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REVIEW ARTICLE

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Optic nerve sheath diameter: present and future perspectives for neurologists and critical care physicians

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Abstract

Background Estimation of intracranial pressure (ICP) may be helpful in the management of neurological critically ill patients. It has been shown that ultrasonography of the optic nerve sheath diameter (ONSD) is a reliable tool for non-invasive estimation of increased intracranial pressure (ICP) at hospital admission or in intensive care. Less is known about the estimation of increased ICP and usefulness of ONSD in the prehospital setting. The aim of this review was to elucidate both prevailing and novel applications of ONSD for neurologists and critical care physicians.

Methods In this review, we discuss the technique and the novel approach of ONSD measurement, the clinical applications of ONSD in neurology and critical care patients.

Results ONSD measurement is simple, easy to learn, and has diverse applications. ONSD has utility for ICP measurement in intracranial hemorrhage and ischemic stroke, meningitis and encephalitis, and idiopathic intracranial hypertension (IIH). It is also valuable for lesser known syndromes, where an increase of ICP is postulated, such as acute mountain sickness and posterior reversible encephalopathy syndrome. ONSD changes develop in inflammatory or ischemic optic neuropathies. Some papers demonstrate the usefulness of ONSD studies in symptomatic intracranial hypotension.

Conclusions ONSD is a safe and low-cost bedside tool with the potential of screening patients who need other neuroimaging and those who may need an invasive measurement of ICP.

Keywords Optic nerve sheath diameter (ONSD) · Transorbital ultrasonography (TSO) · Optic nerve · Symptomatic intracranial hypotension (SIH) · Intracranial pressure (ICP) · Acute mountain sickness (AMS)

Introduction

The sonographic measurement of optic nerve sheath diameter (ONSD) is a non-invasive, simple tool with a reasonable level of diagnostic accuracy for estimating intracranial hypertension (ICP) [1, 2]. Since the subarachnoid space of the optic nerve is a continuum with the intracranial cerebrospinal fluid (CSF) spaces, it can be expanded by an increase of ICP and modify the ONSD. Acute and chronic diseases with an increase in ICP (e.g., idiopathic intracranial hypertension, craniocerebral trauma, malignant middle cerebral artery stroke, intracranial hemorrhage, decompensated hydrocephalus) lead to an increase of ONSD. In cases where the increase of ICP persists, a congested papilla develops with optic disc elevation (ODE), which can be detected with ultrasonography. Furthermore, some recent papers indicate that a diminution of ICP can provoke a decrease in ONSD. Dynamic measurement including a comparison of lying and standing positions can then help further to identify symptomatic intracranial hypotension [3].

In comparison with conventional neuroimaging methods, such as computed tomography (CT) and magnetic resonance imaging (MRI), transorbital sonography (TOS)

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has the advantages of being low cost, with short investigation times, good reproducibility, and bedside availability, and most importantly of being non-invasive and simple [4, 5]. In the clinical decision-making, this technique, combined with clinical and neurological status and neuroimaging may help physicians (especially neurologists) to decide whether to transfer patients with severe neurological pathologies to specialized centers or to place an invasive device instead [2]. However, the modification of ONSD may take place not only alongside the variation in ICP, but may also occur due to inflammatory lesions of the optic nerve itself. In these lesions, a change in the diameter develops on an inflammatory basis due to perilesional edema which may occur in acute optic neuritis [6].

The aim of this review is to provide an update on the state of ONSD technology and potential future applications. In the first part of this review, we focus on the basic physical principles and safety in ocular sonography. In the second part, we describe clinical applications in general neurology and in critical care in the prehospital or intra-hospital setting. At the end of our review, we discuss the limitations of the technique and future perspectives.

Optic nerve sheath diameter ultrasonography for detection of ICP

Intracranial hypertension is an emergency which can be detected using clinical symptoms, imaging data, and ophthalmologic signs. Intracranial hypertension is confirmed by invasive intracranial monitoring, which is the gold standard technique to measure ICP. Because of the risk of complications—in particular hemorrhage or infection—recently non-invasive methods such as transcranial Doppler sonography (TCD), MRI, cranial CT, and ONSD ultrasonography have been developed in order to estimate increased ICP.

The optic nerve is surrounded by CSF, which is connected to the ventricular system of the brain. The sheath of the optic nerve is composed of the dura, arachnoid, and pia mater, which border a small amount of CSF in the subarachnoid space. Increased ICP is, therefore, believed to cause transmission of force through these spaces, resulting in distention of the ONSD. Notably, further support for this theory is suggested in studies showing a similar correlation in the opposite direction (i.e., a small ONSD value in the setting of decreased ICP) [7, 8]. In experimental as well as human studies, an immediate change (within minutes) of ONSD corresponding to a change of ICP has been demonstrated [9–11].

In the following sections, we describe the technique and main parameter settings of ONSD.

Technical and safety issues of optic nerve sheath diameter ultrasonography: static and dynamic measurement

Technique and safety considerations

Ultrasonography of ONSD and the optic nerve can be easily performed using most color ultrasound systems equipped with high-frequency linear probes (7.5 MHz or higher) with a lateral spatial resolution of less than 0.4 mm [12]. As a first step, the system settings should be adjusted (mechanical index = 0.23 and the thermal index (TI) = 0.0) in order to prevent the damage of sensitive structures such as the lens, retina, and vitreous body (cavitation and thermal index) [13]. Secondly, all parameters, such as time gain compensation or gray scale, depth, and gain are individually adapted in order to achieve the best image quality. Vigilant training in the examination technique is advised. Standardization of technique is of great importance to reduce the inter- and intra-observer variation and establish the true axial plane and the exact boundaries of the sheath [14–16]. Otherwise, shadowing artifacts caused by the lens and the optic disc or by inexperienced operators may significantly alter measurement of ONSD [17].

For ONSD measurement, the examiner normally sits at the head of the examination table with the patient positioned supine with the head and upper body raised 20–30° to avoid any pressure on the eye. The patient remains in this position for at least 1 min before data are recorded. A thick layer of gel is applied to the closed upper eyelid. The transducer should be positioned on the temporal side of the eye. To help suppress eye movement and to achieve a better delineation of the major anatomical landmarks (optic nerve and lens), the patient is asked to look forward with closed eyes [15, 18, 19]. With this technique, optic nerve along with the globe and lens can be visualized. The globe appears homogenously anechoic. It is divided into anterior and posterior chambers by the hyperechoic line formed by the lens. In the axial plane, the optic nerve can be visualized posterior to the globe. Brightness and contrast should be adjusted to best define the optic nerve and surrounding sheath. The optic nerves are clearly visible because of their well-defined, longitudinal compact structure (Fig. 1). As previously described, ONSD should be measured 3 mm behind the globe, in each eye perpendicular to the optic nerve axis, using an electronic caliper and an axis perpendicular to the optic nerve (Fig. 2c) [9, 10]. Additionally, the mean of three measured values is computed, in order to reduce the intra-observer variability [15].

The correct way to measure the ONSD is between the outer hyperechogenic borders of the subarachnoid space. The sonographic aspect of the optic nerve is from the center to the periphery: hypoechogenic nerve fibers are closely surrounded by

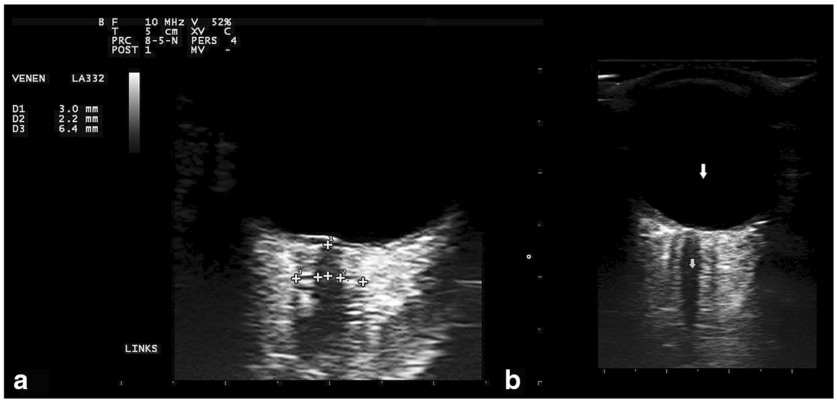

Fig. 1 Measurement of the optic nerve diameter (OND) and optic nerve sheath diameter (ONSD) 3 mm behind the papilla (1) (**a**), using an electronic caliper and an axis perpendicular to the ON. Optic nerve diameter (OND) was measured as the distance inside the pia mater (2) and ONSD as the distance inside the dura mater on the hyperechogenic area surrounding the optic nerve (3). **b** Overview of the eyeball and the retroocular space using B mode. Ultrasonography makes an axial cut through the eye including a longitudinal section of optic nerve: hypoechogenic ocular globe (big arrow) and hypoechogenic optic nerve (small arrow)

the hyperechogenic pia mater; the subarachnoid space appears hyperechogenic due to the trabecular structure and is surrounded by dura mater and periorbital fat (Fig. 1) [1].

Although the correct way of measuring ONSD is clearly described, there remain numerous studies which measure ONSD with improper, non-standard technique. In these studies, ONSD is measured incorrectly by measuring the distance between the outer hypoechogenic borders. This incorrect approach results in false and enlarged ONSD values [20, 21]. The learning curve for experienced sonologists may include as few as 10 examinations, whereas for novice sonologists the number of scans needed may be closer to 25 [22].

Dynamic measurement

A dynamic measurement at two time points and in two different positions has proven useful in patients affected by spontaneous intracranial hypotension (SIH). The ONSD measurement should be conducted starting with the patient in supine position and then in upright position with the patient standing for 2 min (Fig. 2) [3]. Another possibility is the measurement of ONSD approximately 5 min prior to and after a lumbar puncture in order to estimate—in real time—a reduction in CSF pressure or the efficacy of postpunctural treatment in patients with idiopathic intracranial hypertension [23, 24].

Ertl et al. obtained a measurement of changes of ONSD, in supine and orthostatic position, in 31 patients with idiopathic normal pressure hydrocephalus (iNPH) before and after lumbar puncture.

The mean pre-puncture ONSD-variability was significantly lower in healthy volunteers and patients with no response to CSF removal than in responsive patients. In this context, ONSD may also support selection of patients for shunt intervention [25].

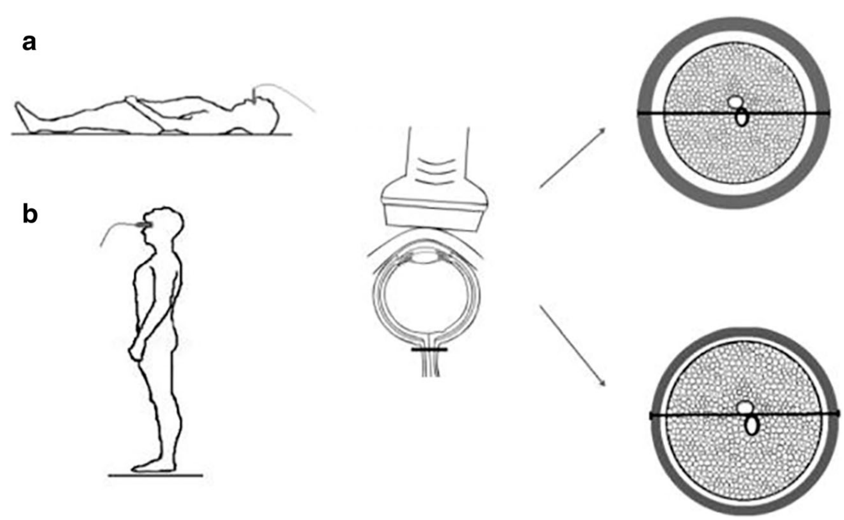

Fig. 2 Dynamic ultrasonography measurement. Optic nerve sheath diameter (ONSD) changes in a symptomatic patient with spontaneous intracranial hypotension from supine to upright body position. **a** Supine position. **b** Orthostatic position. The upper right picture shows how the examination can be performed using transorbital ultrasound. **b** The lower right picture shows the changes of ONSD from supine to orthostatic position

Clinical applications

Neurological application

A variety of potential applications have been described in different neurological settings.

Intracranial hemorrhage and ischemic stroke

In 25 acute intracerebral hemorrhage (ICH) patients with clinical and radiological CT signs of raised ICP, Naldi et al. report sensitivity and specificity of 100% for ONSD for the detection of increased ICP compared to the Doppler indices, with 48% sensitivity and 95% specificity for resistive index (RI) and 80% sensitivity and 62% specificity for retinal venous pulsation (RVP) [26].

Skoulodik et al. found an enlarged ONSD even in the hyperacute phases of acute ICH within 6 h of the symptom onset ($p < 0.0083$), with the best cut-off point to predict intracranial hemorrhage volume of > 2.5 cm^3 corresponding to an ONSD enlargement of > 0.66 cm (> 21%), with 90.3% accuracy and interrater reliability of 0.760 (95% CI 0.509 to 1.000) [27]. Yesilaras et al. measured ONSD on CT scans and found a threshold value of 6.1 mm, with sensitivity and specificity for subarachnoid hemorrhage (SAH) of 72%, to distinguish controls from SAH patients [28]. Bäuerle et al. showed an increase of ONSD in a cohort of 27 patients with subarachnoid hemorrhage (SAH) and acute hydrocephalus after aneurysm rupture, with a persistence of expansion of ONSD after normalization of ICP, postulating an impaired retraction capability of the optic nerve sheath after a massive ICP exposure [29]. Gokcen et al. found that the highest binocular ONSD was detected in patients affected by complete anterior circulation infarction ($p < 0.001$) compared to other ischemic groups, according to the Oxfordshire Community Stroke Project. The authors showed that ONSD could identify middle cerebral artery (MCA) stroke patients at high risk of developing malignant MCA syndrome, permitting early diagnosis of a possible ICP increase using ONSD with the possible benefit of decreasing mortality and morbidity in patients with cerebrovascular diseases [30].

Idiopathic intracranial hypertension

Idiopathic intracranial hypertension (IIH) (also known as primary pseudotumor cerebri syndrome (PTCS)) refers to disorders in which the mechanism of increased CSF remains elusive. It is defined by an increase of ICP without neuroradiological abnormalities [31–33]. Increased ICP typically develops over a period of weeks or months. Typical signs and symptoms of IIH include headache, pulsatile tinnitus, transient visual obscurations, blurred vision, diplopia, and papilledema.

Some studies addressed the role of transorbital sonography in supporting the diagnosis of primary PTCS [23, 34]. Very recently, Lochner et al. found similar results of ONSD measurements in IIH and secondary PTCS [35]. In a recent meta-analysis, Lochner et al. demonstrated that patients showed a significant thickening of ONSD, 6.2–6.76 mm compared to 4.3–5.7 mm in controls. ONSD was significantly higher in IIH patients compared to controls (overall weighted mean difference of 1.3 mm (95% CI 0.6 – 1.9 mm)) [36].

ONSD could be useful for monitoring IIH. After 6 months of diet and medication, a correlation between the variation of ONSD and improvement of headache has been observed by the same author. ONSD decreased significantly from the start of the study (median, 6.51 mm (interquartile range 6.13–7.10)) to 6 months later (6.08 mm (5.59–6.73), $P = 0.002$) [37].

Intracranial hypotension, patch test

Symptomatic intracranial hypotension (SIH) can be spontaneous or occur after lumbar puncture. It is characterized by orthostatic headache, associated with neck pain or stiffness, nausea, or vomiting [38]. However, a minority of SIH cases present with each classical symptom, so it may be difficult to correctly diagnose this condition.

In combination with cerebral and spinal magnetic resonance imaging (MRI) or CT myelography, TOS can be useful for diagnosis and monitoring of SIH, showing a decrease in ONSD compared to normal ONSD values (Fig. 2). Another important aspect is highlighted by the modification of ONSD by treatment of SIH using epidural patching. Indeed, Dubost et al. showed that nine out of ten patients had an increase of ONSD with successful lumbar epidural blood patching [39]. Recently, Fichtner et al. evaluated the diagnostic value of ONSD by performing two orbital ultrasound assessments, in supine and upright positions (Fig. 2), for three groups of patients (symptomatic and asymptomatic spontaneous intracranial hypotension patients and controls). The main finding was a significant decrease of ONSD when changing from the supine to upright position in symptomatic patients with SIH [3].

Posterior reversible encephalopathy syndrome

Posterior reversible encephalopathy syndrome (PRES) is a clinical and radiological syndrome, consisting of headache, visual changes, seizure, and imaging findings, including cerebral edema affecting the cerebral cortex and underlying white matter. It manifests as areas of hyperintensity in T2 and FLAIR imaging, most often involving the occipital and posterior parietal lobes [40]. Although rare, PRES may involve the brainstem and/or cerebellum on neuroimaging. Lee et al. showed that 22 (58%) of 38 episodes of PRES involved the brainstem and/or cerebellum on neuroimaging [41]. Another literature review reported 26 patients with brainstem involvement [42].

Although the pathogenesis of PRES is still not completely understood, it is postulated that an impairment of cerebral auto-regulation—resulting in arterial hypertension above the limit of cerebral self-regulation, breakdown of the blood–brain barrier (BBB), and subsequent brain edema—is the main underlying mechanism. This syndrome may be associated with either increased ICP or altered BBB permeability. In this context, TOS may be useful in demonstrating papilledema and an increase in the size of the ONSD. The thickening of ONSD could therefore occur as a result of increased ICP in some cases or because of an inflammatory cause due to alteration of optic nerve pathways. Very few reports are available in the literature concerning ultrasound diagnostics in patients with PRES where ONSD measurements are used to evaluate the many physiologic parameters of interest [43–45].

Meningitis and encephalitis

Serious bacterial meningitis or encephalitis can lead to an elevation of the ICP and hydrocephalus. To date, there are only few reports of an increase in ICP in the context of viral or bacterial meningitis. It is also reported that ONSD can be used to detect raised ICP in patients with tuberculous meningitis or encephalitis [46, 47].

Acute mountain sickness

The pathophysiology of acute mountain sickness (AMS) remains under investigation. Some recent studies using neuroimaging techniques found that hypoxia may increase cerebral arterial blood flow and venous volume, leading to increased ICP [8, 48]. Further, AMS symptoms can be due to a lower ability of some subjects to cope with an increase in brain volume [49].

The development of portable ultrasound equipment has made it possible to take measurements of ONSD in remote settings, including at high altitude. In this context, some authors exploring the utility of ultrasound at high altitudes showed that ONSD rapidly increased after exposure to progressively increasing altitude [50–52]. In particular, Fagenholz et al. performed serial examinations in 10 out of 284 subjects, who traveled at high altitude through Pheriche, Nepal (4240 m). In these subjects, the change in Lake Louise score had a strong positive correlation with change in ONSD. Mean ONSD was 5.34 mm (95% CI 5.18–5.51 mm) in the 69 subjects with AMS vs. 4.46 mm (95% CI 4.39–4.54 mm) in the 218 other subjects ($P < 0.0001$) [53]. In a recent systematic review, Lochner et al. concluded that the measurement of ONSD might appear to be a promising tool for diagnosis and monitoring of AMS in research on CNS changes at high altitude, but the biggest limitation of this technique are the small variations of ONSD changes after high altitude exposure in some of the reported studies [54].

Hydrocephalus

ONSD was measured as a predictor of increased ICP and for monitoring of hydrocephalus in several studies assessed using CT scan or ultrasound. Lee et al. evaluated ONSD in adult hydrocephalus on preoperative CT and found in eight patients with a higher ICP (> 20 mmHg) and a significant thickening of ONSD (5.8 vs. 4.9 mm, $P = 0.001$) [55]. Brzezinska et al. found a mean ONSD of 3.5 mm with a range of 2.6 to 4.1 mm in 50 patients without signs of increased ICP and a mean ONSD of 5.4 mm with a range between 3.9 and 6.9 mm in 52 patients with signs of ICP elevation [56]. Newman et al. verified the function of ventriculoperitoneal shunt in children and reported a mean of ONSD 2.9 (SD 0.5) mm compared to those with raised ICP 5.6 (SD 0.6) [57].

Finally, Ertl et al. showed that another possible application is the measurement of ONSD changes using dynamic measurements in patients with idiopathic normal pressure hydrocephalus: mean pre-puncture ONSD-variability was significantly lower in healthy volunteers and patients with no response to CSF removal than in responsive patients. ONSD may also support selection of patients for shunt intervention [25].

Taken together, although the technique still requires wide validation, ONSD measurement presents a potentially valuable option in cases where repetitive CT measurements have to be performed to monitor obstructive hydrocephalus in an intensive care unit.

Optic neuritis and non-arteritic ischemic optic neuropathy

Optic neuritis (ON) is an acute multi-etiological inflammatory condition affecting the optic nerve causing retro-orbital pain and visual loss. In a high percentage of cases, it is highly associated with multiple sclerosis [58]. At an early stage of inflammation, there is an abnormal increase in permeability of the blood–brain barrier, revealed by gadolinium-DTPA enhancement in all patients examined, gradually followed by edema, which usually lasts for a few weeks and then diminishes to the point of restoring the normal permeability of the blood–brain barrier [59].

Several studies detected an increased ONSD as an expression of optic nerve inflammation due to increased perineural subarachnoid fluid. In particular, results of seven studies showed an increased ONSD in 78 to 100% of patients in the affected eye compared with its unaffected fellow eye or control subjects [60–66]. Based on the anterior location of clinical involvement, four out of seven studies demonstrated papillitis with a swollen disc in 6–43% of patients. In fact, B-mode transorbital ultrasonography provides promising support for the clinical diagnosis of acute ON (Fig. 3) [6]. Further studies are warranted in order to provide information about therapeutic monitoring in ON. The main finding of non-arteritic ischemic optic neuropathy is the papilledema. In contrast to acute optic neuritis, in non-arteritic ischemic optic neuropathy (nAION), two authors did not report any change of ONSD (Fig. 4) [60, 62].

Neurological complications in not neurological settings

In this section, we will describe some of the major applications in not neurological settings, where primarily systemic diseases can further cause neurological complications.

Pregnancy Pregnancy is associated with pathophysiological changes which predispose to several neurologic disorders [67]. Recent studies report that ONSD can predict the development of preeclampsia and eclampsia [68]. In a recent study, ONSD was significantly higher in preeclamptic patients compared to healthy pregnant women at delivery with 20 to 43% of preeclamptic patients having ONSD values compatible with intracranial pressure above 20 mmHg [69]. Cerebral edema and ICH are common after acute liver failure and are major causes of morbidity and mortality [70, 71]. The role of invasive ICP monitoring remains controversial in this group of patients because of the risk of coagulopathy and intracranial hemorrhage [72–74]. ONSD can therefore play a role in this patient group. Recently, in a retrospective study of 41 patients with liver failure, ONSD and other non-invasive ICP methods were compared with invasive ICP methods [75]. ONSD had an AUC of 0.59 (95% CI 0.37–0.79, $P = 0.54$) with no correlation with mortality. However, in a study in a pediatric cohort with liver failure, ONSD was a good predictor of poor outcome related to increased ICP [76].

Cardiac arrest/coma Few parameters are available to predict neurologic outcome of post-cardiac arrest patients. In the early stage of treatment, ONSD measurement is valuable as a prognostic indicator of hypoxic encephalopathy, both on CT or ultrasound with contrast [77]. The better prognostic value was observed when ONSD was combined with other parameters such as gray-to-white matter ratio on initial CT scan in post-cardiac arrest subjects [78].

In post-cardiac arrest patients conducted by Ueda et al., the mean ONSD at admission associated with a favorable prognosis was 5.0 mm (4.4–6.1 mm). ONSD of 6.1 mm (5.4–7.2 mm) was associated with poor prognosis. ONSD of ≤ 5.4 mm was associated with a favorable prognosis with a sensitivity of 83% (95% CI 36–100) and specificity of 73% (95% CI 39–94) [79]. In a prospective observational study of post-cardiac arrest patients, ONSD was used to predict outcomes due to brain edema caused by hypoxic-ischemic encephalopathy (HIE). For predicting mortality, an ONSD threshold value of 5.75 mm had a specificity of 100% and PPV of 100%. Non-survivors had significantly higher ONSD values ($P < 0.001$) [80]. Other studies of ONSD with serum albumin concentration or ONSD alone have demonstrated similar results [81].

Intraoperative complications Intraoperative use of ONSD has gained popularity over the years and could be used in every type of surgery to monitor the occurrence of neurological complications during anesthesia for general surgery and neurosurgery. An example of an important application of ONSD in the intraoperative setting is in patients undergoing laparoscopic surgery. This technique requires adequate surgical exposure and the application of a CO_2 pneumoperitoneum (PP) and often a concomitant steep head–down position (up to 45°, Trendelenburg position), together increasing the risk for decreased venous return, variation of mean arterial pressure and systemic vascular resistance, hypercapnia, and therefore an increase of ICP [82, 83]. Some authors have reported

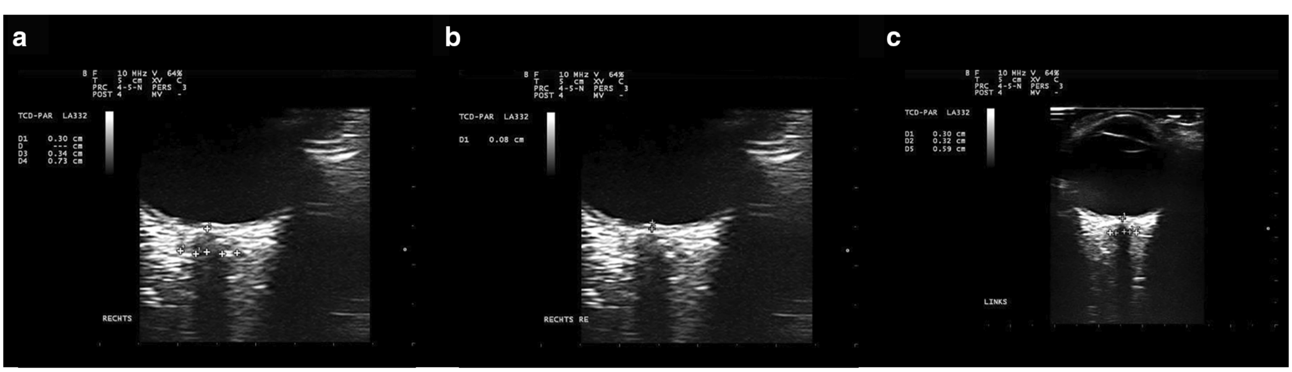

Fig. 3 **a**–**c**. Sonographic examinations of the eye are performed in a patient affected by optic neuritis with papillitis. **a** The dotted arrow (1) denotes where the optic nerve measurement takes place, 3 mm behind the papilla in an axial plane shows the optic nerve (2) in its longitudinal course. The dotted arrow (3) denotes an increase of optic nerve sheath diameter (ONSD) in the right eye (7.3 mm). **b** Optic disc elevation of (0.8 mm) on the right side. The measurement is gauged between the fundus and the dome of the papilla. **c** (5) ONSD of 5.9 mm in the non-affected left eye

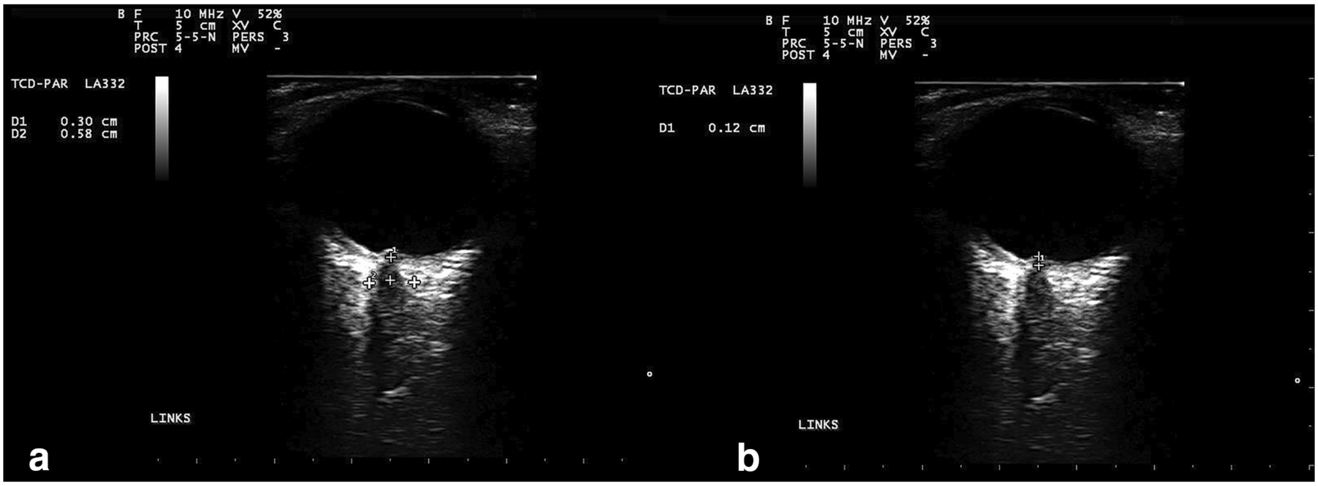

Fig. 4 Patient affected by non-arteritic anterior ischemic optic neuropathy (nAION). In the neurological examination: reduction of visual acuity on the left side (Visus 0.2), otherwise no focal neurological deficit. The picture shows an optic nerve sheath diameter (ONSD) of 0.58 cm, associated with optic disc elevation of 0.12 cm

neurological complications during laparoscopy including cerebral ischemia and cerebral edema, or minor clinical symptoms such as nausea, and headache that could be associated with increased ICP have been reported after laparoscopy [83, 84]. Because an increase of ICP above 20 mmHg has been detected in a significant number of patients without neurological disease (7.5 to 15% of cases), a non-invasive ICP measurement method would be useful [85, 86].

ONSD ultrasonography during PP and Trendelenburg positions has been studied by many authors who have demonstrated a significant increase of ONSD during PP and TP. A meta-analysis of 460 subjects showed that ONSD increases significantly in both the early period (0–30 min) and late period (30–120 min) during CO_2 pneumoperitoneum [87]. In a prospective study in patients who had undergone thoraco-abdominal aortic aneurysm repair surgery, Ertl et al. found a significant increase of ONSD between baseline and different intraoperative time points (right eye: $P = 0.006$; left eye: $P = 0.02$) [88]. In particular, within a group of five patients having an additional increase of ONSD during the surgery, one developed permanent paraplegia. Patients with spinal catheters had significantly lower ONSDs at nearly all time points. This technique could be useful to discover which patients need CSF drainage.

Limitations

The ultrasound method is limited by a lateral resolution of 0.3–0.4 mm. Ultrasonography cannot be performed in patients with ocular trauma, glaucoma, or previous optic nerve atrophy. Another limit of this technique is the marked variability of ONSD, found in studies including both healthy subjects and subjects with pathological conditions, and different cut-offs in pathological conditions. Moreover, it seems to be possible that the distensibility of ONSD is variable in individuals. After a massive increase of ICP, it is possible that the ONSD is not able to shrink. Finally, there are some concerns about the standardization of ONSD measurement.

Future perspectives

While only two studies have been performed in the prehospital setting (in an ambulance as well as on a helicopter), both have demonstrated the feasibility of this technique treating patients with brain traumatic injuries (TBI). Houzé-Cerfon et al. were able to measure ONSD in 19 (82%) patients with moderate and severe TBI with 80% of ONSD measurements validated by the experts [89]. ONSD measurements were possible in 15 (79%) cases. The success rate in the helicopter was 43% compared to 80% in the ambulance. Massain et al. measured ONSD in healthy volunteers during helicopter liftoff and acceleration in the supine position or with a raised headrest. ONSD increased during helicopter acceleration (−9° Trendelenburg, mean = 5.6 ± 0.3 mm) from baseline (0° supine position, mean = 5.0 ± 0.4 mm) [90].

Another field of research could be the development of automated, computerized systems for the segmentation of structures in B-mode ultrasound images that may help to reduce operator-dependency, accelerate the acquisition time, and mitigate the issue of inter-operator variability [91]. In this context, Gerber et al. have developed an algorithm to automatically estimate the ONSD from 23 ocular ultrasound images [92].

Conclusion

In this review, we summarize the main indications for ONSD in neurology and intensive care. ONSD is a still underestimated imaging modality that deserves wider acceptance. Because this bedside tool allows for fast and safe real-time assessment of conditions associated with elevated intracranial pressure, we propose routine inclusion of ONSD measurement in the multimodal monitoring of patients in neurocritical care. ONSD measurement, together with invasive ICP monitoring, is valuable for neurological conditions with clinically suspected variation of ICP and in optic nerve disorders. Currently, the biggest limitation of this technique is the marked variability in ONSD reported across studies in healthy subjects and subjects with pathological conditions. For this reason, further longitudinal prospective studies with standardized technique should be encouraged to better assess the usefulness and limits of this technique.

Compliance with ethical standards This article does not contain any studies with human participants or animals performed by any of the authors.

Conflict of interest The authors declare that they have no conflict of interest.

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