Journal of Clinical Neuroscience 34 (2016) 177–181

Contents lists available at ScienceDirect

Journal of Clinical Neuroscience

journal homepage: www.elsevier.com/locate/jocn

Clinical commentary

Noninvasive assessment of the intracranial pressure in non-traumatic intracranial hemorrhage

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ARTICLE INFO

Article history:
Received 16 March 2016
Accepted 25 June 2016

Keywords:
Adults
Computed tomography (CT) scan
Hemorrhagic stroke
Intracranial pressure
Non-traumatic intracerebral hemorrhage (ICH)
Optic nerve sheath diameter

ABSTRACT

The article describes the modified technique of measuring the diameters of the optic nerve sheath (ONSD) for assessment of the intracranial pressure (ICP) in patients with intracerebral or subarachnoid hemorrhage (SAH). The CT scans of 443 patients were analyzed retrospectively. The ONSDs were measured at 3 mm behind the globe and at the point where the ophthalmic artery crosses the optic nerve. The ONSD/eyeball transverse diameter (ETD) ratio was calculated. The correlation analysis was performed with the Glasgow Coma Scale score, Hemispheric Stroke Scale score, Glasgow Outcome Score, and invasive ICP readings. ONSD was enlarged in 95% of patients with intracerebral hemorrhage or SAH. Pathological ONSDs were 6.6 ± 0.8 mm (cut-off value >5.5 mm; $p < 0.05$). ONSD/ETD ratio was 0.29 ± 0.05 against normative 0.19 ± 0.02 ($p < 0.01$) with no correlation with initial Glasgow Coma Scale score or Hemispheric Stroke Scale score. There was an inverse correlation between ONSD/ETD ratio and Glasgow Outcome Score ($r = -0.7$) and direct correlation with invasive ICP readings. This study provides further evidence that in patients with intracranial hemorrhage and SAH, the presence of ONSD greater than a threshold of 5.5 mm is significantly predictive of invasively measured elevated ICP. The prediction of raised ICP can be further refined by measuring ONSD at the point where the optic nerve and the ophthalmic artery cross, and by determining the ratio between the ONSD and ETD.

1. Introduction

It is well documented that the hemorrhagic stroke or vascular abnormalities that resulted in intracerebral hemorrhage (ICH, parenchymal hemorrhage) or subarachnoid hemorrhage (SAH) almost inevitably lead to the elevated intracranial pressure (ICP) [1–4]. ICH and SAH may be caused by the spontaneous rupture of blood vessels damaged by chronic hypertension or amyloid angiopathy (primary) or by vascular malformations and aneurysms (secondary) [5]. While these two conditions have different clinical pictures and courses, different outcomes, and different treatment strategies, the elevated ICP is a common finding for them and decreasing of it is a part of their treatment because elevated ICP adds its share to an acute neurologic deficit.

The quantitative diagnosis of elevated ICP can be obtained by various invasive detection methods but monitoring ICP changes in a clinical setting is difficult and several qualitative non-invasive methods were also introduced into practice. Of them, CT scanning is used for more than 30 years and the measurement of the optic nerve sheath diameter (ONSD) is used for about 20 years. The ONSD method is based on the finding that the presence of the enlarged optic nerve sheath indicates the elevated ICP [6,7].

While we have no intention to reconfirm again the usefulness of the ONSD method in the current study, we paid attention to lacking of an established protocol of the procedure and to some disagreement between researches. In the emerging literature, various authors measured ONSD at different distances from the eye globe. Most of them measured it at 3 mm behind the globe [8–10], but some others measured it at 4 mm [11], 2 to 5 mm [12], 10 mm behind the globe [13], or did not mention the distance at all [14]. A normal/abnormal cut-off value of ONSD was independently set by different researches from 4.8 mm to ⩾7.3 mm [6,9,15,16]. We demonstrated in our previous publications that the frequently used cut-off value of >5 mm can mislead a practitioner if the standard deviation of the data is taken into account and proposed the cut-off value of >5.5 mm that helps to avoid false positive results [13,17].

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http://dx.doi.org/10.1016/j.jocn.2016.06.008
0967-5868/

To increase accuracy of the ONSD method, it was suggested to use the ONSD to the eyeball transverse diameter (ETD) ratio as a possible index [13]. A strong correlation exists between the ETD and the ONSD and the ONSD/ETD ratio (index) can be calculated. This index provides accurate data for assessment of ICP changes and it equals 0.19 with standard deviation of only 0.02 if measured for the middle third of the optic nerve intraorbital path in healthy individuals [13,18,19]. The usefulness of this index was recently demonstrated for the cases of the traumatic head injury with hemorrhage [20].

The purpose of the current research was to modify the technique of measuring ONSDs for the ICP assessment in cases with non-traumatic ICH or SAH to make it an accurate diagnostic tool. Our aims were to establish the most accurate point to measure the ONSD in the intraorbital path of the optic nerve and to increase precision of the quantitative data.

2. Materials and methods

2.1. Study design and setting

In a retrospective study, we collected and analyzed the CT scans of 443 adult patients (18+) that were admitted to the Department of Radiology from January 2011 to November 2015. The study protocol conformed to the ethical guidelines of the 1975 Declaration of Helsinki (amended 2013) as reflected *a priori* after approval by the Helsinki committee of our Medical Center. We examined the patients who were admitted to the Emergency Department, were referred for CT scans that included the head and neck region, and had non-traumatic ICH, SAH, or combined type of hemorrhage associated with a hemorrhagic stroke or vascular abnormalities. The subsequent investigation of these patients was performed after they were hospitalized to the intensive care unit or to the neurological department. The Hemispheric Stroke Scale (0 = good to 100 = bad) was used to assess patients with ICH [21]. The Glasgow Coma Scale based World Federation of Neurosurgical Societies Surgeons Grading System for Subarachnoid Hemorrhage (WFNS) scale was used to assess patients with SAH.

Inclusion and exclusion criteria were as follows: The patients should not have open or closed head injury. All the selected patients should have confirmed diagnosis or ICH or SAH, at least two available CT scans, the Glasgow Coma Scale score, and the Glasgow Outcome Score. We excluded from the study patients with abnormalities of the sphenoid bone and the orbit, in addition to patients with traumatic brain injury and hemorrhages associated with existing brain tumor. Patients with documented ophthalmological or neuro-ophthalmological disorders were also excluded.

In the current study the ONSD was measured at 3 mm behind the globe and at the point where the ophthalmic artery crosses the optic nerve (the anatomical landmark, 10 mm from the globe on average). The ONSD readings at 3 mm and at 10 mm from the globe were compared for false positive and false negative results for increased ICP and specificity and sensitivity for each position were calculated. In addition to the direct ONSD readings we measured the eyeball transverse diameter (ETD) and calculated the ONSD/ETD index (ratio). We used the ONSD/ETD index with cut-off value of >0.22 indicating the elevated ICP.

2.2. Data sources and measurements

We analyzed data on the following variables: 1. ETD (retina to retina); 2. ONSD at 3 mm behind the globe 3. ONSD at the point where the optic nerve crosses the ophthalmic artery; 4. ONSD/ETD ratio; 5. The Hemispheric Stroke Scale score or the WFNS scale score; 6. The Glasgow Coma Scale score; 7. The Glasgow Outcome Score; 8. sex; and 9. age of the participants.

Analyzed CT scans were obtained by the 256-slice CT scanner (Brilliance iCT, Philips Healthcare), single slice section 0.6 mm. Initial assessments of the CT scans were performed by the radiologists on duty to detect the presence/absence of ICH or SAH or other types of intracranial hemorrhage at the time of admission. These radiologists detected the focal and/or diffuse hyperdense (acute SAH, ICH, and intraventricular hemorrhage) and hypodense (brain swelling) areas and the CT scan patterns specific for blood in the interhemispheric fissures [22].

Our initial aim was to confirm their diagnostic conclusions. When the diagnosis of ICH or SAH was confirmed, the left and right ETD and the ONSD were measured by the computer program at the same scan. The transverse (horizontal) diameter of the eyeball was used because the ONSD is usually measured in the transverse plain. 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 measurements were made using the same window, contrast and brightness. 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 two evaluators. The same equipment and methodological procedures for measurements were adopted by both radiologists.

2.3. Analysis

Measurements or data of nine selected variables were analyzed. A within-group repeated measures experimental statistical analysis was used to test the variables. To verify the normality of the data, 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 sex and age groups (group I: 18–30; group II: 30–65; group III: 65+) and between the ONSD/ETD ratio and the Glasgow Coma Scale score upon admission and the Glasgow Outcome Score. The Student's t-test and the non-parametric Mann–Whitney *U*-test were used to calculate "p" values, and the chi-squared test was applied to analyze correlations and to calculate "r" values.

To calculate correlation coefficient between the ONSD/ETD ratio and the Glasgow Outcome Score we selected a subgroup of 68 patients to whom CT scan was performed four or five times and subsequent assessment of the condition was possible. Another subgroup consisted of 78 patients to whom invasive ICP measurement was applied. The cut-off value for the pathologically elevated ICP was 20 mm Hg. This subgroup was used to calculate any correlation between invasive and non-invasive measurements of the ICP levels.

We used previously published normative data for ETD, ONSD, and ONSD/ETD index for comparison purposes [13,17–19]. The data were statistically evaluated by three-dimensional analysis of variance, SPSS, Standard version 17.0 (SPSS, Chicago, IL, 2007), and chi-squared test criterion using 95% confidence interval (r value). The level of significance for all analyses was set at $p < 0.05$.

3. Results

We selected 443 patients that satisfied inclusion criteria from 1542 patients who were admitted to the Emergency Department and were further referred to ICU or Department of Neurology, Stroke Unit (M 194, F 118). The cohort had a mean age of 52 years (SD 17) and a median admission Glasgow Coma Scale score of 7 (interquartile range: 5–10). Of them, 200 patients had SAH, 188