Optic nerve sheath diameter measurement for predicting raised intracranial pressure in pediatric patients: A systematic review and meta-analysis

Sun Hwa Lee¹, Seong Jong Yun² and Dong Hyeon Kim³

Abstract

Background and objectives: No previous studies have investigated the relationship between the optic nerve sheath diameter and raised intracranial pressure in pediatric patients or have evaluated the usefulness of optic nerve sheath diameter in ocular ultrasound and brain computed tomography/magnetic resonance imaging. This study aimed to meta-analyze the diagnostic performance of optic nerve sheath diameter for the diagnosis of raised intracranial pressure in pediatric patients.

Methods: A database search of PubMed and EMBASE was performed to identify relevant studies. Bivariate modeling and hierarchical summary receiver operating characteristics modeling were performed to evaluate diagnostic performance. A pooled diagnostic odds ratio with a 95% confidence interval, not including 1, was considered informative. Subgroup analysis was performed according to the modality (ocular ultrasound vs brain computed tomography/magnetic resonance imaging). We performed meta-regression analyses for heterogeneity exploration.

Results: Eleven studies involving 546 patients were included. According to pooled diagnostic odds ratios, optic nerve sheath diameter was informative for the evaluation of raised intracranial pressure (diagnostic odds ratio, 47; 95% confidence interval, 11–206). Optic nerve sheath diameter showed a pooled sensitivity of 0.88 (95% confidence interval, 0.79–0.94), a pooled specificity of 0.86 (95% confidence interval, 0.70–0.95), and an area under the hierarchical summary receiver operating characteristics curve of 0.93 (95% confidence interval, 0.91–0.95) for the diagnosis of raised intracranial pressure. According to the subgroup analysis, ocular ultrasound (sensitivity, 0.91 (95% confidence interval, 0.81–0.96); specificity, 0.86 (95% confidence interval, 0.65–0.96)) showed higher sensitivity and comparable specificity than optic nerve sheath diameter measured on brain computed tomography/magnetic resonance imaging (sensitivity, 0.75 (95% confidence interval, 0.51–0.99); specificity, 0.91 (95% confidence interval, 0.74–1.00)). On meta-regression analysis, the study design, number of patients, and reference standard were the sources of heterogeneity.

Conclusion: Optic nerve sheath diameter may be a useful method for predicting raised intracranial pressure in pediatric patients. We recommend that the measurement of optic nerve sheath diameter should be performed using ocular ultrasound for a more accurate diagnosis of raised intracranial pressure in pediatric patients.

Keywords

Pediatrics, optic nerve sheath diameter, intracranial pressure, meta-analysis

¹Department of Emergency Medicine, Ewha Womans University Mokdong Hospital, Seoul, Republic of Korea
²Department of Radiology, G SAM Hospital, Gunpo-si, Republic of Korea
³Department of Radiology, National Cancer Center, Goyang-si, Republic of Korea

Corresponding author:
Seong Jong Yun, Department of Radiology, G SAM Hospital, 591, Gunpo-ro, Gunpo-si 15839, Gyeonggi-do, Republic of Korea.
Email: zoomknight@naver.com
Introduction

In adults, raised intracranial pressure (ICP) in the presence of acute neurological disease is an important cause of secondary brain injury and may lead to fatal complications.1,2 In pediatrics, although anatomical differences such as cranial rigidly and subdural space are present, this condition is just as detrimental because the resulting impact on intracranial compliance is unpredictable.3 Ultimately, as in adults, raised ICP causes secondary ischemic injury in children via decreased cerebral blood flow which results in limited delivery of cerebral oxygen.4,5

The gold standard for raised ICP diagnosis is direct ICP monitoring via an intracranial catheter. However, this procedure is invasive and carries a risk of serious complications, such as infection.6,7 Alternatively, the presence of papilledema on fundoscopy has been used as an indirect tool for detecting raised ICP; however, it has low sensitivity, especially in children under 8 years.8 Furthermore, there are many reports on brain computed tomography (CT), which has been traditionally used for indirect measurement of raised ICP, and the measurement of midline shifts > 5 mm and basal cistern and subfalc effacement is considered unreliable for the prediction of raised ICP.9,10

Recently, optic nerve sheath diameter (ONSD) on ocular ultrasonography (US) and brain CT/magnetic resonance imaging (MRI) has been introduced as an indirect tool for raised ICP measurement, and its reliability and usefulness have been demonstrated.3,11,12 Because the optic nerve connects to the dura mater that surrounds the brain and the cerebrospinal fluid (CSF) fills the cavity between the optic nerve and optic nerve sheath, raised ICP and increased CSF between the optic nerve and optic nerve sheath result in an enlarged ONSD.13

Few meta-analyses14–17 have demonstrated the relationship between ONSD on US and raised ICP. Furthermore, these studies focus only on adults14,15,17 or mixed populations,16 and only evaluate the usefulness of ONSD on ocular US. They did not evaluate the relationship between ONSD and raised ICP in pediatric patients or evaluate the usefulness of ONSD on ocular US and brain CT/MRI. Therefore, we believe that the diagnostic performance of ONSD for predicting raised ICP in pediatric patients needs further exploration, and high-level evidence needs to be presented via quantitative synthesis of data from the existing studies. In addition, the pooling of results will be interesting because published studies have used different modalities (ocular US vs brain CT/MRI) and different cutoff values.

This meta-analysis aimed to evaluate the diagnostic performance of ONSD for the prediction of raised ICP in pediatric patients. In addition, we performed a subgroup analysis to evaluate the performance of different modalities for the diagnosis of ONSD.

Methods

This meta-analysis followed the revised guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses of Diagnostic Accuracy Studies (PRISMA-DTA) statement.18 Institutional review board approval and informed consent were waived because the nature of this study was a systemic review and meta-analysis.

Data sources

The PubMed and EMBASE databases were searched up to 1 March 2019 to identify English-language studies on the use of ONSD for predicting raised ICP in pediatric patients. The search terms “optic nerve sheath diameter,” “intracranial pressure,” or “pediatric” were combined with “diagnosis,” “sensitivity,” “specificity,” or “receiver operating characteristic” as follows: (“optic nerve sheath diameter”) or (“ONSD”) AND (“intracranial pressure”) OR (“ICP”) AND (“child”) or (“children”) or (“pediatric”) OR (“pediatric”) OR (“adolescent”) AND (“diagnosis”) OR (“sensitivity”) OR (“specificity”) OR (“receiver operating characteristic”) OR (“ROC curve”). The bibliographies of the identified articles were screened to identify additional relevant studies. Two investigators screened the titles and abstracts for potential eligibility, and any disagreements were resolved through discussion.

Study selection

We included the following: (1) studies on pediatric patients (under 18 years), (2) studies on the use of mean ONSD (average ONSD of left and right eyes) on ocular US or brain CT/MRI as the index test, (3) studies on the use of invasive or noninvasive ICP monitoring as the reference standard, (4) studies with sufficient information to reconstruct 2 × 2 contingency tables regarding sensitivity and specificity, and (5) studies that were original research articles.

We excluded the following: (1) studies that were case reports or case series; (2) studies that were review articles, guidelines, consensus statements, letters, editorials, clinical trials, and conference abstracts; (3) studies not pertaining to the field of interest; (4) studies involving repetitive ONSD measurements; and (5) studies with insufficient information to reconstruct 2 × 2 contingency tables.

Quality assessment and data extraction

Two investigators independently extracted data on patient and study characteristics. The same investigators evaluated methodological quality using the Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2) tool.19 Any disagreement between the reviewers was resolved through discussion.
A standardized form was used to extract data on: (1) patient characteristics, including patient numbers, percentage of raised ICP, clinical features, mean age, age range, and sex; (2) study characteristics, including study origin, publication year, study design, study period, reference standard, and blinding to reference standard; and (3) interpretative characteristics, including modality, interpreter, ONSD measurement method, and ONSD cutoff value.

We extracted the study outcomes to construct 2 × 2 tables (i.e. true-positive, true-negative, false-positive, and false-negative results). We calculated the 2 × 2 tables using the Bayesian method if only sensitivity and specificity were presented in an eligible study. For the overall diagnostic performance of ONSD, the result with the highest accuracy was extracted. If two or more reviewers independently assessed the diagnostic accuracy, the result with the highest accuracy was extracted.

**Data synthesis and analysis of the diagnostic performance**

Patient demographic characteristics and extracted covariates were summarized using standard descriptive statistics. Continuous variables were expressed as means and 95% confidence intervals (CIs). Categorical variables were expressed as frequencies or percentages, unless otherwise stated.

We used a bivariate random-effects model for analyzing and pooling the diagnostic performance (sensitivity and specificity) across studies. To derive summary estimates of diagnostic performance, we plotted estimates of the observed sensitivities and specificities for each test in forest plots and hierarchical summary receiver operating characteristic (HSROC) curves derived from individual study results. These results were plotted using HSROC curves with 95% confidence and prediction regions. In addition, pooled sensitivities, specificities, diagnostic odds ratios (DORs), areas under the curve, and positive and negative likelihood ratios were calculated. Features showing a pooled DOR with a 95% CI not including 1 were considered informative.

Heterogeneity was determined using Cochran’s Q test ($p < 0.05$ indicated the presence of heterogeneity) and the $F$ test (0%–40%, possibly no heterogeneity; 30%–60%, moderate heterogeneity; 50%–90%, substantial heterogeneity; and 75%–100%, considerable heterogeneity). When heterogeneity was noted, heterogeneity according to a “threshold effect” was analyzed by visual assessment of the coupled forest plots of sensitivity and specificity. A meta-analysis of diagnostic test accuracy studies simultaneously evaluates a pair of outcomes (i.e. sensitivity and specificity). Sensitivity and specificity are commonly inversely correlated and influenced by the threshold (cutoff) value. In addition, Spearman’s correlation coefficient between the sensitivity and false-positive rate was calculated to determine any threshold effect, and a coefficient of >0.6 indicated a considerable threshold effect.

**Subgroup analysis**

For detailed evaluation of the diagnostic performance of ONSD for predicting raised ICP according to modality, we performed an additional subgroup analysis according to ocular US and brain CT/MRI. In addition, we compared the diagnostic performance of ONSD for the prediction of raised ICP using ocular US and brain CT/MRI.

**Meta-regression analyses**

Meta-regression analyses were performed using several covariates to investigate the potential causes of heterogeneity: (1) study design (prospective vs retrospective), (2) total patients ($\geq 30$ vs $< 30$), (3) proportion of raised ICP ($\geq 50\%$ vs $< 50\%$), (4) study population (only children vs children and adolescents), (5) reference standard (only invasive monitoring vs invasive monitoring with the inclusion of noninvasive methods), (6) blinding (blinding vs not reported), (7) interpreter (only radiologists vs include non-radiologists), and (8) ONSD cutoff value ($\geq 5\, \text{mm}$ vs $< 5\, \text{mm}$).

All statistical analyses were performed by one author with 5 years’ experience in performing systematic reviews and meta-analyses. Statistical analyses were performed using the “midas” and “metandi” modules in Stata software (version 10.0; StataCorp LP, College Station, TX, USA) and the “mada” package in R software (version 3.4.1; R Foundation for Statistical Computing, Vienna, Austria). A $p$-value of $<0.05$ was considered statistically significant.

**Results**

**Literature search**

Figure 1 shows a flow diagram summarizing the literature search. During the initial search, 168 studies were identified. After removing 36 duplicates, we reviewed 132 titles and abstracts and excluded 117 studies. These studies were case reports, letters, editorials, and conference abstracts ($n=48$), review articles, guidelines, and consensus statements ($n=26$), or not in the field of interest ($n=43$). After reviewing the full text of 15 eligible articles, we excluded four studies as they involved repetitive ONSD measurements ($n=1$) or lacked sufficient information to reconstruct 2 × 2 contingency tables ($n=3$). Ultimately, 11 original research articles ($n=3$) including a total of 546 patients, were included in the meta-analysis.

**Study characteristics**

Patient characteristics are summarized in Table 1. Patient numbers ranged from 11 to 174 (mean age, 3–14.1 years). Study and interpretative characteristics are summarized in
Tables 2 and 3, respectively. All studies were single-center studies with consecutive patient recruitment. Nine studies from 11 articles used ocular US, one study used brain CT, and one used brain MRI. All studies measured ONSD 3 mm behind the globe/optic disk/papilla. All studies used the average ONSD (ONSD of right eye + ONSD of left eye/2) for evaluation of diagnostic performance of ONSD. Six studies from 11
articles used only invasive ICP measurements via an ICP monitoring catheter as the reference standard, four studies\(^{11,13,30,32}\) used invasive or noninvasive ICP measurements (such as CT or fundoscopy) as the reference standard, and one study\(^{35}\) used only noninvasive ICP measurements (CT) as the reference standard.

### Quality assessment

Supplemental Figure S1 shows the risk of bias and applicability concerns for the 11 included studies. No studies were considered to be seriously flawed according to the QUADAS-2 tool. All studies satisfied \(\geq 4\) of the seven items.

Regarding the patient selection domain, three studies\(^{3,32,36}\) were considered to have a high risk of bias because they included only severe traumatic brain injury (TBI) patients. Regarding the index test domain, four studies\(^{32-34,36}\) were considered to have a high risk of bias because they used a pre-designated ONSD cutoff value before study processing. Regarding the reference standard domain, all studies were considered to have a low risk of bias. Regarding the flow and timing domains, all studies showed an unclear risk of bias because the mean interval between ONSD measurement and the reference standard was not reported. All studies exhibited low concerns in regard to applicability to our research question with regard to patient selection, index testing, and reference standard domains.

### Diagnostic performance of ONSD for prediction of raised ICP

The pooled sensitivity and specificity were 0.88 (95% CI, 0.79–0.94) and 0.86 (95% CI, 0.70–0.95), respectively.
According to the pooled DORs with 95% CIs, ONSD was informative for the evaluation of the raised ICP (DOR, 47; 95% CI, 11–206). The pooled positive and negative likelihood ratios were 6.5 (95% CI, 2.6–16.3) and 0.14 (95% CI, 0.07–0.27), respectively. The \( Q \) test revealed significant heterogeneity (\( Q = 6.393, p = 0.02 \)). Sensitivity (\( I^2 = 74.74\% \)) and specificity (\( I^2 = 85.46\% \)) indicated substantial and considerable heterogeneity, respectively. A threshold effect was shown by visual analysis of the coupled forest plot of sensitivity and specificity (Figure 2) as well as a corresponding correlation coefficient of 0.286 (95% CI, −0.177 to 0.722) between sensitivity and the false-positive rate. The area under the HSROC curve was 0.93 (95% CI, 0.91–0.95; Figure 3).

### Ocular US vs brain CT/MRI

For ocular US, the pooled sensitivity and specificity were 0.91 (95% CI, 0.81–0.96) and 0.86 (95% CI, 0.65–0.96), respectively. For brain CT/MRI, the pooled sensitivity and specificity were 0.75 (95% CI, 0.51–0.99) and 0.91 (95% CI, 0.74–1.00), respectively. The sensitivity was significantly higher for ocular US compared to brain CT/MRI (\( p = 0.02 \)). However, the specificity was not significantly different (\( p = 0.84 \)).

### Meta-regression analysis results

The results of the meta-regression analyses (Supplemental Table S1) showed that the significant sources of heterogeneity in sensitivity were study design (\( p = 0.02 \)) and total number of patients (\( p = 0.03 \)), with higher sensitivity reported in prospective studies with a relatively small number of patients (<30) compared to those with a relatively large number of patients (≥30). The only significant source of heterogeneity in specificity was the reference standard (\( p = 0.04 \)), with lower specificity reported in studies with only invasive ICP monitoring as the reference standard compared to studies with mixed or only noninvasive ICP methods. Other factors, including proportion of raised ICP, study population, blinding, interpreter, and ONSD cutoff value, were not significantly different (sensitivity, \( p = 0.12–0.90 \); specificity, \( p = 0.13–0.85 \)).

### Discussion

According to the present meta-analysis, ONSD measurement was an informative method (DOR, 47) with excellent performance for diagnosis of raised ICP in pediatric patients (sensitivity, 88%; specificity, 86%). In the subgroup analysis, ONSD measured on ocular US (sensitivity, 91%; specificity,
86%) showed higher sensitivity and comparable specificity than ONSD measured on brain CT/MRI (sensitivity, 75%; specificity, 91%).

The mechanism of ONSD enlargement in raised ICP is well-known. The optic nerve and optic nerve sheath are cylindrical structures that directly connect the eyeball to the cranium, running posterior-centrally and slightly upward toward the optic chiasm. The ONSD is surrounded by the optic nerve sheath which is filled with CSF, and it communicates directly with the subarachnoid space and reflects raised ICP due to increased pressure that causes enlargement of the ONSD.37,38

Our results have important clinical implications because neurocritical care management of pediatric patients focuses on prevention and prompt treatment of secondary insults.2 In adults, enlarged ONSD is a predictive factor of mortality and poor prognosis.39-41 In fact, patients with enlarged ONSD show a 2.0–22.7-fold greater risk of mortality compared to those with normal ONSD.39,40 Thus, early detection of raised ICP is crucial. ONSD measurements on ocular US or brain CT have many advantages as they are simple, effective, and can be measured in real-time. Moreover, ONSD measurement may help in active surveillance by allowing the assessment of ICP changes during follow-up.42

Four previous meta-analyses14–17 evaluated the diagnostic performance of ONSD, although these studies had several limitations. First, they only evaluated the usefulness of ultrasonographic ONSD and did not include brain CT or MRI. In addition, no studies have compared the diagnostic performance of ONSD measured on ocular US and brain CT/MRI. Second, these studies did not perform a thorough analysis of the potential sources of heterogeneity, as they did not distinguish between sensitivity and specificity for the effects of covariates, precluding any recommendations regarding methods to improve the diagnostic performance of ONSD. Finally, two studies14,16 did not use hierarchical models such as bivariate or HSROC models, which are recommended statistical tools for the meta-analysis of studies regarding diagnostic accuracy.20,21

Figure 2. Coupled forest plots of pooled sensitivity and specificity of the optic nerve sheath diameter measurement for diagnosis of raised intracranial pressure in pediatric patients. Numbers are pooled estimates with 95% CIs in parentheses. Dots in squares represent sensitivity and specificity. Horizontal lines represent the 95% CI for each included study. The combined estimate ("Combined") is based on the random-effects model and is indicated using diamonds. Corresponding heterogeneities ($I^2$) with 95% CIs are provided in the bottom right corners: $P = 100\% \times (Q - df)/Q$, where $Q$ is Cochran’s heterogeneity statistic and $df$ is the degrees of freedom.
In terms of cutoff values, the proposed ONSD showed variation. Most studies used 4.5 mm or more as the ONSD cutoff value for differentiating raised and normal ICP. In studies with children younger than 1 year, ONSD cutoff values for differentiating raised and normal ICP were decreased and 4.0 mm was used as the cutoff value. It has been clearly demonstrated that an ONSD < 4.5 mm for children over 1 year and < 4.0 mm for children younger than 1 year indicates no significant ONSD enlargement. Since we did not have raw data from the studies, a single ONSD cutoff value could not be calculated based on this meta-analysis.

Our subgroup analysis revealed that ocular US was more useful than brain CT for diagnosis of raised ICP. In particular, the pooled sensitivity of the ONSD was higher in prospective studies with a relatively small number of patients (<30) than in retrospective studies with a relatively large number of patients (≥30). In addition, pooled specificity of the ONSD was higher in studies with mixed or only noninvasive ICP methods as the reference standard than those with only invasive ICP monitoring. Further prospective studies with larger sample sizes and invasive ICP monitoring as the reference standard are needed.

This study had several limitations. The first limitation was the relatively small number of included studies. Nevertheless, we were able to draw several important conclusions regarding the diagnostic performance of ONSD and related factors (modality), which we believe provides a useful overview because we used broad search terms and only included easily accessible studies (published in English and available in the PubMed and EMBASE databases). The second limitation was that all included studies revealed positive results and that fact could be attributed to publication bias, which is impossible to quantify. Although we omitted Deeks’ funnel plots according to the PRISMA-DTA guidelines, we observed a low probability of publication bias (p = 0.52), which suggests that this factor did not undermine our results. The third limitation was the methodological differences between the included studies, and the extensive meta-regression analysis revealed that these variables were also significant sources of heterogeneity. This methodological diversity might affect the pooled estimates, especially as the symptom onset, time to examination, and pre-hospital management were not assessed in the meta-regression analysis because not all studies reported these factors. Further prospective studies with larger sample sizes and standardization of patient management are needed to establish the optimal parameters and cutoff value for ONSD.

**Conclusion**

In conclusion, the present meta-analysis revealed that ONSD measurement may be a useful method for predicting raised ICP in pediatric patients. We recommend that ONSD measurement should be performed using ocular US to more accurately diagnose raised ICP in pediatric patients. The use of routine ocular US, which is less time-consuming and easily accessible without radiation hazard, may be helpful for the detection of raised ICP in pediatric patients.
Author contributions
S.H.L. and D.H.K. designed the study and the literature search; S.H.L. and S.J.Y. analyzed data; S.H.L. and D.H.K. wrote the manuscript; S.H.L., S.J.Y., and D.H.K. made the critical revision of this manuscript. All the authors read and approved the final manuscript.

Declaration of conflicting interests
The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding
The author(s) received no financial support for the research, authorship, and/or publication of this article.

Availability of data and materials
All data generated or analyzed during this study are included in this published article. The materials described in the manuscript will be freely available to any scientist wishing to use them for non-commercial purposes, without breaching participant confidentiality.

Informed consent
Since the study was a meta-analysis, informed consent was not obtained. Written informed consent was not necessary because no patient data have been included in the manuscript.

Ethical approval
This study was approved by the local ethics committee. To maintain patient confidentiality, the forms did not include any data that would have enabled identification of any patients. The procedures performed in this study followed the ethical standards in the 1964 Declaration of Helsinki, as revised in 2008, as well as the national law.

Human rights
This study was conducted according to the World Medical Association Declaration of Helsinki. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

ORCID iD
Seong Jong Yun https://orcid.org/0000-0002-3775-5701

Supplemental material
Supplemental material for this article is available online.

References
1. Carney N, Totten AM, O’Reilly C, et al. Guidelines for the management of severe traumatic brain injury, fourth edition. Neurosurgery 2017; 80: 6–15.
2. Whitaker-Lea WA and Valadka AB. Acute management of moderate-severe traumatic brain injury. Phys Med Rehabil Clin N Am 2017; 28(2): 227–243.
3. Young AM, Guilfoyle MR, Donnelly J, et al. Correlating optic nerve sheath diameter with opening intracranial pressure in pediatric traumatic brain injury. Pediatr Res 2017; 81(3): 443–447.
4. Balestreri M, Czosnyka M, Hutchinson P, et al. Impact of intracranial pressure and cerebral perfusion pressure on severe disability and mortality after head injury. Neurocrit Care 2006; 4(1): 8–13.
5. Treggiari MM, Schutz N, Yanez ND, et al. Role of intracranial pressure values and patterns in predicting outcome in traumatic brain injury: a systematic review. Neurocrit Care 2007; 6(2): 104–112.
6. Blaha M, Lazar D, Winn RH, et al. Hemorrhagic complications of intracranial pressure monitors in children. Pediatr Neurosurg 2003; 39(1): 27–31.
7. Pople JK, Muhlauer MS, Sanford RA, et al. Results and complications of intracranial pressure monitoring in 303 children. Pediatr Neurosurg 1995; 23(2): 64–67.
8. Tuite GF, Chong WK, Evason J, et al. The effectiveness of papilledema as an indicator of raised intracranial pressure in children with craniosynostosis. Neurosurgery 1996; 38(2): 272–278.
9. Hiler M, Czosnyka M, Hutchinson P, et al. Predictive value of initial computerized tomography scan, intracranial pressure, and state of autoregulation in patients with traumatic brain injury. J Neurosurg 2006; 104(5): 731–737.
10. Miller MT, Pasquale M, Kurek S, et al. Initial head computed tomographic scan characteristics have a linear relationship with initial intracranial pressure after trauma. J Trauma 2004; 56(5): 967–972; discussion 972.
11. Haredy M, Zuccoli G, Tamber M, et al. Use of neuroimaging measurements of optic nerve sheath diameter to assess intracranial pressure in craniosynostosis. Childs Nerv Syst 2018; 34(5): 939–946.
12. Padayachy L, Brekken R, Fieggen G, et al. Noninvasive transorbital assessment of the optic nerve sheath in children: relationship between optic nerve sheath diameter, deformability index, and intracranial pressure. Oper Neurosurg 2019; 16: 726–733.
13. Helmke K and Hansen HC. Fundamentals of transorbital sonographic evaluation of optic nerve sheath expansion under intracranial hypertension II. Pediatr Radiol 1996; 26(10): 706–710.
14. Dubourg J, Javouhey E, Geeraerts T, et al. Ultrasonography of optic nerve sheath diameter for detection of raised intracranial pressure: a systematic review and meta-analysis. Intensive Care Med 2011; 37(7): 1059–1068.
15. Kim SE, Hong EP, Kim HC, et al. Ultrasonographic optic nerve sheath diameter to detect increased intracranial pressure in adults: a meta-analysis. Acta Radiol 2019; 60(2): 221–229.
16. Ohle R, McIsaac SM, Woo MY, et al. Sonography of the optic nerve sheath diameter for detection of raised intracranial pressure compared to computed tomography: a systematic review and meta-analysis. J Ultrasound Med 2015; 34(7): 1285–1294.
17. Robba C, Santori G, Czosnyka M, et al. Optic nerve sheath diameter measured sonographically as non-invasive estimator of intracranial pressure: a systematic review and meta-analysis. Intensive Care Med 2018; 44(8): 1284–1294.
18. McInnes MDF, Moher D, Thombs BD, et al. Preferred reporting items for a systematic review and meta-analysis of diagnostic test accuracy studies: the PRISMA-DTA statement. *JAMA* 2018; 319(4): 388–396.

19. Whiting PF, Rutjes AW, Westwood ME, et al. QUADAS-2: a revised tool for the quality assessment of diagnostic accuracy studies. *Ann Intern Med* 2011; 155: 529–536.

20. Kim KW, Lee J, Choi SH, et al. Systematic review and meta-analysis of studies evaluating diagnostic test accuracy: a practical review for clinical researchers-part I. *Korean J Radiol* 2015; 16: 1175–1187.

21. Suh CH and Park SH. Successful publication of systematic review and meta-analysis of studies evaluating diagnostic test accuracy. *Korean J Radiol* 2015; 16(6): 1188–1196.

22. Higgins J and Green S. *Cochrane handbook for systematic reviews of interventions* (Version 5.1.0). The Cochrane Collaboration. [http://handbook.cochrane.org/chapter_9/9.5_2_identifying_and_measuring_heterogeneity.htm](http://handbook.cochrane.org/chapter_9/9.5_2_identifying_and_measuring_heterogeneity.htm)

23. Deeks JJ, Macaskill P and Irwig L. The performance of tests of publication bias and other sample size effects in systematic reviews of diagnostic test accuracy. *Korean J Radiol* 2016; 17(1): 5–6.

24. Deville WL, Buntinx F, Bouter LM, et al. Conducting systematic reviews of diagnostic studies: didactic guidelines. *BMC Med Res Methodol* 2002; 2: 9.

25. Whiting PF, Rutjes AW, Westwood ME, et al. QUADAS-2: a revised tool for the quality assessment of diagnostic accuracy studies. *Ann Intern Med* 2011; 155: 529–536.

26. Deeks JJ, Macaskill P and Irwig L. The performance of tests of publication bias and other sample size effects in systematic reviews of diagnostic test accuracy was assessed. *J Clin Epidemiol* 2005; 58(9): 882–893.

27. Shofty B, Ben-Sira L, Constantini S, et al. Optic nerve sheath diameter on MR imaging: establishment of norms and comparison of pediatric patients with idiopathic intracranial hypertension with healthy controls. *AJNR Am J Neuroradiol* 2012; 33(2): 366–369.

28. Newman WD, Hollman AS, Dutton GN, et al. Measurement of optic nerve sheath diameter by ultrasound: a means of detecting acute raised intracranial pressure in hydrocephalus. *Br J Ophthalmol* 2002; 86(10): 1109–1113.

29. Choi SH, Min KT, Park EK, et al. Ultrasonographic demonstration of the optic nerve sheath to assess intracranial pressure changes after ventriculoperitoneal shunt surgery in children with hydrocephalus: a prospective observational study. *Anaesthesia* 2015; 70(11): 1268–1273.

30. Steinborn M, Friedmann M, Makowski C, et al. High resolution transbulbar sonography in children with suspicion of increased intracranial pressure. *Childs Nerv Syst* 2016; 32(4): 655–660.

31. Padayachy LC, Padayachy V, Galal U, et al. The relationship between transorbital ultrasound measurement of the optic nerve sheath diameter (ONSD) and invasively measured ICP in children: part I: repeatability, observer variability and general analysis. *Childs Nerv Syst* 2016; 32(10): 1769–1778.

32. Le A, Hoehn ME, Smith ME, et al. Bedside sonographic measurement of optic nerve sheath diameter as a predictor of increased intracranial pressure in children. *Ann Emerg Med* 2009; 53(6): 785–791.

33. Irazuzta JE, Brown ME and Akhtar J. Bedside optic nerve sheath diameter assessment in the identification of increased intracranial pressure in suspected idiopathic intracranial hypertension. *Pediatr Neurol* 2016; 54: 35–38.

34. Hall MK, Spiro DM, Sabbaj A, et al. Bedside optic nerve sheath diameter ultrasound for the evaluation of suspected pediatric ventriculoperitoneal shunt failure in the emergency department. *Childs Nerv Syst* 2013; 29(12): 2275–2280.

35. Beare NA, Kampondeni S, Glover SJ, et al. Detection of raised intracranial pressure by ultrasound measurement of optic nerve sheath diameter in African children. *Trop Med Int Health* 2008; 13(11): 1400–1404.

36. Agrawal S and Brierley J. Optic nerve sheath measurement and raised intracranial pressure in paediatric traumatic brain injury. *Eur J Trauma Emerg Surg* 2012; 38(1): 75–77.

37. Selhorst JB and Chen Y. The optic nerve. *Semin Neurol* 2009; 29: 29–35.

38. Sheth S, Branstetter BF IV and Escott EJ. Appearance of normal cranial nerves on steady-state free precession MR images. *Radiographics* 2009; 29(4): 1045–1055.

39. Legrand A, Jeanjean P, Delanghe F, et al. Estimation of optic nerve sheath diameter on an initial brain computed tomography scan can contribute prognostic information in traumatic brain injury patients. *Crit Care* 2013; 17(2): R61.

40. Sekhon MS, McBeth P, Zou J, et al. Estimation of optic nerve sheath diameter as a predictor of raised intracranial pressure in children. *Crit Care* 2013; 16(6): 1188–1196.

41. Padayachy LC, Padayachy V, Galal U, et al. The relationship between transorbital ultrasound measurement of the optic nerve sheath diameter (ONSD) and invasively measured ICP in children: part I: repeatability, observer variability and general analysis. *Childs Nerv Syst* 2016; 32(10): 1769–1778.

42. Le A, Hoehn ME, Smith ME, et al. Bedside sonographic measurement of optic nerve sheath diameter as a predictor of increased intracranial pressure in children. *Ann Emerg Med* 2009; 53(6): 785–791.