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Initial evaluation of the intracranial pressure in cases of traumatic brain injury without hemorrhage

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A B S T R A C T

Our objective was to apply the technique of measuring diameters of optic nerve sheath (ONSD) for the intracranial pressure assessment for the cases with traumatic head injury without hemorrhage. In a retrospective study, CT data of 720 adult patients were collected and analyzed. ONSDs were measured at the point where the ophthalmic artery crosses the optic nerve (anatomical landmark) together with the eyeball transverse diameter (ETD). The ONSD/ETD index was calculated. The correlation analysis was performed with gender, age, the Glasgow Coma Scale score, and the Glasgow Outcome Score. ONSD was enlarged in 82% cases ($n = 591$). Enlarged right/left ONSDs were $6.7 \pm 1.0/6.7 \pm 0.9$ mm (cut-off value $>$ 5.5 mm). ONSD/ETD ratio was 0.28 ± 0.05 against 0.19 ± 0.02 in healthy adults ($p = 0.02$). We did not find correlation between ONSD/ETD ratio with initial Glasgow Coma Scale score but there was an inverse correlation between ONSD/ETD ratio and the Glasgow Outcome Score ($r = -0.64$). We conclude that in majority of cases with traumatic head injury without hemorrhage the ONSD is significantly enlarged indicating elevated intracranial pressure even if CT scans are negative.

1. Introduction

The traumatic brain injury may cause modifications of the brain-blood barrier that may lead to intracranial pressure (ICP) increase. Even if the trauma did not cause an intracerebral hemorrhage, brain swelling and focal brain damage occur as a result of contusions. Localized or generalized brain swelling contributes to the elevation of ICP by impeding hemodynamic corrections within the brain following trauma. The main component of the swelling is the neurotoxic edema that is understood as a cellular swelling of astrocytes. The cellular and interstitial edema leads to intracranial hypertension [1–5].

In cases of sizable brain tumors, tumors growing into the fourth ventricle, or head injuries with hemorrhage and hematoma initial CT scan performed at an Emergency Department indicates a space occupying lesion and conclusion about the raised ICP is almost obvious even before invasive or non-invasive ICP reading was taken. In cases with a head trauma without intracranial hemorrhage the initial CT scan may not indicate brain swelling and a practitioner can be hesitant about implementing the invasive ICP measurement and the ICP monitoring because of risks arising from infections, improper handling, and decalibration. The mild traumatic brain injury, often referred to as concussion, usually does not present visible evidences for raised ICP even if brain magnetic resonance imaging was used [6]. Complaints usually associated with raised ICP, such as headache, nausea, and vomiting, are neither sensitive or specific for intracranial hypertension. Therefore any additional indicator for the elevated ICP could be of help for a decision making process for the implementation of the invasive ICP monitoring.

Among non-invasive methods of ICP assessment, the measurement of the optic nerve sheath diameter (ONSD) is used at least since 1996. This method is based on the finding that the presence of the enlarged ONSD indicates the elevated ICP [7,8]. It was recently suggested to use either ONSD to the eyeball transverse diameter (ETD) ratio for CT scan assessment or the optic nerve diameter to ONSD ratio for ultrasonography as possible indexes to increase precision of the ONSD-ICP detection method [9,10]. A strong correlation exists between ETD and ONSD because the size of the eyeball varies from person to person and normative dimensions of the optic nerve and ONSD vary accordingly. In healthy adults, the ONSD/ETD index equals 0.19 ± 0.02 if measured in the middle third of the optic nerve intraorbital path (the point where the ophthalmic artery crosses the optic nerve serves as an anatomical landmark) [9]. The recent study indicated that an increase of this index $>$0.22 accurately detects the elevated ICP in patients with head injury that followed by a hemorrhage [11]. Similar observations however were not reported yet for patients with head injury without a hemorrhage.

In a non-comatose patient the ICP will fluctuate considerably with normal activity. Therefore CT based assessment of the ICP cannot

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substitute the ICP monitoring even in cases when repeated CT scans were performed. However initial Emergency Department CT scans can be used not only for general assessment of the patient's condition and for the Marshall (or Rotterdam) CT scale score calculation, but also for the calculation of the ONSD/ETD index. Our aim was to implement this index-based methodology of the ONSD method for initial detection of the elevated ICP in cases with traumatic brain injury without hemorrhage. While patients with mild traumatic brain injury might have negative CT scans we hypothesized that using the same initial Emergency Department CT scans for measuring ONSD/ETD index might improve the process of initial detecting the elevated ICP.

2. Methods

2.1. Study design and setting

In a retrospective study, we collected and analyzed the CT data of 720 adult patients (age 18+) that were admitted to the Department of Radiology at our Medical Center from January 2010 to February 2016.

2.2. Inclusion criteria

We selected the patients who were admitted to the Emergency Department, were referred to the CT investigation of the cranial region, and appeared to have traumatic head injury without hemorrhage (Marshall CT score DI I – DI IV). The patients could have the fractured skull that did not result in a direct connection between the brain and the outside (closed head injury). All the selected patients should have at least two available CT scans, Glasgow Coma Scale score, and Glasgow Outcome Score (GOS) being indicated in their charts. *Exclusion criteria*: cases with the penetrating brain injury and the traumatic head injury with intracranial/intracerebral hemorrhage (Marshall CT score DI V – DI VI) were excluded from the study as well as patients with traumas/fractures that could affect the sphenoid bone and the orbit. Patients with known ophthalmological or neuro-ophthalmological disorders were also excluded. We also excluded charts with incomplete data. Following these criteria, 720 cases were selected from 1376 cases with traumatic brain injury.

2.3. Groups and subgroups of the cases

Out of 720 cases (the Main group) several subgroups of patients were chosen for multiple comparisons. By the Medical Center protocol, all patients with head injury underwent initial noncontrast head CT that followed with a subsequent CT performed six hours later to exclude delayed intracranial hemorrhage. Based on the CT findings we divided the patients in two groups: Group 1, with negative CT scans (Marshall CT score DI I); Group 2, with positive CT scans (Marshall CT score DI II – IV). In addition to the Marshall scale and according to suggested classification [12], Group 2 consisted of patients with CT scans indicating (1) swelling adjacent to contusions, (2) diffuse swelling of one cerebral hemisphere, and (3) diffuse swelling of both cerebral hemispheres. Therefore, Group 2 was accordingly divided into three subgroups: 2 A, 2B, and 2C. Group 3 was formed to analyze the correlation between the ONSD/ETD ratio and the ICP readings obtained from the invasive ICP measurement. Finally, we selected cases with repeated measurements of CT, GOS, and Glasgow Coma Scale scores into Group 4 to analyze correlation between these variables. These groups and subgroups are described in the Table 1.

Table 1
The description of groups and subgroups of cases selected for multiple comparisons in the current study.

Group	Data/reason/purpose	# of patients
Main group	Data for all main variables were collected	720 (100%)
Group 1	Cases with negative CT scans	332 (46.1%)
Group 2	Cases with positive CT scans	388 (53.9%)
Subgroup 2A	Swelling adjacent to contusions	205 (28.5%)
Subgroup 2B	Diffuse swelling of one cerebral hemisphere	87 (12.1%)
Subgroup 2C	Diffuse swelling of both cerebral hemispheres	96 (13.3%)
Group 3	ONSD/ETD index correlation with invasive ICP reading	167 (23.2%)
Group 4	ONSD/ETD index to Glasgow Coma Scale score and GOS	248 (34.4%)

Abbreviations: ONSD, the optic nerve sheath diameter; ETD, the eyeball transverse diameter; ICP, intracranial pressure; GOS, the Glasgow outcome score.

2.4. Data sources and measurements

We retrospectively collected, analyzed, and compared data on the following variables: 1. ETD (retina to retina); 2. ONSD in the middle third of the intraorbital path (the point where the ophthalmic artery crosses the optic nerve serves as an anatomical landmark); 3. the ONSD/ETD index, 4. the Glasgow Coma Scale score, 5. GOS, 6. invasive ICP readings, 7. gender, and 8. age of the participants. The presence/absence of papilledema was not analyzed because papilledema was rarely present in acute trauma cases.

We analyzed CT scans obtained by the 256-slice CT scanner (Brilliance iCT, Philips Healthcare), initial single slice section 3 mm, area of interest slice section 0.6 mm. The initial step in radiological differential diagnosis was to separate high-density hemorrhagic lesions from low-density nonhemorrhagic lesions. To detect contusions radiologists analyzed anterior and middle cranial fossae, sphenoid wings, petrous ridges, and undersurfaces of frontal lobes as areas of interest. To detect brain swelling, obliteration of cerebral sulci and basal cisterns, effacement of gray matter–white matter interface, and hypodense areas usual for edematous brain were taken into account.

When diagnosis of traumatic head injury without hemorrhage was confirmed, the left and the right ETD and the ONSD were measured by the computer program at the same CT scan (Fig. 1 and Fig. 2). Window parameters were: spine window, middle third; WW 60, WL 360, (sometimes abbreviated as C:60,0. W:360,0 spine), accuracy 1 pixel. All analyzed measurements were made using the same window, contrast and brightness. Two radiologists were blinded to the other radiologist's reading. The error margin was expressed by means of the technical error of measurement (TEM) to calculate the intra-evaluator variability and inter-evaluator variability between the evaluators. The same equipment and methodological procedures for measurements were adopted by both evaluators.

2.5. Analysis

Measurements of eight selected variables were analyzed. A within-group repeated measures experimental statistical analysis was used to test the variables. Normal probability plots and basic descriptive statistics (mean, standard deviation (SD), min, and max) were calculated for every variable. The data obtained from the left eyeball and the optic nerve and from the right eyeball and the nerve was compared. The correlation analysis was performed with gender and age groups (group I: 18–30; group II: 30–65; group III: 65+). A non-parametric Mann–Whitney *U* test was to analyze those variables that were measured more than once (ONSD, ONSD/ETD ratio, Glasgow Coma Scale score, ICP readings). To analyze the correlation between the ONSD/ETD ratio and the ICP we used readings taken from patients who underwent an invasive ICP measurement in less than two hours before or after CT scan procedure. The cut-off value for the pathologically elevated ICP was set at 20 mmHg.