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Optic nerve sheath diameter based on preoperative brain computed tomography and intracranial pressure are positively correlated in adults with hydrocephalus

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ABSTRACT

Objective: The usefulness of optic nerve sheath diameter (ONSD) in predicting increased intracranial pressure (ICP) is not well established in adults with hydrocephalus. In this retrospective study, we evaluated the correlation between ONSD measured on brain computed tomography (CT) and ICP in adults with hydrocephalus.
Patients and Methods: ONSDs were measured on preoperative brain CT images from 64 adult patients with hydrocephalus who underwent extracranial ventricular drainage or a ventriculoperitoneal shunt in 2016. ICP was defined as ventricular fluid pressure.
Results: The ONSD measured on preoperative CT was greater in patients (n = 8) with a higher ICP (> 20 mmHg, 5.8*vs.* 4.9 mm, P = 0.001). The ONSD was linearly correlated with ICP (r = 0.543, P < 0.001) and was predictive of increased ICP with an area under the receiver operating characteristic curve of 0.834. The optimal cut-off value of 5.3 mm ONSD yielded 88% sensitivity and 79% specificity. The inter-class coefficient of ONSD on preoperative CT was 0.882. The correlation between ONSD on preoperative CT and ICP was detected only in patients with communicating and non-communicating hydrocephalus (r = 0.437 and r = 0.585, P = 0.037 and P = 0.002, respectively).
Conclusion: ONSD measured on preoperative brain CT was linearly correlated with ICP in adult patients with communicating and non-communicating hydrocephalus, and it was a predictor of increased ICP with good discrimination and high inter-observer reliability. These results suggest that preoperative ONSD measurement on brain CT can be helpful to safely manage such patients by providing information about ICP.

1. Introduction

Hydrocephalus is a clinical condition characterized by the abnormal accumulation of cerebrospinal fluid (CSF) due to an obstruction of passage or a disturbance in reabsorption. The early detection and treatment of increased intracranial pressure (ICP) is critical when managing a patient with hydrocephalus because it can cause fatal complications, including cerebral hypoperfusion and brainstem herniation. However, clinical manifestations of an increased ICP such as headache, vomiting, and double vision are not reliable because such symptoms are subject to confounding by multiple factors [1,2]. Moreover, previous studies have indicated that various cerebral ventricular indices, showing ventricular enlargement on brain computed tomography (CT), were not useful to predict ICP in patients with hydrocephalus [3,4].

Optic nerve sheath diameter (ONSD) measured using various imaging modalities (CT, magnetic resonance imaging [MRI], and ultrasonography) is a reliable non-invasive predictor of ICP in patients with diverse neurological disorders, including traumatic brain injury, intracerebral hemorrhage, subarachnoid hemorrhage, meningitis, hepatic encephalopathy, and cardiac arrest [5–10]. However, few studies have investigated the relationship between ONSD and ICP in patients with hydrocephalus. Previous studies conducted in pediatric patients with a ventriculoperitoneal shunt (VPS) showed an increase in ONSD in patients with increased ICP [11–13]. However, no study has assessed the correlation between ONSD and ICP in adults with hydrocephalus. Therefore, the diagnostic value of ONSD in predicting ICP must be evaluated in adult patients with hydrocephalus.

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In this study, we tested the hypothesis that ONSD on preoperative brain CT would be positively correlated with ICP and be a predictor of increased ICP in adults with hydrocephalus.

2. Patients and methods

2.1. Subjects

This study was approved by the institutional review board of our hospital (number: 1711-114-901, date: Nov 27 2017). Informed consent was waived due to the retrospective design. Brain CT images and electronic medical records from all patients with hydrocephalus who underwent VPS or extracranial ventricular drainage (EVD) at Seoul National University Hospital during 2016 were reviewed. Patients with a pre-existing VPS or EVD catheter and children were excluded. Patients without brain CT images within 3 days before surgery were also excluded. Hydrocephalus was diagnosed as an enlarged ventricle on brain CT or MRI. The surgical procedure was decided by neurosurgeons based on the severity of a patient's symptoms and the extent of disease progression.

2.2. Data collection

Data on demographics, the type of hydrocephalus (communicating, non-communicating, or normal-pressure hydrocephalus [NPH]), underlying disease, type of anesthesia, preoperative medical treatment (steroids, mannitol, and hypertonic saline), preoperative Glasgow Coma Scale (GCS) score, and neurological symptoms and signs (motor weakness, abnormal light reflex, dysphagia, dysarthria, visual field defect, extraocular muscle movement limitation, facial nerve palsy, urinary symptoms, gait disturbance, memory disturbance, rigidity, and spasticity) were collected. NPH as a specific subgroup of communicating hydrocephalus was defined when patients had a triad of clinical manifestations (gait disturbance, urinary incontinence, and dementia) and normal or slightly increased ICP [14]. The verbal GCS score of an intubated patient was estimated using the method of Rutledge and co-workers [15].

2.3. Surgical procedure and anesthetic management

The patient was placed in the supine position and routine monitors (electrocardiography, noninvasive blood pressure, and pulse oximetry) were applied. Patients undergoing EVD received local anesthesia using lidocaine infiltrated into the skin; patients undergoing VPS received general anesthesia using total intravenous anesthesia with propofol and remifentanil. Rocuronium was administered in cases of VPS to facilitate endotracheal intubation; the end-tidal carbon dioxide concentration was maintained at 30–35 mmHg. In all patients, the patient's head was placed on a horseshoe headrest, and a semicircular skin incision was made at Kocher's point. Then, a burr hole was trephined and a catheter was inserted into the lateral ventricle. After checking for oscillations in the CSF, ventricular fluid pressure was measured using a water column manometer. The catheter was connected to an external drainage system for EVD and connected to one of two programmable valves for VPS: the Strata valve (Medtronic, Minneapolis, MN, USA) or the proGAV valve (Aesculap, Tuttlingen, Germany).

2.4. ICP definition

ICP was considered the ventricular fluid pressure recorded on the operation record. Increased ICP was defined as an ICP $>$ 20 mmHg.

2.5. ONSD measurement

The CT images analyzed in this study were taken during routine clinical practice; no CT scan was performed for research purposes. The ONSD was measured on preoperative brain CT (the last CT scan before surgery) images. Infinitt PACS viewer (Infinitt Healthcare, Seoul, Korea) was used to measure the ONSD with 500% zooming, a window level of 50 Hounsfield units, and a window width of 250 Hounsfield units [8]. Among many CT slices, the axial slice where the optic nerve was observed with the largest thickness was used. The ONSD was measured 3 mm behind the eyeball and was expressed as an average of the left and right ONSDs. The transverse diameters of bilateral eyeballs were also measured on the preoperative brain CT slice where the transverse diameter of the eyeball was maximal. The ONSD/ED ratio was calculated and expressed as an average value of both sides.

All measurements were performed by a researcher (WJL) blinded to the patient's ICP. To obtain inter-observer reliability, 40 randomly sampled preoperative CTs were rechecked in the same way by another researcher (HCL). The value of the former researcher was used for the actual analysis.

2.6. Statistical analysis

A previous study reported that a correlation coefficient between ONSD and ICP was 0.59 [16]. In this study, in order to reproduce the correlation coefficient of 0.59 with a two-tailed alpha error of 5% and a beta error of 10%, a minimum 26 patients were needed.

The primary outcome of this study was the extent of the correlation between ONSD on preoperative brain CT and ICP (ventricular fluid pressure). The secondary outcome was the correlation between the ONSD/ED ratio measured on preoperative brain CT and ICP (ventricular fluid pressure).

Comparisons of the general characteristics, GCS scores, neurological signs, ONSD, and the ONSD/ED ratio were made between patients with and without increased ICP. Continuous variables were tested by either the *t*-test or the Mann-Whitney *U* test according to the result of the Shapiro-Wilk test. Discrete variables were compared using the chi-square test or Fisher's exact test based on the observation frequency.

Correlation coefficients between ONSD or the ONSD/ED ratio on brain CT and ICP were calculated. A linear regression analysis was performed to obtain an equation for the relationship between ICP and ONSD. A receiver operating characteristic (ROC) curve analysis was performed to evaluate the predictive ability of ONSD and the ONSD/ED ratio for increased ICP. The optimal cut-off value for predicting increased ICP was determined by the value that maximized the sum of sensitivity and specificity. The intraclass correlation (ICC) of ONSD and the ONSD/ED ratio was calculated between the two researchers to evaluate inter-observer reliability.

All data are expressed as means (standard deviation) for normally distributed continuous variables, medians (interquartile range) for non-normally distributed variables, and numbers (percent) or the number in each group for categorical variables. The statistical analysis was performed with SPSS 21 (IBM Corp., Armonk, NY, USA) and R ver. 3.3.2 (R Foundation for Statistical Computing, Vienna, Austria). A P-value $<$ 0.05 was considered significant.

3. Results

During the study period, 138 patients underwent VPS and EVD for hydrocephalus. Of the 138, 54 were excluded because of a history of VPS or EVD. Nineteen patients were excluded because they did not have a preoperative CT image within 3 days before surgery. One patient was excluded because there was no ICP recorded on the operation record. A total of 64 patients were included in the final analysis. The general characteristics of the patients are shown in Table 1. Patients with increased ICP were younger and had more non-communicating hydrocephalus than those with a normal ICP (P = 0.001 and P = 0.013, respectively).

The ONSD on preoperative CT was greater in patients with an increased ICP than in those with a normal ICP (5.8 *vs.* 4.9 mm, P = 0.001,