outcome [p<0.001 F=40.38 (95% CI: 6.499-250.87)].

Table 3. The distribution of trauma-related pathologies on head computed tomography according to traumatic injury mechanisms

	Fractures	PNC	SAH	EDH	SDH	Contusion	Edema	Shift
Total	40	26	22	16	18	13	8	6
Low energy	13	9	3	6	6	4	80	2
High energy	27	17	19	10	12	9	8	4
p-value	0.583	0.500	**0.070**	0.439	0.685	0.905	0.103	1

PNC: Pneumocephalus, SAH: Subarachnoid hemorrhage, EDH: Epidural hemorrhage, SDH: Subdural hemorrhage

Table 4. ONSD, ETD, and ONSD/ETD values of the right eye and left eye and mean values for age subgroups

Age	Right			Left			Mean		
	ONSD	ETD	OND/ETD	OND	ETD	OND/ETD	OND	ETD	OND/ETD
0-2	2.67	19.96	0.133	2,74	19.89	0.137	2,71	19.93	0.135
2-4	3.27	21.17	0.154	3.30	21.17	0.156	3.29	21.17	0.155
4-10	3.70	21.94	0.168	3.88	21.99	0.177	3.79	21.96	0.172
>10	4.23	22.76	0.186	4.26	22.83	0.187	4,24	22.80	0.187

ONSD: Optic nerve sheath diameter, ETD: Eye transverse diameter

Table 5. Comparison of ONSD values according to age groups and Rotterdam classification subgroups

	Rotterdam classification subgroups		
Age	Mild TBI	Severe TBI	p-value
0-2	2.64±0.47	3.68±0.53	**0.006**
2-4	3.28±0.61	N/A	
4-10	3.8±0.8	3.73±0.28	0.847
>10	4.11±0.66	5.08±0.95	**0.017**

TBI: Traumatic brain injury, ONSD: Optic nerve sheath diameter

DISCUSSION

Imaging and early detection of increased ICP is of major importance in the management of patients with TBI because early intervention plays a crucial role in preventing mortality. CT is the method of imaging for trauma patients. It is fast and easily accessible; it also provides a variety of information on the extent of the injury. Multidimensional and thin-slice reformatting makes CT scans indispensable in trauma, at the expense of radiation.

The possibility that ONSD may reflect CSF pressure was suggested in the early 1990s (8), and ever since then, many studies on ONSD measurements and correlation with outcomes in TBI have been published in the literature. However, most of these studies are in adult populations, whereas there are fewer studies on pediatric cases (1,3,4,8-12).

In our study, we found a significant correlation between ONSD and age, corroborating many studies in the literature (13-16). In this study, the mean ONSD was higher in males ($p=0.055$); however, we mainly attribute this difference to the heterogeneity of the sample size and the male predominancy in >10-year group. The normal distribution of ONSD among age groups has been provided by different studies using different imaging methods (13-15). CT and MRI reading data are usually similar, US and CT reading may not give the same results (11).

Legrand et al. (12) reported ONSD at admission CT was associated with a higher mortality rate in the ICU, with a cut-off value of 7.3 mm in the adult population. Similarly, Sekhon et al. (9) studied 220 severe TBI patients with invasive ICP monitoring and found that ONSD was associated with increased ICP. This study also revealed that a 1-mm increase in sheath diameter was associated with a 2-fold increase in mortality (9).

In their study, which involved 11 PICU patients with TBI, Agrawal and Brierley (10) compared the US measurement of ONSD 3 mm posterior to the optic disk and simultaneous invasive ICP measurement results. This study suggested that in children older than 1 year, ONSD more than 4.5 mm should be considered pathological (10). Another study by Bekerman et al. (11) on ONSD correlation with ICP changes showed that the most accurate interpretations were made in patients with 15-30 mmHg ICP. In the same study, ONSD readings of 5-13 mmHg were defined as "not informative" (11). In a similar study, Young et al. (16) measured the ONSD of TBI patients in PICU on CT scan and suggested a cut-off value of 6.1 mm for invasive ICP monitoring.

The correlation of ONSD with Rotterdam scores has been reported in a few studies (3,4,13). Compared with the Marshall classification, the Rotterdam classification additionally considers subrachnoid hemorrhage and evaluates epidural and subdural hematomas separately. In children, lower Rotterdam scores in TBI have been shown to result in lower mortality (17). In their study on 150 adults with TBI, Das et al. (4) found higher ONSD in patients with a Rotterdam score of 4 or higher, indicating moderate to severe TBI. The authors also suggested that a normal ONSD could be used to determine mild TBI patients, thus avoiding unnecessary follow-up CT scans (4). Waqas et al. (3) conducted their retrospective study on adults who underwent decompressive craniectomy. Similar to our study, for poor outcome and mortality prediction, Rotterdam scores were better predictors. Although ONSD was higher than normal at admission in these patients, it did not predict mortality or outcome (3).

Recently, Kayadibi et al. (13) compared ONSD at CT scans of pediatric patients with traumatic and non-traumatic complaints. Non-traumatic patients who had normal scans were included as a control group. Similar to our study, ONSD was also found to be correlated with age, and ONSD was higher in patients with severe TBI (Rotterdam 4-5-6) (13).

As a secondary end point, we evaluated patients with solely one-sided pathology on admission CT scan. When the intracranial pathology was only left-sided, the ipsilateral ONSD was significantly higher. However, this was not the case for the right-sided pathologies. Retrospective analysis for this discrepancy showed that the majority of patients with right-sided pathologies had focal subarachnoid hemorrhages and displaced fractures, without space-occupying hematomas, and with higher GCSs. In the case of increased ICP, a diffuse expansion of both sides of ONSD is expected, therefore, in the literature, the majority of studies take a mean value for analysis. However, when trauma is the etiology, intracranial pathologies can be unilateral, particularly in mild TBI cases (Rotterdam score 1-3). In these cases, measurement of only one side may lead to misconclusions.

Study Limitations

Our study has some limitations. First, it has a small sample size and a heterogeneous distribution of injury severity. The lack of severe TBI dominance interfered with further analysis. Second, the study did not have a control group, which would certainly help identify a cut-off point and add value. There was also lack of invasive ICP measurement in most of the cases because they were mild TBI patients.

CONCLUSION

In conclusion, CT is a fast and easily accessible imaging method in the emergency department and is frequently used in trauma patients. Initial head CT at admission is a pivotal scan that may provide the clinician with more than hemorrhages and fractures. ONSD on the initial CT should be evaluated because it may provide valuable information for the increased ICP and therefore the outcome. Unilateral ONSD changes in ipsilateral pathologies should warn the interpreter to always measure both eyes and compare the results.

Ethics

Ethics Committee Approval: This is a single-centered retrospective study that was approved by the regional ethics committee (date: 07/03/2023, decision number: 810).

Informed Consent: Informed consent was obtained from each patient's parent or guardian before CT.

Peer-review: Externally and internally peer reviewed.

Authorship Contributions

Surgical and Medical Practices: B.Ç., A.D., Concept: G.T., MB., B.Ç., A.D., Design: G.T., MB., B.Ç., A.D., Data Collection or Processing: G.T., MB., B.Ç., A.D., Analysis or Interpretation: G.T.,Literature Search: G.T., MB., B.Ç., A.D., Writing: G.T., MB., B.Ç., A.D.

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