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The ultrasound study of the optic canal for detecting raised intracranial pressure (a literature review and critical analysis)

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ABSTRACT Intracranial hypertension (ICH) is a frequent and serious complication that occurs in pa-tients with severe traumatic brain injury (TBI) and non-traumatic brain damage. Persistent ICH significantly worsens the prognosis of the disease course and increases the risk of adverse outcomes. In this regard, one of the main tasks of intensive care of patients with intracranial bleeding (ICB) is diagnosis and timely management of ICH. The gold standard is invasive intracranial pressure (ICP) monitoring. The advantages of direct measurement of ICP include accuracy and continuity of registration. The disadvantages are the invasiveness of the method, high cost, the risk of developing infectious and hemorrhagic complications and possible dislocation of sensors. It is necessary to search for a method of non-invasive assessment of the level of ICH most correlated with the data of direct measurement of ICP. Ultrasonography of the optic nerve structures can be such an alternative cheap way to assess ICP. Its advantages are the possibility of repeated dynamic use, no need for surgical intervention, simplicity and high accuracy of measurement. However, the results obtained with ultrasound vary, since this method is operator dependent and requires precise adherence to the technique of the study. When the optic nerve ultrasound is performed, a contact gel for ultrasound examinations is applied to the anterolateral surface of the closed upper eyelid, and a scanning plane is displayed behind the eyeball for visualization in the central part of the ultrasound image of the optic nerve, lens and retina. To visualize the vertical course of the ophthalmic artery (and the vertical course of the optic nerve), the color flow Doppler mode is used. The study includes measuring the diameter of the optic nerve and the optic nerve sheath diameter (ONSD). There is subarachnoid space with cerebrospinal fluid between the optic nerve and its sheath. With an increase in intracranial pressure, the expansion of this space occurs, ONSD grows as well. This article contains an analysis of the literature describing the anatomy of the optic nerve and various ultrasound techniques, as well as data from various authors on the threshold value of the optic nerve sheath diameter.

Keywords: intracranial hypertension, intracranial pressure, optic nerve sheath, ultrasonography, traumatic brain injury, subarachnoid bleeding, intracranial bleeding

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CSF — cerebrospinal fluid
DCFI — Doppler color flow imaging
ICB — intracranial bleeding
ICH — intracranial hypertension
ICP — intracranial pressure
ON — optic nerve
OND — optic nerve diameter
ONSD— optic nerve sheath diameter
TBI — traumatic brain injury

Intracranial pressure (ICP) is the difference between pressure in the cranial cavity and atmospheric pressure [1–3]. The main volume in the cranial cavity is occupied by the substance of the brain (up to 85%), cerebrospinal fluid (5-7%) and blood (5%). Dynamic balance of these components and reserve of intracranial spaces maintains ICP within the normal range of 3–15 mm Hg. [1, 4, 5]. The appearance of additional volumes in the cranial cavity (hematomas, tumors, foci of ischemia, abscesses) or an increase in the volume of the main components (cerebral edema, hydrocephalus) can lead to an increase in ICP [6-10]. Permanent increase in ICP to 20 mm Hg and more,

continuing more than 5 min, considered intracranial hypertension (ICH) [11]. ICH leads to dislocation and impairment of brain structures, disruption of its blood supply and oxygenation, which significantly worsens the patient's condition [1-4]. According to various studies, patients with severe traumatic brain injury (TBI), a persistent increase in ICP is accompanied by an increase in mortality rate of up to 92% [12, 13]. In this regard, an important task of intensive care of patients with brain damage is timely diagnosis and adequate correction of increased ICP [3, 4, 14].

The most accurate method for measuring ICP is to install sensors into ventricles or brain [1, 15, 16]. The advantages of direct measurement of ICP include accuracy and continuity of registration. The disadvantages are the invasiveness of the method, high cost, risk of developing infectious and hemorrhagic complications and possible dislocation of sensors [2, 11].

At present, attempts are being made to create alternative non-invasive methods for dynamic assessment of ICP levels, which should meet the following requirements: 1) correlation with direct ICP measurement data, 2) possible multiple dynamic measurments 3) no need for surgery, 4) simplicity and high accuracy of measurement [17]. The ultrasound examination of the optic nerve is one of such methods. However, ultrasound is an operator- dependent method and requires compliance with all the rules for removing an object to visualize and measure the structures of ON for the correct interpretation of the results [17].

THE OPTIC NERVE CANAL ANATOMY

The optic nerve, like the brain, is surrounded by three brain tunics. The complex of the ON structures consists of the optic nerve, which is a continuation of white brain matter and tunics forming the external and internal vagina of ON. The external vagina is formed by the dura mater, the internal one consists of the arachnoid and the pia mater and directly surrounds the trunk of the brain. A subarachnoid space is located between the external and internal vaginas [18]. The length of the ON is 40 mm, the average diameter of the ON (OND) is 3.0 mm, the average thickness of the dura mater is 0.3 mm, the subarachnoid space between the ON and its sheath is 0.1 mm [19]. The space between the ON and its dura mater is occupied by cerebrospinal fluid (CSF) in a volume of 0.1 ml and structures of trabecules, septs and pillars. The diameter of the ON structures (ONSD), which is defined as the length of the segment between the dura mater of the ON, passing through the center of ON, is about 4.0 mm (Fig. 1) [20].

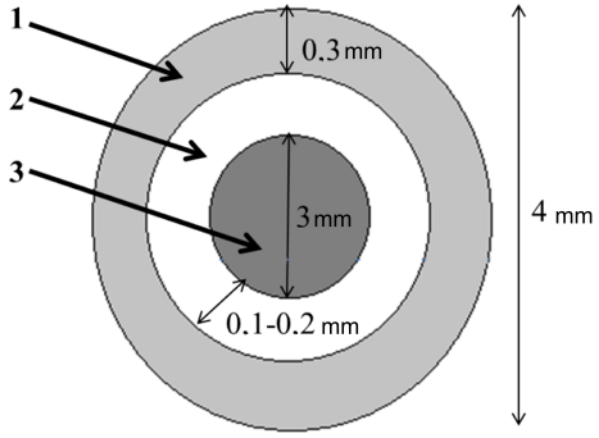

Fig. 1. The complex of the optic nerve structures (scheme): 1 — sheath of the optic nerve; 2 — subarachnoid space; 3 — optic nerve

Normal values of ONSD in patients under the age of 1 year are 4.5 mm, in patients over 1 year are 5.0 mm [21–25]. Increased intracranial pressure may lead to expansion of the ON sheath [20-25].

THE DIAMETER OF THE SHEATH OF THE OPTIC NERVE AT DIFFERENT LEVELS OF INTRACRANIAL PRESSURE

For the first time, the presence of a connection between ICP and the state of ONSD was shown in the experimental work of *S.S. Hayreh* (1964) on 32 rhesus macaques. The researcher implanted a rubber balloon into the subdural space of the brain of animals and inflated it while measuring ICP. The author noted a direct correlation between the rate of balloon inflation and the severity of edema of the ON disk. *S.S. Hayreh* found that the retrobulbar part of the periorbital subarachnoid space is elastic and can stretch with an increase in ICP, which is transmitted to the ON sheath through the subarachnoid space of the brain, leading to swelling of the disk and edema [26].

N.S. Helmke and *K.A. Hansen* (1996) studied 20 autopsied preparations of ON with sonographic examination before and after the introduction of a 20% gelatin solution heated to 40° C to the subarachnoid space of ON. After the introduction of gelatin, an expansion of the ON sheath occurred. Researchers measured the ONSD and found that at a distance of 3 mm behind the retina (bulbous segment) it increased in 60%, and at a distance of 10 mm in 35% of observations. Thus, the authors found that, at a distance of 3 mm behind the retina of the eyeball, the ON segment is most compliant for expansion, and the longitudinal plane of ultrasound scanning is optimal for

measurement [22]. *N.S. Helmke* and *K.A. Hansen* (1997) examined 12 patients with different neurological disorders. All patients underwent ultrasound of ON and lumbar puncture. The patients were divided into two groups: in the first group, the pressure of the CSF was 20 mm Hg and less, in the second group it was higher than 20 mm Hg. In patients of the first group, the ONSD was 3.3–5.4 mm, in the second group it was 3.5–6.1 mm. The growth of ONSD up to 5 mm and more was observed more often in patients with CSF pressure more than 20 mm Hg. Thus, in the diagnosis of elevated pressure of CSF, the value of ONSD as 5.0 mm was taken as the upper limit of normal. In the course of the study, a strict linear correlation was established between the pressure in the CSF and ONSD [23].

ULTRASOUND EXAMINATION OF THE OPTIC NERVE STRUCTURES

In 1970, *K..C Ossoing* for the first time demonstrated with the help of the *A*-mode ultrasound scan that the ON substance looks homogeneous with a low-intensity of echo signal in comparison with the high-intensity signal from the ON sheath [27]. In the next decade, the ultrasound technique was introduced into clinical practice using the *B*-mode, which allowed measuring the diameter of the optic zone and the diameter of its shath at the required distance behind the retina of the eyeball.

O. Berges et al. (2006) described a normal echo pattern of ON structures (from the center to the periphery): hypoechoic nerve fibers are closely surrounded by echogenic pial sheath and arachnoid meninx, covered by the hypoechoic subarachnoid space of ON, surrounded by an anechoic dura mater (Fig. 2, 3) [28].

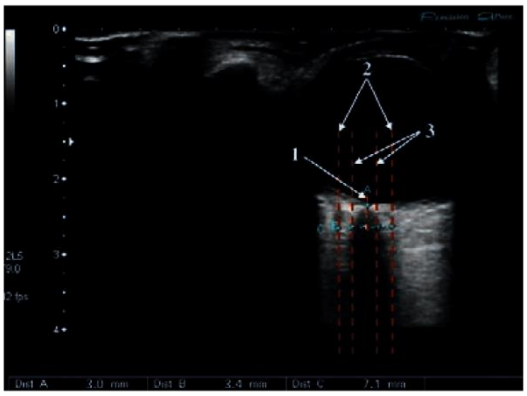

Fig. 2. Visualization of the optic nerve by ultrasound. 1 — the point 3 mm behind the retina for assessment of ONSD; 2 — diameter of the sheath of the optic nerve; 3 — diameter of the optic nerve

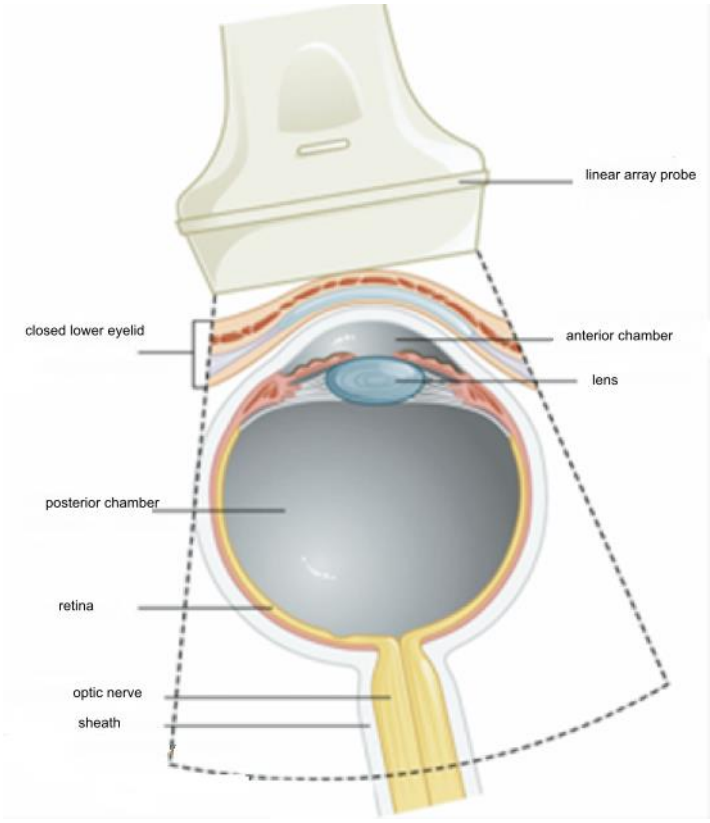

Fig. 3. The pattern of ultrasound examination of the eye ball, structures of the optic nerve [24]

Ultrasound technique of the optic nerve:

During the ON ultrasound, a linear sensor with a frequency of 7.5–14 MHz , a program “small organs” or “surface” are used, an ultrasound focus is placed on the retro-bulbar space, the scanning depth is 5–8 cm [22-24]. The acoustic power of the device is reduced to a minimum (about 30–40%) to prevent damage to the lens. To prevent local thermal effects on tissues, the values of the thermal and mechanical indices are set to less than 1.0, and the duration of the ultrasound should not exceed 5 minutes for each eyeball [29]. The contact gel for ultrasound studies is applied On the anterolateral surface of the closed upper eyelid or a plastic wrap is put on the upper eyelid of the closed eye and the gel is applied over it (Fig. 4). The scanning plane behind the eyeball is displayed to visualize the full scope of the optic nerve, lens and retina. ONSD measurement is carried out at a distance of 3 mm behind the retina using an electronic meter as a perpendicular to the axial projection [22-24]. The average data of ONSD, obtained by repeated 3–4 measurements, is recorded for both eyes. Each ON is measured in two projections: vertical and horizontal. If the ON is visualized not in the central part of the image behind the retina, but at the periphery with a linear hypoechoic artifact from the cribriform plate, then such an image is not taken into account, since the value of the ONSD may be overestimated.

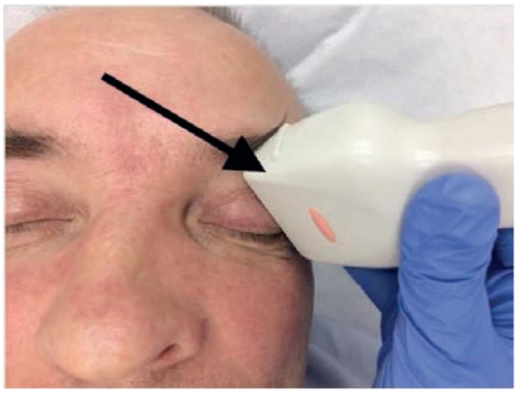

Fig. 4. The ultrasound examination of the optic nerve. The arrow indicates the location of the linear sensor on the closed upper eyelid

DIAGNOSIS OF INTRACRANIAL HYPERTENSION WITH OPTIC NERVE ULTRASOUND

The emergence of modern ultrasonic devices and the widespread introduction of ICP monitoring into practice has made it possible to assess changes in the ONS at various ICP levels. The maximum efforts of researchers were focused on determining the threshold values of ONSD at ICP 20 mm Hg and higher [23, 30, 31].

T. Geeraerts et al. (2008) conducted a prospective study in 37 patients with severe TBI, nontraumatic subarachnoid bleedings and intracranial hematomas. ICP was monitored for all patients, and ONSD and ON diameter were also measured. The value of the ICP level was 24.8±16 mm Hg; ONSD — 5.99 ± 0.40 mm; ON diameter — 4.53 ± 0.33 mm. A close statistically significant correlation between ONSD and ICP level was found. The authors established a threshold value of ONSD for ICP greater than 20 mm Hg — 5.86 mm. The ON diameter did not correlate with ICP level [30].

R. Moretti et al. (2009) examined 53 patients with subarachnoid hemorrhage, severe head injury and 53 patient without brain pathology (control group). All patients underwent ultrasound of the ON, patients with brain damage were invasively monitored for ICP. In 19 patients with a registered increase in ICP to 20 mm Hg and higher ONSD accounted for 6.2±0.6 mm, in 34 patients without ICH — 5.0±0.5 mm, and in the control group — 4.9±0.4 mm, The threshold value of ONSD for the diagnosis of ICH was 5.2 mm [32].

The data on the threshold value of ONSD presented in the literature varies considerably (Table 1). The greatest value was obtained in the study of *M. Siranovic et al.* (2011), where ONSD was 6.1 mm (*n*=4), the least value was registered by *L. Wang et al*. (2015) and it was 4.1 mm (*n*=279) [33, 34].

Table 1

The threshold value of the optic nerve sheath diameter for the diagnosis of intracranial pressure 20 mm Hg and higher

Author	Number of patients	Threshold value of ONSD, mm	Sensitivity (%)	Specificity (%)
H.C. Hansen, K. Helmke 1997 [23]	39	5		
M. Blaivas et al. 2003 [25]	35	5.0	100	95
T. Geeraerts et al. 2007 [31]	31	5.7	100	
V.S. Tayal et al. 2007 [24]	59	5	100	63
H.H. Kimberly et al. 2008 [35]	15	5	88	93
T. Soldatos et al. 2008 [36]	76	5.7	74	100
T. Geeraerts et al. 2008 [30]	37	5.9	90	84
R.S. Goel et al. 2008 [37]	100	5	98.6	92.8
R. Moretti et al. 2009 [32]	53	5.2	93	74
R. Moretti et al. 2009 [38]	63	5.2	94	76
J. Bauerle et al. 2011 [39]	10	5.8	90	84
V. Rajajee et al. 2011 [17]	65	4.8	96	94
A. Strumwasser et al. 2011 [40]	10	6	26	38
A. Amini et al. 2013 [41]	50	5.5	100	100
H. Qayyum et al. 2013 [42]	24	5	100	75
T.S. Caffery et al. 2014 [43]	51	5	75	44
C. G. Shirodkar et al. [44]	101	4.6 (for men) 4.8 (for women)	84.6 75	100 100
M. Mehrpour 2015 [45]	32	5.7	100	
L. Wang et al. 2015 [34]	279	4.1	95	92
R. Major et al. 2011 [46]	26	5	86	100
M. Siranovic et al. 2011 [33]	20	6.1	100	83
E. Flumin et al. 2014 [47]	27	5.2	83.3	100
I. M. Maissan et al. 2015 [48]	18	5.0	94	98
M. Raffiz et al. 2017 [49]	41	5.2	95.8	80.4

The majority of authors (37.5%) consider the threshold value of the ONSD 5.0 mm, 29.1% — 5.5–6.0 mm, 16.7% of the authors — 5.0–5.4 mm, and 8.3 % — 4.5–5.0 mm. Only in one work (4.2%) it was recommended to count 4.1

mm as the threshold value of ONSD, and in one work (4.2%) — 6.1 mm. Differences in the interpretation of the obtained data are associated with an insufficient number of measurements of the ONSD in one patient (they were not always carried out more than 1 time). The information on the average value of ONSD obtained by repeating the study 2 or 3 times was more accurate [22-24].

Another factor affecting the threshold value of ONSD is measurement inaccuracy associated with the erroneous addition of the shadow width of the artifact from the cribriform plate or the measurement of the ON sheath in the area of its bend, that is, obtaining a known larger size [39].

R. Copetti and *L. Cattarossi* (2009) entered into controversy with *T. Geeraerts*. The essence of the discussion was that *T. Geeraerts* did not take into account the ON pathway, the measurement was performed not strictly perpendicular, which led to an overestimation of the values of ONSD. According to *R. Copetti* and *L. Cattarossi*, visualization of the ophthalmic artery with the help of the Doppler color flow imaging (DCMI) mode [50] could help to determine the direction of the ON path. Since the ophthalmic artery goes in the structure of the ON canal, respectively, its visualization allows you to correctly hold the absolute perpendicular to the ON. The use of such an additional mode for ON ultrasound allows to unify the methodology and lead to uniformity.

After analyzing the 24 sources listed in the Table 1, we found scans of ultrasound images of the ONSD dimensions only in 14 of them. At the same time, in 5 works, the quality of the image was insufficient for interpretation. In assessing the available information resources, we found that in 2 studies, ONSD was significantly overestimated (5.7–5.8 mm) [50], and in a work of *V. Rajajee et al*. (2011) the indicator of ONSD was underestimated (4.8 mm), since the authors did not take into account one of the ON sheaths [17].

Only 6 articles had high-quality photos of ultrasound images of ON structures, in which the measurements of the ONSD were carried out correctly. *J. Bauerle et al*. (2011) complied with all the subtleties of the technique of ON ultrasound in their study: the absence of artifacts, the correct display and perpendicular measurement. In their work, the threshold value of ONSD was 5.8 mm, but measurements were performed only in 10 patients with ICB [39].

The threshold values of ONSD cited in the last 6 papers ranged from 4.6 to 5.8 mm. In the remaining 10 out of 24 articles, photographs of ultrasound images are not given, which does not allow a more detailed analysis of the causes of heterogeneity of data on the threshold value of ONSD to be performed.

Due to the high operator dependence of the method, the lack of provided works is the lack of information about the specialists who performed ultrasound sonography of the ON: radiology, anesthesiology and intensive care specialists or laboratory assistants.

None of the articles cited dynamic studies on the measurement of ONSD for several days after surgery or injury. All authors performed 1–2 studies within a day in one patient.

CONCLUSION

Intracranial hypertension is a terrible complication that occurs in patients with traumatic and non-traumatic brain damage and significantly worsens the prognosis of the disease. One of the main tasks of the intensive care of patients with intracranial hemorrhage is the diagnosis and correction of intracranial hypertension. The ultrasound of the optic nerve may be an alternative non-invasive method for measuring intracranial pressure. However, more research is needed for the widespread introduction of the method into clinical practice.

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