

ORIGINAL RESEARCH CONTRIBUTION

Point-of-care Ocular Ultrasound to Detect Optic Disc Swelling

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Abstract

Objectives: Emergency physicians (EPs) frequently evaluate patients at risk for diseases that cause optic disc swelling, and they may encounter conditions that make traditional fundoscopy difficult or impossible. The objective was to assess whether EP-performed point-of-care (POC) ultrasound (US) could accurately assess swelling of the optic disc.

Methods: This was a blinded, prospective study using a convenience sample of patients presenting to a neuroophthalmology clinic who were thought to be at risk for conditions associated with optic disc edema. Two EPs performed POC US examinations. Patients then underwent standard clinical assessment by a specialist.

Results: Fourteen patients were assessed with disc swelling noted on dilated fundoscopic exam in 11 of 28 (39%) eyes. A maximum disc height greater than 0.6 mm as measured by US predicted the presence of optic disc edema noted on fundoscopic exam, with a sensitivity of 82% (95% confidence interval [CI] = 48% to 98%) and a specificity of 76% (95% CI = 50% to 93%). A threshold value of 1.0 mm for disc height yielded a sensitivity of 73% (95% CI = 39% to 94%) and a specificity of 100% (95% CI = 81% to 100%). Measurements of disc height as determined by optical coherence tomography (OCT) exhibited good correlation when compared to US measurements ($r = 0.836$, $p < 0.0001$, 95% CI = 0.65 to 0.93).

Conclusions: These data suggest that EP-performed POC US can detect clinically apparent optic disc swelling. Because sonography can be performed readily at the bedside, even in cases where fundoscopy is difficult or impossible, this technique may prove to be a valuable tool for the assessment of optic disc swelling in the emergency department (ED).

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Emergency physicians (EPs) frequently evaluate patients at risk for conditions that cause optic disc swelling. Elevated intracranial pressure (ICP), inflammatory diseases, infection, infiltrative conditions, and microvascular infarction, such as occurs with malignant hypertension, may all cause varying degrees of optic disc edema. Although assessment of the optic disc is an essential diagnostic skill, nonophthalmologist physicians report a general lack of confidence in their ability to perform fundoscopy and have been shown to

use this skill with inadequate frequency and accuracy in cases where it is indicated.^{1,2} Further, fundoscopy may be difficult or impossible in patients with significant ocular or periorbital trauma, severe photophobia, altered mental status, or contraindications to mydriatics.

Prior reports have demonstrated that visualization of optic disc swelling is possible using point-of-care (POC) ultrasound (US); however, the test characteristics of this technique have not been formally studied.³ EP-performed POC US has already been shown to be a useful tool in the evaluation of other ocular pathology such as retinal detachment, vitreous hemorrhage, and lens dislocation,^{4,5} and multiple studies have attempted to correlate sonographic evaluation of the retrobulbar optic nerve sheath with ICP measurements.⁶⁻⁹ Because sonography is routinely available in the emergency department (ED) for other indications and can be performed quickly even in cases where traditional fundoscopy is difficult or impossible, this technique may be of significant value in the evaluation of patients at risk for conditions associated with optic disc swelling.

The primary goal of our study was to assess the performance of EP-performed POC US by establishing specific

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values for optic disc height (ODH) that corresponded to the presence or absence of disc swelling as determined by dilated fundoscopic exam performed by an expert. As a secondary outcome, we also recorded disc height as determined by optical coherence tomography (OCT) for both normal and abnormal subjects.

METHODS

Study Design

After approval by our institution's Committee on Human Research, we performed a blinded, prospective observational study using a convenience sample of patients referred to our hospital's neuroophthalmology clinic. All participants provided written, informed consent.

Study Setting and Population

The setting was the University of California, San Francisco, a large, urban academic medical center. Patients were enrolled over an 18-month period from May 2010 through November 2011 in the neuroophthalmology clinic. We enrolled patients who were known or suspected to have clinical conditions associated with optic disc edema and for whom a standard clinical assessment, including OCT imaging, was planned. Exclusion criteria included age younger than 18 years, a history of glaucoma, and recent ocular trauma.

Study Protocol

After being greeted by the investigators, patients were taken to a separate exam room where bedside US was performed by EPs using the technique described below. One EP was a senior resident with 4 years of US experience (PL) and the second was an attending physician with 8 years of US experience who had completed an emergency US fellowship (NT). The first four patients enrolled were evaluated by both investigators independently, and disc height measurements were found to be similar between investigators (intraclass correlation coefficient = 0.87). Thus, for the remainder of the study, only one or the other investigator obtained US measurements, depending on availability (NT performed four of the remaining studies, PL performed six). In the first four patients examined by both investigators, values for disc height were averaged for the purpose of data analysis.

After sonography had been completed, patients underwent routine clinical assessment by an attending neuroophthalmologist (AG) that included a dilated fundoscopic exam (Figure 2D) and OCT (Spectralis spectral domain OCT, Heidelberg Engineering, Carlsbad, CA). OCT imaging consisted of 19 B-scans (cross-sectional) centered on the optic disc (Figure 2C). Signal intensity was required to be greater than 18 for all images, with a minimum number of B-scans averaged per image of 16. All investigators were blinded to each other's findings. Ultrasonographers and the OCT technician were also blinded to the patients' underlying diagnoses.

Sonographic Technique. A SonoSite M-Turbo (Bottle, WA) portable US machine was used for all patients. Images were obtained using a standard 10- to



Figure 1. Ultrasound scanning technique.

5-MHz linear transducer on a closed eyelid over which US coupling gel was placed (Figure 1). Dynamic range was set to +2 and the optimization preset (a machine-specific setting that adjusts focal zone, aperture size, and frequency) was set to "general." Overall gain was adjusted manually to achieve adequate midfield brightness. The patient lay supine with the head in a neutral position and was instructed to fixate at a distance in primary gaze with the eyes closed. The investigator scanned through the eye in the horizontal axial plane, searching for a smoothly contoured, echogenic prominence arising at the junction of the retrobulbar optic nerve and the globe. The "zoom" function was used to magnify the gray-scale image by 100%. ODH was determined by measuring the distance between the anterior-most peak of the disc and its intersection with the arc of the posterior surface of the globe (Figure 2B). Care was taken to acquire images in which the above structures appeared distinct and free of distortion by artifact or blurring with the adjacent retinal surface. Those patients in whom no recognizable disc elevation was identified were documented as having a disc height of zero.

Key Outcome Measures

For each patient, we recorded age, sex, primary diagnosis and comorbidities, measurements of maximum disc height measured by US and OCT and whether disc swelling was noted on fundoscopic exam as determined by the neuroophthalmologist.

Data Analysis

We constructed a receiver operating curve (ROC) to compare the presence of disc swelling found on dilated fundoscopic exam against cutoff values for ODH measured by US. We also assessed the relationship between US and OCT measurements of disc height using Pearson's correlation coefficient. Data analysis was conducted using Stata (Version 10.0, StataCorp, College Station, TX) and ROC analysis: web-based calculator for ROC curves (Eng, J. Baltimore: Johns Hopkins University [updated 2006 May 17]. Available from <http://www.jrocf.org>).

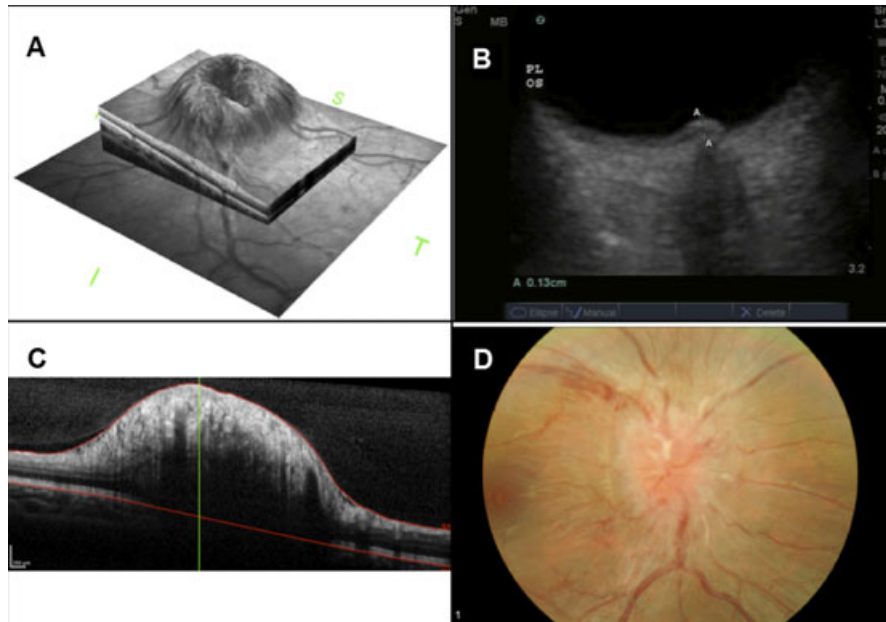


Figure 2. Images showing disc and various pathologies. (A) 3-D OCT image of optic disc. (B) Sonogram of optic disc with elevated disc height. (C) 2-D OCT image of optic disc. (D) Fundus photograph showing severe papilledema. OCT = optical coherence tomography.

RESULTS

Results are presented in Table 1. The average patient age was 37 years (range = 19 to 62 years). Two men and 12 women were enrolled with the following conditions ultimately diagnosed: idiopathic intracranial hypertension, also called pseudotumor cerebri ($n = 8$), multiple sclerosis ($n = 5$), and neuromyelitis optica ($n = 1$). Four US measurements were obtained in two patients who did not undergo OCT, but who were examined clinically; these values were included in the construction of the ROC curve but not in the determination of correlation between US and OCT measurements.

Because disc swelling may be an asymmetric or unilateral finding, we treated each eye as an individual entity. Eleven of 28 (39%) eyes were found to have disc swelling on dilated fundoscopic exam. The area under the ROC curve (Figure 3) was 0.91 ($p < 0.0001$; 95% confidence interval [CI] = 0.74 to 0.98). The use of a cutoff value of 0.6 mm for ODH produced a sensitivity of 82% (95% CI = 48% to 98%) and a specificity of 76% (95% CI = 50% to 93%). A cutoff value of 1.0 mm yielded a sensitivity of 73% (95% CI = 39% to 94%) and specificity of 100% (95% CI = 81% to 100%) for clinically apparent disc swelling.

Because of possible differences in the baseline position of the disc height measurement and other inherent technical differences between US and OCT, we did not attempt to assess direct numerical agreement between sonographic and OCT disc height measurements. However, we did note a correlation between the two modalities, which is demonstrated in Figure 4. The Pearson's correlation coefficient for the fitted line was $r = 0.836$ ($p < 0.0001$; 95% CI = 0.65 to 0.93).

DISCUSSION

To our knowledge, our study is the first to compare POC US assessment of the optic disc to clinical exam findings by an expert. We noted good sensitivity (82%) using a cutoff value of 0.6 mm for ODH. A cutoff of 1.0 mm yielded 100% specificity with 73% sensitivity.

How might the clinician use our findings in practice? We would suggest that US could best serve as an initial test in cases where a fundoscopic exam could not be performed. Thus, we would favor a conservative cutoff of 0.6 mm to ensure that patients with disc swelling are not missed. Given its sensitivity at this threshold, this technique could be used in advance of ophthalmologic consultation in most cases. Conversely, EPs should also recognize that a disc height of 1.0 mm or greater is highly likely to represent true disc swelling, either from elevated ICP or from another condition and that further evaluation is required urgently.

Second, it is important to note that although US appears to be capable of identifying optic disc swelling, it cannot offer insight into its etiology. In our study, the majority of patients had idiopathic intracranial hypertension causing disc swelling due to elevated ICP, but even severe disc edema can occur in the absence of ICP elevation. In our study, disc swelling was also found in patients with multiple sclerosis, although many other conditions will cause similar findings, including infiltrative processes such as sarcoidosis or lymphoma, infections directly affecting the optic nerve, and microvascular infarction caused by malignant systemic hypertension. Indeed, prior case reports have described significant disc swelling diagnosed by POC US not only in the setting of ICP elevation but in patients with neurosyphilis and malignant hypertensive retinopathy.¹⁰ Thus, in cases where disc swelling is a new diagnosis,

Table 1
Study Population and Results

Patient	Age (yr), sex	Diagnosis	Disc Height as Measured by EP* (mm)		OCT Nerve Peak (mm)	Disc Swelling by Exam
1	27, F	IIH	OD:	0.65	0.68	No
			OS:	0.55	0.72	No
2	19, F	IIH	OD:	1.25	0.99	Yes, severe grade 3
			OS:	1.25	1.18	Yes, severe grade 3
3	26, F	IIH	OD:	1.2	1.08	Yes, severe grade 3
			OS:	1.5	1.10	Yes, severe grade 3
4	53, M	MS	OD:	0.55	0.42	No
			OS:	0.0	0.39	No
5	53, F	MS	OD:	0.3	—	No
			OS:	0.4	—	No
6	62, F	MS	OD:	0.0	—	No
			OS:	0.4	—	No
7	38, F	IIH	OD:	0.7	0.65	No
			OS:	0.6	0.65	No
8	43, M	Neuromyelitis optica	OD:	1.1	0.83	Yes, grade 2
			OS:	0.0	0.59	No
9	32, F	IIH	OD:	0.7	0.63	Yes, grade 1
			OS:	0.4	0.62	Yes, grade 1
10	32, F	IIH	OD:	0.7	0.64	No
			OS:	1.0	0.63	No
11	33, F	IIH	OD:	0.0	0.50	No
			OS:	0.5	0.42	No
12	23, F	IIH	OD:	1.1	0.90	Yes, grade 2–3
			OS:	1.3	1.24	Yes, grade 3
13	18, F	MS	OD:	0.6	0.77	Yes, grade 1
			OS:	1.1	0.76	Yes, grade 1
14	53, F	MS	OD:	0.6	0.56	No
			OS:	0.4	0.53	No

IIH = idiopathic intracranial hypertension; MS = multiple sclerosis; OCT = optical coherence tomography; OD = right eye; OS = left eye.

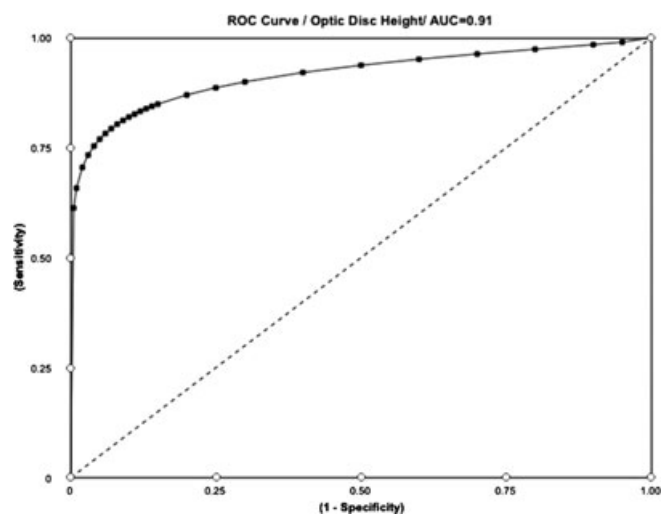


Figure 3. ROC comparing EP ultrasound measurement to the presence of disc edema as determined by expert exam; AUC = 0.91. ROC = receiver operating curve.

neuroimaging and lumbar puncture should be performed urgently to assess for conditions causing elevated ICP. If ICP is normal, further testing is required to investigate the alternative etiologies.

Related to this, it is important to recognize that ICP elevation does not cause disc swelling in the acute setting, especially if the rise in ICP is gradual. Papilledema

(bilateral optic disc swelling caused by increased ICP; Figure 2D) is thought to be a consequence of impaired retrograde axoplasmic flow within the fibers of the optic nerve, and thus, even in cases with significant rapid rise in ICP, may take hours to days to develop.¹¹ Therefore, in patients with conditions such as acute traumatic brain injury, intracranial hemorrhage, or other conditions associated with extremely recent and evolving central nervous system insult, significant ICP elevation may not manifest as optic disc swelling at the time of ED evaluation.

Finally, the measurement of ODH to identify optic disc swelling, the subject of our study, should be differentiated from the measurement of the retrobulbar optic nerve sheath diameter. Because the retrobulbar optic nerve is encased within a dural sheath containing cerebrospinal fluid (CSF) that is in communication with the rest of the central nervous system, dilation of the optic nerve sheath diameter has been proposed as a marker for elevated ICP.⁶⁻⁹ In theory, then, a patient with chronically elevated ICP should exhibit both optic disc edema and a dilated, CSF-filled, retrobulbar optic nerve sheath. As noted above, however, a patient with acutely elevated ICP would be expected to have normal optic discs but a widened optic nerve sheath diameter. Our study seeks to establish a specific threshold for sonographic ODH that predicts clinically apparent disc edema from any cause rather than proposing that ODH serve as a direct surrogate for elevated ICP.

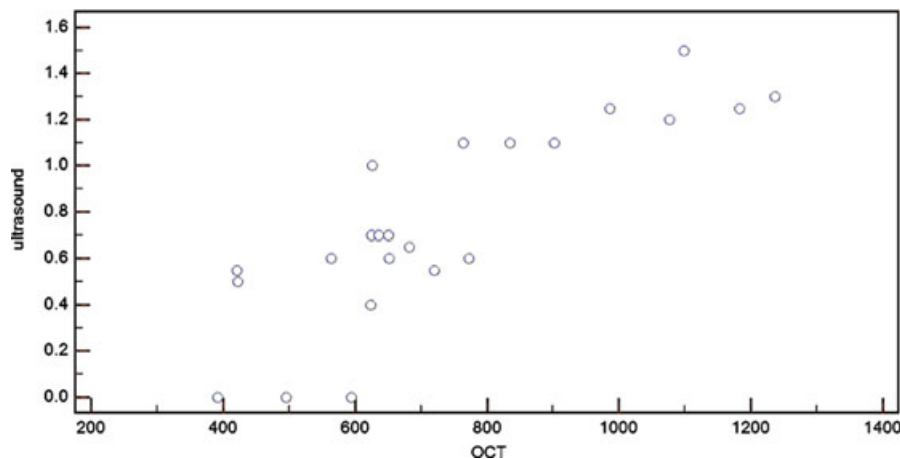


Figure 4. Scatter plot showing points measured by ultrasound and optical coherence tomography.

LIMITATIONS

Although axial B-scan US of the optic disc has been in use for decades by sonographers using specialized ophthalmic transducers, no standard technique using general POC US currently exists.¹² Thus, we developed our own approach for identifying and measuring the optic disc. We also made the assumption that measurement of the height of the disc (rather than, for instance, its width or volume [Figure 2A]) would be a reliable marker of disc edema overall, although we acknowledge that some cases of disc edema may be missed if only the disc height is taken into account. Based on our own practice, we expect that as EPs become familiar with this technique, a subjective assessment of the degree of disc swelling may also be valuable in actual practice.

A second important technical consideration is that the incremental differences in disc height we observed (tenths of millimeters) are near the limits of resolution of a standard POC US platform using a 10- to 5-MHz linear transducer. Alterations in gaze, subtle irregularities in the surface of the retina or disc itself, and technical imprecision could have all contributed to inaccuracies in disc height measurement. This appears to be true especially for nonswollen discs. Normal optic discs often appeared completely flat on US, although OCT frequently measured these discs in the 0.3- to 0.4 mm range. This suggests that many normal discs may have “blended in” with the adjacent retinal surface and thus precluded a precise numerical measurement of disc height by US. Fortunately, using a normal cutoff value of 0.6 mm as discussed, this technical limitation is unlikely to affect clinical interpretation in actual practice.

A further limitation is the fact that our study population was not representative of any ED. We had a large number of positive findings with more than one third of patients judged to have disc swelling by exam. This was intentional for the purposes of the study. However, it is possible that the investigators performing sonography assumed a high prevalence of disease and thus overestimated their measurements, despite blinding. Related to this, because disc edema is well known to occur asymmetrically or even unilaterally (indeed, one of our

subjects was found to have one normal and one swollen disc), we treated each eye individually for the purpose of data analysis. We note, however, that disc height did appear highly correlated in most subjects and that this may have introduced bias on the part of the investigators. Finally, US exams were performed on cooperative, ambulatory patients by experienced investigators in the controlled environment of a specialty clinic. Because our data are unlikely to be representative of what is found in a “real-world” ED, further investigation in this setting is warranted.

Another limitation of our study was the small number of enrolled patients. Due to the unique design of our study based in a subspecialty, tertiary care clinic, our ability to enroll patients was limited, and the fairly small number of patients in our study is reflected in the wide CIs of the sensitivity and specificity analyses. Nevertheless, we feel confident that our results can serve as the groundwork for future investigation in this area.

Finally, the inherent limitations of OCT deserve mention. Although OCT is capable of providing detailed images of the optic disc, due to variation among individuals in the baseline anatomy of the nerve fiber layer, there is no standard numerical threshold for disc height by OCT that predicts disc edema noted clinically. Thus, direct observation of the disc on funduscopy remains the criterion standard for assessing the presence of disc swelling. Because of this, and because of inherent technical differences in the degree of resolution between US and OCT, we used clinical examination findings rather than numerical values from OCT imaging as our reference standard and did not attempt to assess direct agreement between the two imaging modalities. Nonetheless, the quantitative correlation we noted provides a measure of reassurance that POC US provides reliable disc height measurements.

CONCLUSIONS

Emergency physicians may be able to use point-of-care sonography to accurately assess the optic disc for evidence of swelling. Patients with an optic disc height of 0.6 mm or less measured by sonography were unlikely to have disc swelling diagnosed by fundoscopic exam,

suggesting that this may be a suitable threshold to use as an initial test for patients at risk for elevated intracranial pressure or other conditions associated with optic disc edema. Optic disc heights greater than 1.0 mm were strongly associated with clinically apparent disc swelling as diagnosed by expert examination. Because sonography can be performed readily at the bedside even in cases where traditional funduscopy is difficult or impossible, this technique may prove to be a valuable tool for the assessment of optic disc swelling in the ED.

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