ORIGINAL COMMUNICATION

Sonographic assessment of the optic nerve sheath in idiopathic intracranial hypertension

Jochen Bäuerle · Max Nedelmann

Abstract The aim of this work was to investigate the potential of ultrasound-based optic nerve sheath diameter (ONSD) measurements in detecting raised intracranial pressure in patients with idiopathic intracranial hypertension (IIH) and to describe ONSD response to lumbar puncture. In ten patients with newly diagnosed IIH, transorbital sonography was carried out to assess ONSD, OND (optic nerve diameter), and optic disc elevation before and after lumbar puncture. Twenty-five patients with other neurological disorders served as controls. Subjects with IIH showed a significantly enlarged ONSD on both sides (6.4 ± 0.6 mm vs. 5.4 ± 0.5 mm in controls; $p < 0.001$). The best cut-off value of ONSD for detecting raised ICP was 5.8 mm with a sensitivity of 90% and a specificity of 84%. After lumbar puncture, ONSD decreased bilaterally (right 5.8 ± 0.7 mm, $p < 0.004$; left 5.9 ± 0.7 mm, $p < 0.043$). No post-puncture changes could be observed with regard to OND and optic disc elevation. Sonographic ONSD evaluation may be useful as an additional tool to identify patients with raised intracranial pressure, as in IIH. Furthermore, our data suggest a potential usefulness of this method for monitoring of treatment effects. The degree of ONSD response to lumbar puncture differs in subjects with IIH, which may possibly be related to findings of a defective CSF circulation in the optic nerve sheath in this disorder, a state that is referred to as optic nerve compartment syndrome.

Keywords Optic nerve sheath diameter · Optic nerve sonography · Idiopathic intracranial hypertension · Optic nerve diameter

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Introduction

Sonographic assessment of the optic nerve sheath diameter (ONSD) has been proven to be feasible and reliable in detecting raised intracranial pressure in neurocritical care patients [6]. Only limited data exists that deals with this issue in idiopathic intracranial hypertension (IIH) [3]. Anatomically, these findings can be explained by the continuity of the meninges and the subarachnoid space surrounding the optic nerve in the orbita. Consequently, the subarachnoid space of the optic nerve will be altered by intracranial pressure changes. A correlation of short-term ONSD changes with ICP variations in brain injured patients has been demonstrated in an ultrasound-based study previously [6]. In contrast, there is evidence of an optic nerve compartment syndrome in idiopathic intracranial hypertension with a reduced CSF turnover in the optic nerve sheath, which may have an influence on ICP-related ONSD alterations [11, 12]. The aim of this study was therefore to investigate the potential of transorbital sonography in detecting raised intracranial pressure in patients suffering from IIH and to evaluate the short-term effects of therapeutic lumbar puncture on the ONSD.

Methods

Study subjects

The study was approved by the local ethics committee and was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. Subsequently, study subjects were recruited in the Department of Neurology of the University Hospital Giessen. Consecutive patients were enrolled if they granted informed consent and

met the inclusion and exclusion criteria for one of the following study groups.

The control group consisted of patients who suffered from neurological disorders without signs of elevated intracranial pressure and who had not undergone lumbar puncture in the past.

Study subjects with idiopathic intracranial hypertension were recruited according to the updated diagnostic criteria [2]. All patients underwent magnetic resonance imaging with venography to exclude venous sinus thrombosis or structural CNS lesions. In all patients, diagnosis was newly established and all individuals had to be naive to treatment. Bilateral papilledema was documented in all probands by an ophthalmological examination including funduscopy. In both groups, patients had to be 18 years old or older with no history of glaucoma, amblyopia, or diseases of the optic nerve.

Transorbital sonography

Ultrasound examinations of the eye were carried out in B-mode using a Philips iU22 ultrasound system and a 9–3 MHz linear array transducer (Philips Medical Systems; Bothell, WA). The patients were examined in supine position with the upper part of the body and the head elevated to 20–30°. In patients with IIH, measurements were performed before lumbar puncture and the day after the procedure. For safety reasons of biomechanical side-effects, the mechanical index (MI) was reduced to 0.2. The probe was placed on the temporal part of the closed upper eyelid using a thick layer of ultrasound gel. The anterior part of the optic nerve was depicted in an axial plane showing the papilla and the optic nerve in its longitudinal course. ONSD and optic nerve diameter (OND) were assessed 3 mm behind the papilla, as described previously [1]. In order to gauge the ONSD, the distance between the external borders of the hyperechogenic area surrounding the optic nerve was quantified. The OND was measured marking the internal borders of this formation. Each bulb was examined three times and means were calculated. The optic disc elevation was gauged between the fundus and the dome of the papilla (Fig. 1).

Lumbar puncture

Prior to lumbar puncture, written informed consent was obtained from all IIH patients. The procedure was performed with the patient lying in supine position on the right side. After measuring the CSF opening pressure, therapeutic removal of 30–50 ml of CSF was carried out by the attending physician.
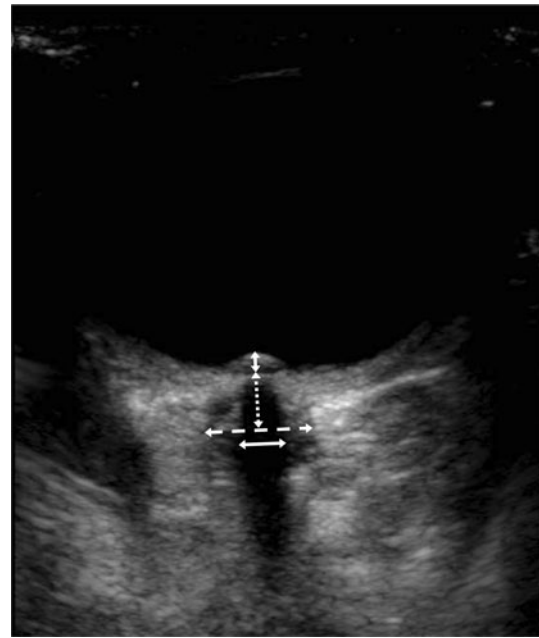

Fig. 1 ONSD and OND were measured 3 mm behind the papilla (*dotted arrow*) in an axial plane showing the optic nerve in its longitudinal course. The *dashed arrow* denotes the ONSD and the *continuous arrow* the OND. The optic disc elevation was gauged between the fundus and the dome of the papilla

Statistics

Values were expressed as mean ± standard deviation. The sonographic results and the demographic and clinical parameters for the groups were univariately compared using Fisher's exact tests for categorical variables and unpaired or paired t tests, single Wilcoxon Mann–Whitney tests or Wilcoxon signed-rank tests for continuous variables, as appropriate. Correlations were calculated using Pearson's product moment procedure. To assess the diagnostic accuracy for raised intracranial pressure, receiver operating characteristic (ROC) curves were plotted for ONSD and areas under the curve (AUC) were estimated. Statistical analyses were performed using SigmaStat software version 3.5 and SigmaPlot software version 11 (Systat Software, Inc., San Jose, CA).

Results

Demographics

Demographic data are shown in Table 1. Twenty-five individuals participated in the control group including 11 women and 14 men with a mean age of 45.8 ± 13.6 years and a mean BMI of 26.6 ± 4.7 kg/m². These patients suffered from Bell's palsy (n = 4), generalized tonic-

Table 1 Demographics, ONSD, and OND in controls and in patients with IIH

	Control group (n = 25)	IIH group (n = 10)	p value
Age (years)	45.8 ± 13.6	26.2 ± 5.5	<0.001
Women (%)	44	80	0.071
BMI (kg/m²)	26.6 ± 4.7	34.3 ± 7.6	0.007
Right ONSD (mm)	5.4 ± 0.5	6.4 ± 0.6	<0.001
Left ONSD (mm)	5.4 ± 0.5	6.4 ± 0.6	<0.001
Right OND (mm)	2.6 ± 0.4	2.7 ± 0.4	0.37
Left OND (mm)	2.7 ± 0.3	2.7 ± 0.3	0.94

Values represent means and standard deviation

clonic seizure ($n = 4$), peripheral neuropathy ($n = 4$), myelitis or syringomyelia ($n = 4$), migraine or tension-type headache ($n = 4$), Lyme borreliosis ($n = 2$), viral meningitis ($n = 1$), transient ischemic attack ($n = 1$), or angioedema ($n = 1$). No subject had clinical signs of elevated intracranial pressure and where applicable MRI disclosed no cerebral mass lesion. The IIH group consisted of eight women and two male participants aged

26.2 ± 5.5 years with a mean BMI of 34.3 ± 7.6 kg/m². Except for one patient, all participants had symptoms of increased intracranial pressure (Table 2). The one individual without symptoms had diagnosis of bilateral papilledema in a routine ophthalmological examination.

Transorbital sonography

Evaluation of ONSD and OND was possible in all subjects. In controls, mean sheath diameter was 5.4 ± 0.5 mm bilaterally, with a range of 4.4–6.5 mm. OND was 2.6 ± 0.4 mm in the right eye and 2.7 ± 0.3 mm in the left with a range of 2.1–3.7 mm. Prior to lumbar puncture, the OND of IIH patients did not differ from controls and was, respectively, 2.7 ± 0.4 mm ($p = 0.37$) and 2.7 ± 0.3 mm ($p = 0.94$). However, ONSD was significantly enlarged among individuals with IIH to 6.4 ± 0.6 mm bilaterally ($p < 0.001$) (Fig. 2). Compared to this, post-punctural assessment revealed a bilateral decrease of ONSD (right ONSD 5.8 ± 0.7 mm, $p < 0.004$; left ONSD 5.9 ± 0.7 mm, $p < 0.043$). However, in some patients with IIH, the ONSD was not or only slightly altered, e.g., a

Table 2 Clinical data and ONSD measurements before and after lumbar puncture in patients with IIH

Patient ID	Age (years)	BMI (kg/m²)	Symptoms	CSF opening pressure (cm H₂0)	CSF removal (ml)	Right ONSD Before LP	Right ONSD After LP	p	Left ONSD Before LP	Left ONSD After LP	p
1	25	33.5	Headache, dizziness, tinnitus, 6th nerve palsy	40	40	6.7	6.5		6.6	6.8	
2	25	38.7	Headache, nausea, visual obscuration	42	50	5.9	5.7		5.4	5.3	
3	22	40.1	Headache, nausea, visual obscuration	45	40	5.8	5.5		5.9	6.0	
4	34	29.7	Headache, dizziness, tinnitus	26	30	6.1	6.2		7.1	7.1	
5	20	27.6	None[a]	34	34	6.6	6.4		6.6	6.4	
6	29	23.9	Visual obscuration	20	30	5.5	5.2		5.9	5.5	
7	36	33.9	Headache	28	40	6.6	5.4		6.3	5.1	
8	20	41.9	Headache, tinnitus, 6th nerve palsy	49	50	6.3	4.7		7.0	4.8	
9	23	26.0	Headache, visual obscuration	37	30	6.8	5.9		6.2	5.5	
10	28	47.4	Headache, nausea	50	38	7.4	6.9		7.1	6.0	
Mean ± SD	26.2 ± 5.5	34.3 ± 7.6	na	37.1 ± 10.1	38.2 ± 7.5	6.4 ± 0.6	5.8 ± 0.7	0.004	6.4 ± 0.6	5.9 ± 0.7	0.043

[a] In patient 5, bilateral papilledema was diagnosed by chance in a routine ophthalmological examination
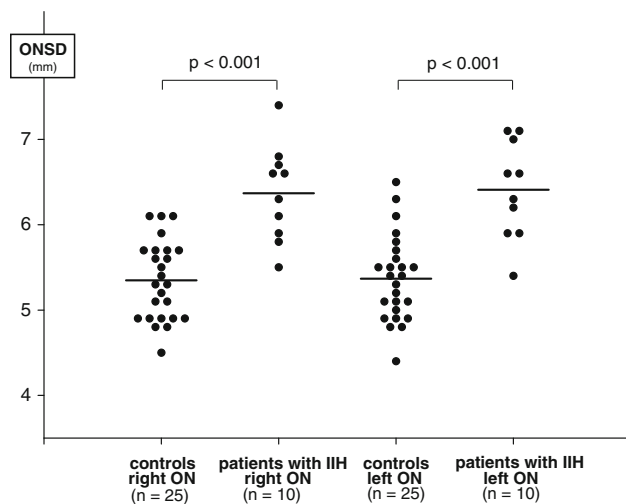
Fig. 2 ONSD in controls and in therapy-naive patients with IIH. The *horizontal bar* represents group means. *ON* optic nerve

decline of 0.4 mm or more was only present in five patients. No change could be observed with regard to the OND (right OND 2.7 ± 0.3 mm, $p = 0.36$; left OND 2.7 ± 0.3 mm, $p = 1.0$). No correlation was identified between ONSD response and the removed CSF volume ($r = 0.4$).

In control subjects, no signs of papilledema were found. Mean optic disc elevation in IIH patients was 1.2 ± 0.3 mm in both eyes and was not influenced by CSF removal (right papilla 1.1 ± 0.2 mm, $p = 0.31$; left papilla 1.1 ± 0.4 mm, $p = 0.30$). One patient showed no evidence of optic disc elevation in transorbital sonography but had signs of papilledema in funduscopy. Detailed results are presented in Tables 2 and 3.

There were no correlations between ONSD and age, gender, or BMI among controls and among patients with IIH. Additionally, no correlation was demonstrated with ONSD and CSF opening pressure. With respect to the IIH group, a significant association between CSF opening pressure and BMI was detected ($r = 0.84$, $p = 0.003$) (Fig. 3).

The ROC curve analysis revealed an optimal cut-off value of ONSD for predicting elevated intracranial pressure of 5.8 mm (AUC = 0.92; 95% confidence interval = 0.83–1.01; $p = 0.0001$). The sensitivity and the specificity of this cut-off value were 90 and 84%, respectively (Fig. 4).

Discussion

This prospective study analyzed ONSD, OND, and optic disc elevation in adults with newly diagnosed IIH before and after lumbar puncture. Ten patients were examined using transorbital B-mode sonography. In one patient, bilateral papilledema was diagnosed incidentally during routine ophthalmological examination. We chose to include this patient in our analysis because asymptomatic presentations of IIH are not uncommon [4].

In accordance with studies in neurocritical care patients, our investigations show that the ultrasound-based evaluation of the ONSD is potentially useful and feasible in detecting raised intracranial pressure [6]. Compared to controls, patients with IIH displayed an increased ONSD. Optic disc swelling could be demonstrated in nine subjects out of ten. Predominantly, ONSD values and optic disc levels were slightly asymmetric, reflecting the complex anatomy of the subarachnoidal space of the optic nerve and its possible influence on the cerebrospinal fluid dynamics [13]. For this reason, each eye should be evaluated separately and mean ONSD values should be designated for both eyes. The threshold of ONSD predicting an elevated intracranial pressure was proposed to be between 5.7 and 5.9 mm in adults with brain injury [5–7, 16]. Very similar to these data, we found an ONSD cut-off for raised intracranial pressure of 5.8 mm.

Furthermore, the mean ONSD was significantly reduced in the IIH group after lumbar puncture, indicating a rapid response to CSF removal. Our results resemble those published by Geeraerts et al. [6], who found a strong correlation of short-term ONSD changes with ICP variations in neurocritical care patients. However, in five patients with IIH, the ONSD was not (or only slightly) altered and we could not identify a relation between ONSD decrease and removed CSF volumes. This may be due to a possible compartmentation of the subarachnoidal space of the optic nerve in patients with IIH [11]. Killer et al. found a decreased CSF circulation along the optic nerve in patients with IIH and other causes of papilledema [12]. This may limit sonographic ONSD assessment in its value for follow-up monitoring of patients with IIH. Certainly, follow-up data during the course of the disease are needed to give a clearer view on ONSD sonography for long-term treatment monitoring. Nevertheless, it could provide important additional information on the course of the disease since CSF segregation in the optic nerve sheath may be crucial in the development of optic nerve damage [10]. Studying long-term changes of the ONSD in IIH may be an interesting issue of future investigations.

With regard to the OND, we observed no differences between the study groups and found no change of OND after lumbar puncture in patients with IIH, indicating no relation between OND and intracranial pressure alterations. These findings may be explained by the anatomy of the optic nerve and its sheath. The optic nerve is a part of the central nervous system that extends into the orbit and is surrounded by meninges and CSF. Thus, in conditions with

Table 3 Results of OND and optic disc elevation assessment before and after lumbar puncture in patients with IIH

Patient ID	Right OND		p	Left OND		p	Right papilla		p	Left papilla		p
	Before LP	After LP		Before LP	After LP		Before LP	After LP		Before LP	After LP	
1	3.0	2.9		2.9	2.8		1.6	1.2		1.6	1.8	
2	2.8	2.6		2.6	2.7		1.2	0.9		1.2	1.2	
3	2.8	2.5		2.9	3.2		na[a]	na		na	na	
4	2.3	2.5		2.8	2.9		0.9	0.9		0.8	0.8	
5	2.4	2.3		2.3	2.4		1.4	1.4		1.2	1.0	
6	2.7	2.6		2.8	2.9		1.1	1.2		1.7	1.4	
7	2.8	2.8		2.6	2.4		0.9	1.0		0.9	0.5	
8	2.2	2.4		2.3	2.2		1.3	1.2		1.0	1.2	
9	2.8	2.6		2.6	2.5		1.5	1.5		1.1	1.1	
10	3.4	3.3		3.1	2.9		1.0	1.0		1.0	0.8	
Mean ± SD	2.7 ± 0.4	2.7 ± 0.3	0.36	2.7 ± 0.3	2.7 ± 0.3	1.0	1.2 ± 0.3	1.1 ± 0.2	0.31	1.2 ± 0.3	1.1 ± 0.4	0.30

[a] Patient 3 showed no evidence of optic disc elevation in transorbital sonography but had signs of papilledema in funduscopy
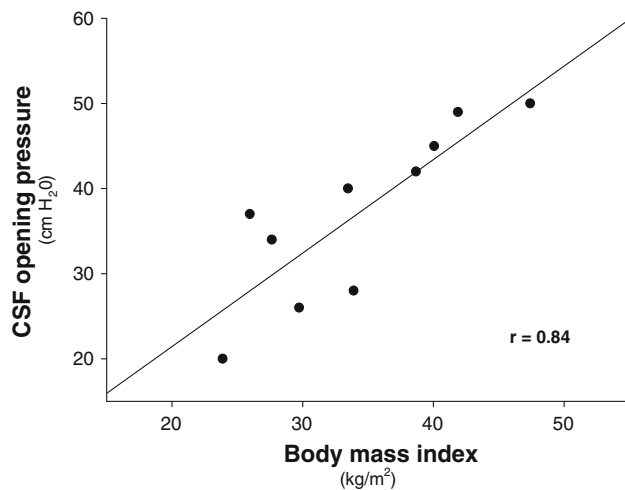

Fig. 3 Linear regression analysis identified a significant relationship between BMI and CSF opening pressure

Fig. 4 ONSD accurately predicted an elevated intracranial pressure (AUC = 0.92; 95% confidence interval = 0.83–1.01; $p = 0.0001$). The best cut-off value of ONSD for detecting raised ICP was 5.8 mm with a sensitivity of 90% and a specificity of 84%

elevated intracranial pressure, ONSD distension is probably due to the increase of CSF pressure and is not related to a dilation of the optic nerve by itself. Accordingly, several clinical investigations observed that OND does not depend on intracranial pressure changes [6, 7]. Corresponding to previous studies, we found no short-term decrease of the optic disc elevation after lumbar puncture [8].

Moreover, our results confirm normal values of ONSD published previously [1]. Additionally, mean and standard deviation of the OND in our analysis match closely with results derived from an MRI-based investigation, which indicated a mean OND of 2.7 ± 0.3 mm in brain-injured patients ($n = 38$) and 2.7 ± 0.2 mm in healthy adults ($n = 36$) [7]. Rohr et al. found a value of 2.4 ± 0.4 mm ($n = 123$) in patients with mental disorders [14].

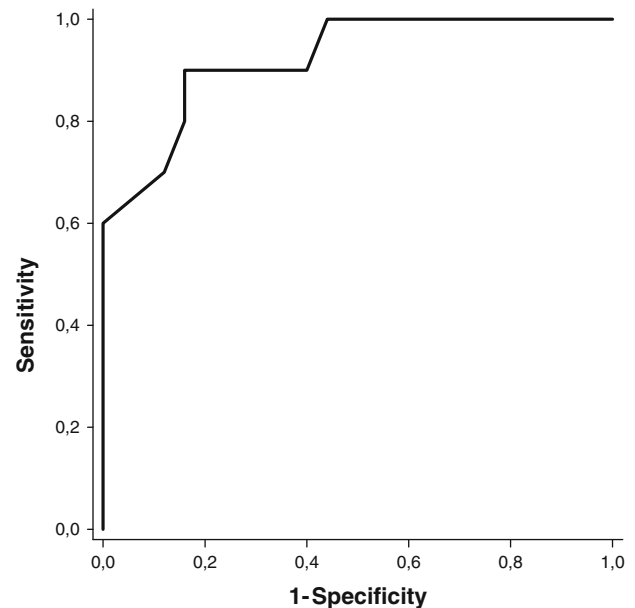Sonographic evaluation of the optic nerve was possible in all subjects. Previously, the hyperechogenic area surrounding the optic nerve was presumed to represent the subarachnoidal space [6]. Magnetic resonance imaging of the orbita visualizes the subarachnoid space in T2-weighted sequences as a homogenous, fluid-filled tube surrounding the optic nerve [7, 14]. However, electron microscopy of the optic nerve demonstrated a complex structure of the subarachnoid space containing arachnoid trabeculae [13]. The hyperechogenic zones bordering the optic nerve (Fig. 1) may thus correspond to ultrasound reflection at these trabeculae. This conclusion is supported by the finding that the subarachnoidal mesencephalic

cisterns, that also contain trabecular structures, are also hyperechogenic on transcranial B-mode sonography.

We found no correlation between ONSD and intracranial pressure which may be explained by the small study population or a varying compliance of the optic nerve sheath in patients with IIH. In addition, we identified no association between ONSD and age, gender, or BMI. On the other hand, a correlation between BMI and CSF opening pressure was ascertained, which highlights the role of obesity in the pathogenesis of IIH and the role of weight reduction in treatment of IIH [15].

The study groups were not matched with respect to age, sex, and BMI. Our previous investigations and several other studies did not find any relationship between these parameters and ONSD in adults [1, 9, 14]. Thus, these limitations would not have biased our results. However, since obesity is a risk factor or even a causative factor in the etiology of IIH, a possible correlation of ONSD with high BMI values cannot be excluded entirely. Furthermore, without measuring CSF opening pressure, our study is limited by the fact that intracranial pressure was presumed to be normal in control subjects by taking history, performing clinical examination, and MRI where applicable.

In conclusion, our study shows that sonographic ONSD measurements may be useful in detecting raised intracranial pressure in patients with presumed IIH. Furthermore, we found differing ONSD responses to lumbar puncture in individuals with IIH. This corresponds to previous studies indicating a defective CSF circulation in the optic nerve sheath in IIH. Thus, optic nerve sonography may serve as an additional diagnostic tool in the diagnostic work-up and in the follow-up of patients with IIH.

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

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