

Detection of Increased Intracranial Pressure by Ultrasound

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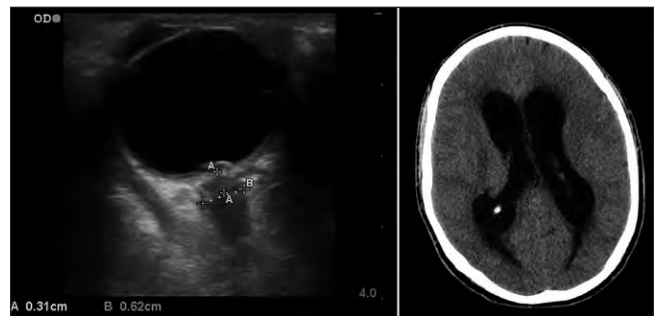
ABSTRACT

Increases in intracranial pressure (ICP) may damage the brain by compression of its structures or restriction of its blood flow, and medical providers may encounter elevated ICP in conventional and non-conventional medical settings. Early identification of elevated ICP is critical to ensuring timely and appropriate management. However, few diagnostic methods are available for detecting increased ICP in an acutely ill patient, which can be performed quickly and noninvasively at the bedside. The optic nerve sheath is a continuation of the dura mater of the central nervous system and can be viewed by ocular ultrasound.

Pressure changes within the intracranial cavity affect the diameter of the optic nerve sheath. Data acquired from multiple clinical settings suggest that millimetric increases in the optic nerve sheath diameter detected via ocular ultrasound correlate with increasing levels of ICP. In this review, we discuss the use of ocular ultrasound to evaluate for the presence of elevated ICP via assessment of optic nerve sheath diameter, and describe critical aspects of this valuable diagnostic procedure. Ultrasound is increasingly becoming a medical fixture in the modern battlefield where other diagnostic modalities can be unavailable or impractical to employ. As Special Forces and other austere medical providers become increasingly familiar with ultrasound, ocular ultrasound for the assessment of increased intracranial pressure may help optimize their ability to provide the most effective medical management for their patients.

Review

Increased intracranial pressure (ICP), defined as a cerebrospinal fluid (CSF) pressure of ≥ 20 mmHg and also known as intracranial hypertension, can damage the brain through compression of its structures or restriction of its blood flow. Medical providers may encounter causes of



Sonographic (Left) optic nerve sheath diameter (ONSD) of a patient with increased intracranial pressure evident on corresponding computed tomography in the form of dilated lateral ventricles (right). The ONSD measured at 0.62cm ("B" calipers) at a point 0.31cm behind the globe ("A" calipers) is above the 0.50cm upper limit of normal.

increased ICP in both conventional and non-conventional medical settings such as trauma, infection (encephalitis or meningitis), vascular abnormalities, intracranial hemorrhage, intracranial mass, and status epilepticus. Patients presenting with intracranial hypertension can exhibit a wide array of signs and symptoms such as persistent headaches, blurred vision, changes in mental status, focal neurological deficits, and seizures. The neurological consequences of untreated intracranial hypertension and associated pathologies are adverse and often irreversible. Early identification of elevated ICP is critical to ensuring timely and appropriate management.

Few methods exist for physicians, medics, and other providers to quickly and noninvasively detect increased ICP at the bedside of an acutely ill patient. The physical exam alone can have significant limitations, especially if the patient is unconscious, intubated, or paralyzed.¹ Computed tomography (CT), magnetic resonance imaging (MRI), and lumbar puncture are often used in modern-hospital settings to assist in the evaluation of a

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patient with suspected intracranial hypertension; however, in an austere environment where resources are limited and performance of sterile procedures can be challenging, these diagnostic modalities can be unavailable or impractical to employ.

Advances in the portability and image quality of ultrasound over the past 10 years have led to ultrasound machines being specifically designed for emergency care providers and the unique settings in which they practice.² The important role of ultrasound in out-of-hospital emergency care is highlighted by the Emergency Ultrasound guidelines published by the American College of Emergency Physicians in 2008. In settings where there is limited access to advanced imaging technology, unavailable or unreliable electrical source, and limited access to subspecialty-trained healthcare providers, ultrasound has become an invaluable tool to assist in a myriad of clinical and emergent settings.²

Emergency physicians use ultrasound extensively to aid in both the diagnosis and management of a variety of patient presentations, and many professional organizations consider its use to be the standard of care for guidance in invasive procedures. Standard uses include EFAST (extended focused assessment with sonography for trauma), detection of gallbladder pathology and DVT (deep venous thrombosis), echocardiogram, fracture detection, soft tissue foreign body detection, and assessment of IVC (inferior vena cava) diameter as a measure of resuscitation. Special Operations medical providers are also becoming more familiar with the use and clinical application of ultrasound since the implementation of the Special Operator Level Clinical Ultrasound (SOLCUS) initiative that began in 2008.³

A growing body of evidence supports the use of ocular sonography as a means for detecting increased ICP. Data acquired from multiple clinical settings suggests that millimetric increases in the optic nerve sheath diameter (ONSD) correspond to increasing levels of ICP. The optic nerve is a part of the central nervous system (CNS) and the optic nerve sheath is a continuation of the dura mater surrounding the optic nerve.⁴ The subarachnoid space which is located between the optic nerve and the optic nerve sheath is a communicating space with the CNS. Pressure changes in the intracranial cavity are transmitted via the subarachnoid space and affect the diameter of the optic nerve sheath.⁵ Eventually, any rise in ICP will be transmitted to the head of the optic nerve, leading to the swelling of the optic disc and papilledema. In the setting of acutely-elevated ICP, however, papilledema can take hours to develop and patients may have increased ICP long before they show clinical signs of optic disc swelling.⁶ While the mechanism of papilledema and distension of the ONSD is similar, ONSD changes

occur within seconds of ICP elevation. This rapidity is particularly useful for the detection of acute (and possibly hyper-acute) elevations in ICP.⁶

A review of the available medical literature regarding the use of ocular ultrasound and its value in the detection of intracranial hypertension reveal a strong correlation between the ONSD and the levels of ICP.^{1,4-29} Relevant studies include several hundred patients with diagnoses such as subarachnoid hemorrhage, traumatic brain injury, intracranial hemorrhage, and brain tumors. Overall, authors conclude that there is a significant correlation between ONSD and elevated ICP and evidence of good intra- and interobserver reliability.^{1,4-30} Although consensus is evolving, a generally accepted normal ONSD is considered less than 0.5cm at a location 0.3cm posterior to the optic disc, with greater diameters strongly associated with increased ICP (Figure).⁷⁻⁹ To perform this exam, sonographers generally recommend a high-resolution 7.5 to 10MHz or higher linear array ultrasound transducer used after the application of copious ultrasound transmission gel to a patient's closed eyelid.⁷⁻⁹

The inability to use this technique on some patients with severe ocular trauma such as an open globe injury is a potential limitation to using ocular ultrasound for the detection of increased ICP in an austere setting. As many as 10% of patients with TBI may present with some form of facial trauma that may involve the orbit.⁴ The effects of ocular trauma on ONSD measurement are unclear, but it is likely that it would be difficult to interpret such scans. It is also important to note that a number of rare etiologies can lead to the dilation of the optic nerve sheath without reflecting increased ICP, such as optic neuritis, arachnoid cyst of the optic nerve, optic nerve trauma, and an anterior orbital or cavernous sinus mass.⁹

The level of operator experience is a possible confounder in assessing the intrinsic value of using ultrasound as a means to measure ONSD.^{1,4-6,9-14} Most studies have experienced operators who are familiar with and well-trained in ocular sonography. The ability of providers with less experience, such as Special Operations medical providers, has been less assessed.^{15,31} The small dimensions being measured and the frequent occurrence of artifact in the sonographic area of interest may yield inconsistent results when performed by inexperienced operators.⁶ This limitation may be minimized if inexperienced providers are required to perform a minimum number of supervised measurements of both normal and distended optic nerve sheath diameters prior to independently performing ONSD measurements that would affect management. One study conducted estimated that the learning curve seems to be fairly rapid, suggesting that an experienced sonographer needs as few as 10 measurements and three abnormal scans to obtain adequate

results; for those providers who are inexperienced, up to 25 scans may be necessary prior to developing an appropriate level of proficiency.¹⁵ This criteria is similar to what is already required for other point-of-care ultrasound applications such as the FAST exam.⁶

Small differences in measured ONSD beyond those related to the experience level of the operator could be due to the model of the ultrasound device used or the position of the probe. As the optic nerve courses medially from the globe to its exit through the orbit, the optic nerve sheath can be visualized from a variety of angles in relation to the globe.⁶ Different ONSD measurements can result from differences in probe and eye position. Measurements of the ONSD in the axial plane have been found to be consistently larger than ONSD measurements obtained from the sagittal plane.⁶

Ultrasound is becoming a medical fixture in the modern battlefield and other austere settings. It is a simple, rapid, and noninvasive method that can be readily employed at the patient's bedside, and ultrasound has been used safely for the past 20 years for ophthalmic evaluation without specific contraindication except for wounds of the ocular globe.⁷ In situations where there is high clinical suspicion of increased ICP, but invasive monitoring is either unavailable or it is too risky to perform, using a portable ultrasound to measure the ONSD is of potential value to determine whether evacuation to a higher-level facility is warranted and what evacuation triage category would be most appropriate.^{3,4} However, prior to widespread implementation of this technique, proper training of Special Forces medical providers may help optimize their ability to provide the most effective medical management for their patients.

Disclaimer

The views expressed herein are solely those of the authors and do not represent the official views of the Department of Defense, Air Force, or Army Medical Department.

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