Optic Nerve Sheath Diameter Assessment Used As a Non-Invasive Tool To Dynamically Monitor Intracranial Pressure

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Research Article

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Abstract

Objective: This study aimed to detect whether optic nerve sheath diameter (ONSD) can be used to dynamically monitor intracranial pressure (ICP).

Methods: Adult patients being monitored for invasive ICP on day one after hospital admission were included. For each patient, ONSD was first measured in the supine position, then at the 30° head-up position. The dynamic test was conducted in 16 patients. The ONSD was measured in the supine position once a day for three continuous days (day one to day three after admission).

Results: The ONSD and ICP values obtained in the supine position on admission were strongly correlated (r of 0.799). When patients changed their position from supine to the 30° head-up position, the ICP and ONSD values decreased correspondingly. However, the change in ICP did not correlate well with the change in ONSD (r of 0.358). In the dynamic test, a good agreement between ICP and ONSD only existed in three (18.75%) patients. In addition, three patients had completely different profiles for ICP and ONSD.

Conclusions: The results suggest that the changes in ONSD and ICP values were not correlated well after dynamic observation. Measurement of ONSD may not be a suitable tool to dynamically monitor ICP.

Introduction

Several neurological comorbidities (such as head injury, subarachnoid hemorrhage, and hydrocephalus) can result in increased intracranial pressure (ICP)(1, 2). Increased ICP can lead to cerebral ischemia, brain herniation, and even death(3). The monitoring of ICP is regarded as a crucial component in the management of high ICP. Currently, monitoring methods are invasive and include intra-parenchymal sensors and subarachnoid bolts. Both are reference standards for ICP measurements. However, these invasive methods can cause complications including bleeding and infection(4). Therefore, non-invasive ICP estimation would be beneficial.

Measurement of the optic nerve sheath diameter (ONSD) by magnetic resonance imaging, computed tomography, or ultrasonography are promising non-invasive ICP estimation methods(5, 6). The meningeal envelope around the optic nerve sheath (ONS) is a continuation of the dural and subarachnoid space. Therefore, a high ICP could result in the presence of cerebrospinal fluid (CSF) in the ONS, enlarging the ONSD(7). Previous studies have demonstrated that ONSD assessment is associated with ICP. Chen et al. studied 84 patients and found that ultrasonic measurement of ONSD could reflect the relative real-time changes in ICP(1). Hanafi et al. found that ultrasonic measurement of ONSD had high sensitivity and specificity in the detection of patients with high ICP(8). A prospective study by Robba et al. indicated that ONSD was the best non-invasive method to estimate ICP(4) and suggested the following formula to estimate ICP using ONSD: $nICP_{ONSD} = 5.00 \times ONSD - 13.92$ mmHg(4). However, a recently published study revealed that ultrasonic measurement of ONSD could not accurately estimate ICP in patients with subarachnoid hemorrhage(5). Kavi's study also indicated that the measurement of ONSD was not a

reliable method to monitor ICP, as ONSD expansion could persist even after the ICP was controlled(9). Therefore, the application of ONSD assessment in the dynamic monitoring of ICP remains controversial.

This study aimed to detect whether the ONSD can be used to dynamically monitor ICP. Two studies were conducted to achieve this goal. First, the correlations between the changes of the ONSD and ICP values when patients changed position from supine to 30° head-up were detected. Second, a dynamic test was conducted to observe the changes of ONSD and ICP values from day one to day three after hospital admission.

Patients And Methods

Patients

This prospective study was performed in the Department of Neurology of the Third Hospital of Hebei Medical University from May 2019 to June 2021. The study protocol was approved by Institutional Review Board of the Third Hospital of Hebei Medical University (No. K2019-010-1). All patients enrolled in this study signed informed consent.

The inclusion criteria were as follows: (1) patients were 18 years of age or older, (2) patients required ICP monitoring and underwent invasive ICP monitoring on day one after hospital admission, and (3) their Glasgow Coma Scale (GCS) score was between three and 12. Patients with a known history of ophthalmological disorders or optic nerve trauma were excluded from this study.

ONSD assessment

The ONSD assessment was performed in B-mode using the iU22 ultrasound system (Philips, Amsterdam, The Netherlands) and a 9-3 MHz linear array transducer (Philips) with the lowest possible acoustic power that could measure ONSD to avoid damage to the retina and lens(10). The patients were placed in the supine position or the 30° head-up position. The probe was covered with ultrasonography gel and carefully placed on the closed upper eyelid without exerting pressure on the eye. The ONSD was measured at 3 mm behind the optic disc. There were two measurements performed for each optic nerve: one in the transverse plane with the probe in a horizontal position and one in the sagittal plane with the probe in a vertical position(11). Each eye was assessed twice in each position. The final ONSD value for each position was the mean of all 8 values. The ONSD assessment was conducted by an operator with 30 years of ultrasound examination experience.

Data collection

All patients were managed carefully in accordance with international guidelines(12, 13). Mechanical ventilation was used as necessary to maintain adequate oxygenation ($\text{SaO}_2 > 90\%$) and normocapnia ($\text{PaCO}_2 = 35\text{--}40$ mmHg). Clinical data for each patient were collected, including gender, age, GCS score at admission, Acute Physiology and Chronic Health Evaluation II score at admission, height, weight,

systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean arterial blood pressure (calculated as $1/3 \times \text{SBP} + 2/3 \times \text{DBP}$). Two methods were used to detect invasive ICP: one was performed by an intraparenchymal fiberoptic transducer (Camino Laboratories, Integra Lifesciences, CA, USA) and the other was a catheter that was connected to an external pressure transducer and was inserted into the brain ventricles (Codman, Johnson & Johnson Medical Ltd., MA, USA). For each patient, the ONSD was measured in the supine position first, then in the 30° head-up position. The ICP value in each position was recorded.

To further detect whether the ONSD values increased or decreased in response to ICP changes, a dynamic test was conducted in 16 patients. The ONSD was measured in the supine position once a day for three continuous days (day one to day three after admission). The ICP values were recorded each day.

Statistical analysis

The data were analyzed with SPSS 22.0 software. Quantitative data were described as mean $\pm$ standard deviation (SD) or median with range. Categorical data were described as numbers and percentages. The Pearson correlation analysis was used to detect the correlation between the ONSD and the ICP at different positions. The correlation between the changes in ONSD and ICP from the supine position to the 30° head-up position was also evaluated with a Pearson correlation analysis. In the dynamic test, because of the different units of ONSD and ICP, the values of ONSD and ICP were standardized using Z-scores (produced in consideration of the intra-patient mean and SD). The Z-scores were calculated at three time points (D1, D2, and D3) and graphically described as points connected by a line. For each patient, if two lines (representing ONSD and ICP) were parallel, the ONSD and ICP would have good agreement. Conversely, if the two lines were divergent, the agreement was incomplete or absent(5). Statistical significance was indicated by $P < 0.05$.

Results

Patient characteristics

A total of 49 patients with a median age of 61 years (ranged: 18–75) who required ICP monitoring upon admission were enrolled in this study. Among them, 38 (77.55%) patients were men, and 11 (22.45%) patients were women. Twenty-seven (55.10%) patients had hypertension cerebral hemorrhage, six (12.24%) patients had an aneurysmal subarachnoid hemorrhage, 13 (26.53%) patients had a traumatic brain injury, and three (6.12%) patients underwent ICP monitoring due to other reasons. The characteristics of these 49 patients are shown in Table 1.

Table 1
Patient characteristics

Characteristics	N (%) or median (range)
Total number	49
Male/female	38 (77.55) / 11 (22.45)
Age (years)	61 (18–75)
Height (cm)	174 (160–180)
Weight (kg)	70 (50–95)
GCS at admission	6 (3–12)
APACHE II score at admission	19 (17–24)
SBP (mmHg)	132 (99–202)
DBP (mmHg)	74.5 (34–100)
MAP (mmHg)	93 (59–126)
ICP measurements	
Intraparenchymal fiberoptic transducer	27 (55.10)
External ventricular drainage system	22 (44.90)
Diagnosis	
Hypertension cerebral hemorrhage	27 (55.10)
Aneurysmal subarachnoid hemorrhage	6 (12.24)
Traumatic brain injury	13 (26.53)
Others	3 (6.12)
Complications	
Intracranial infection	3 (6.12)
Cerebral hernia	8 (16.33)
Sepsis	1 (2.04)
Note: GCS, Glasgow Coma Scale; APACHE, Acute Physiology and Chronic Health Evaluation; SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial blood pressure.	

Of the 49 patients, 16 underwent dynamic tests. The median age of these 16 patients was 62 years (range: 34–75). Of these 16 patients, 12 (75.00%) were men and four (25.00%) were women. Thirteen (81.25%) patients underwent ICP monitoring through intraparenchymal fiberoptic transducer and three (18.75%) underwent ICP monitoring through the external ventricular drainage system.

The effect of position on intracranial pressure and optic nerve sheath diameter

Correlation between change in ICP and change in ONSD when patients changed the position are presented in Fig. 1.

In the supine position, the mean ICP of the enrolled patients was 18.30 ± 6.71 mmHg, and 30 (61.22%) patients presented with an ICP ≥ 20 mmHg. The mean ONSD was 6.39 ± 0.66 mm. The ONSD and ICP values obtained in the supine position upon admission were strongly correlated, with an r of 0.799 (95% CI, 0.668–0.882; $P < 0.001$).

In the 30° head-up position, the mean ICP of the enrolled patients was 16.36 ± 6.16 mmHg, and 15 (30.61%) patients presented with an ICP ≥ 20 mmHg. The mean ONSD was 6.17 ± 0.58 mm. The Pearson correlation coefficient between the ONSD and ICP values obtained in the 30° head-up position was 0.686 (95% CI, 0.502–0.81; $P < 0.001$).

When patients changed position from supine to 30° head-up, the ICP and ONSD values decreased correspondingly. The mean changes in ICP and ONSD were 4.27 ± 1.98 mmHg (range: 0–8.00 mmHg) and 0.46 ± 0.34 mm (range: 0.01–1.39 mm), respectively. However, the change in ICP was not strongly correlated with the change in ONSD, with an r of 0.358 (95% CI, 0.086–0.58; $P = 0.012$), according to the Pearson correlation analysis. The greatest disconnects in changes in ICP and ONSD were in a patient with a change in ICP of 7 mmHg and a change in ONSD of 0.037 mm.

The analysis of the dynamic test

The dynamic test was performed on 16 patients. The Z-scores at D1, D2, and D3 for ICP and ONSD for each patient are presented in Fig. 2. Of the 16 patients, eight (50.00%) patients demonstrated a decrease in ICP from day one to day three. Three (18.75%) patients demonstrated a decrease in ICP from day one to day two and an increase in ICP from day two to day three. Five (31.25%) patients had an increase in ICP from day one to day two and a decrease in ICP from day two to day three. In three patients (patients 11, 13, and 16), the lines of ICP and ONSD were completely parallel. This indicates that a good agreement between ICP and ONSD only existed in three (18.75%) patients in the dynamic test. Three patients had completely different profiles for ICP and ONSD (patients 1, 2, and 7).

Discussion

This study's results indicated that the change in ICP was not correlated with the change in ONSD when patients changed from the supine position to the 30° head-up position. Additionally, in the dynamic test, only three of 16 patients showed good agreement between ICP and ONSD, indicating that ONSD was not an accurate tool to dynamically estimate ICP.

The ONSD measured by ultrasonography is an important noninvasive tool to estimate ICP. It can be used to screen patients with high ICP while avoiding the placement of intracranial probes and avoiding the risks of bleeding and infection(5). Previous studies have demonstrated the accuracy of ONSD for ICP

measurement(4, 14). A meta-analysis performed by Robba et al. demonstrated that ultrasonographic ONSD could offer good accuracy for detecting intracranial hypertension(6). A recently published meta-analysis enrolled 779 patients from 22 studies and suggested that ONSD had high sensitivity and specificity to diagnose patients with high ICP(15). Consistent with these studies, this study revealed that the ONSD and ICP values obtained in the supine position on admission were strongly correlated ($r = 0.799$).

The head-up position has been used in the treatment of patients with high ICP for decades, as this position decreases ICP quickly(16). In this study, when patients changed position from supine to 30° head-up, the ICP and ONSD decreased by 4.27 ± 1.98 mmHg and 0.46 ± 0.34 mm, respectively. However, the change in ICP was not strongly correlated with the change in ONSD ($r = 0.358$). Kerscher et al. detected dynamic changes in ONSD and ICP after ICP decreasing therapy, and no correlation between Δ ICP and Δ ONSD was found(17). Kavi found that ONSD expansion could persist even after ICP control, so ONSD assessment throughout the acute phase of neurologic injury may not be a reliable method to monitor ICP(9). Bäuerle et al. reported similar findings; the ONSD remained expanded after normalization of ICP in 27 patients with subarachnoid hemorrhage after aneurysm rupture(18). This result was most likely related to the impairment of the retraction capability of the ONS(18). Zoerle et al. explored the changes in the ONSD at the time of fairly rapid changes in ICP after CSF drainage(5). Unfortunately, the changes in ONSD related poorly to the ICP alterations. The impairment of ONS elasticity after subarachnoid hemorrhage may have contributed to this result(5).

The impairment of ONS elasticity could be used to explain this study's results. Usually, high ICP results in a shift of CSF into the ONS, causing the enlargement of the ONSD(6). When ICP decreases, the CSF will flow back into the intracranial subarachnoid space, and the ONS will reduce to its initial diameter. However, these changes require normal function of ONS elasticity(5). Hansen et al. isolated human optic nerve preparations to explore the elastic properties of the ONS(19). They found that ONSD reversibility may be impaired after episodes of prolonged intracranial hypertension(19). In this study, when the patients changed position from supine to 30° head-up, the ICP immediately decreased. However, intracranial hypertension impaired the ONS elasticity, so the ONSD did not correspondingly rapidly reduce. Therefore, ONSD might not be suitable to dynamically monitor ICP.

This study's dynamic test further confirmed this hypothesis. From day one to day three, a good agreement between ICP and ONSD only existed in three (18.75%) patients. In addition, three patients had completely different profiles for ICP and ONSD. This result further demonstrated that ONSD might not be suitable to monitor ICP dynamically. However, the study conducted by Wand et al. indicated that ONSD measurements were a useful tool for dynamically evaluating ICP(11). They found that the changes in ICP and ONSD values were correlated ($r = 0.669$) from admission through follow-up. Wang et al. study had a long follow-up period (one month) and the maximum ICP value was only 400 mmH₂O (29.41 mmHg)(11). The impairment of ONS elasticity may have recovered during the long follow-up period. Therefore, further studies are needed to clarify this issue.

The present study had several limitations. First, this study was limited by its small sample size, especially in the dynamic test (only 16 patients). Studies with more patients from different centers should be conducted to confirm this study's findings. Second, the dynamic test was only conducted from day one to day three after admission. This monitoring time was too short. A study with a longer follow-up time should be performed to determine if ONSD can be used to dynamically monitor ICP. Furthermore, in this study, the mechanism of why ONSD was not suitable for ICP dynamic monitoring was not clarified. In addition, the impairment of ONS elasticity and whether it contributed to the findings should be investigated further. Finally, this study did not focus on the difference in ONSD measurements for each eye. The variance of ONSD measurements in the transverse and sagittal axes was not detected either. For ONSD measurement, a consensus was not reached regarding the axis to be measured and the eye to be used (20). These issues should be investigated in future studies.

Conclusions

This study's results suggest that the changes in ONSD and ICP values are not correlated well after dynamic observation. The ONSD might not be a suitable tool to dynamically monitor ICP.

Declarations

Ethics approval and consent to participate

This study was conducted in accordance with the Declaration of Helsinki and approved by the ethics committee of the Second Hospital of Hebei Medical University.

Consent for publication

Not applicable.

Availability of data and materials

All data generated or analyzed during this study are included in this published article

Competing interests

All of the authors had no any personal, financial, commercial, or academic conflicts of interest separately.

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Authors' contributions

Guo-Biao Wu, Jun Tian conceived of the study, and Xiao-Bing Liu and Zhi-Yong Wang participated in its design and coordination and , Jian-Ying Guo helped to draft the manuscript. All authors read and

approved the final manuscript

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Figures

Figure 1

Correlation between change in ICP and change in ONSD when patients changed the position. ICP, intracranial pressure; ONSD, optic nerve sheath diameter.

Figure 2

ICP and ONSD z-scores during dynamic test. In 3 patients (patient 11, 13, and 16), the lines of ICP and ONSD showed completely parallel. ICP, red line; ONSD, blue line; ICP, intracranial pressure; ONSD, optic nerve sheath diameter.