BRIEF REPORTS

Elevated Intracranial Pressure Detected by Bedside Emergency Ultrasonography of the Optic Nerve Sheath

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Abstract

Patients with altered level of consciousness may be suffering from elevated intracranial pressure (EICP) from a variety of causes. A rapid, portable, and noninvasive means of detecting EICP is desirable when conventional imaging methods are unavailable. **Objectives**: The hypothesis of this study was that ultrasound (US) measurement of the optic nerve sheath diameter (ONSD) could accurately predict the presence of EICP. **Methods**: The authors performed a prospective, blinded observational study on emergency department (ED) patients with a suspicion of EICP due to possible focal intracranial pathology. The study was conducted at a large community ED with an emergency medicine residency program and took place over a six-month period. Patients suspected of having EICP by an ED attending were enrolled when study physicians were available. Unstable patients were excluded. ONSD was measured 3 mm behind the globe using a 10-MHz linear probe on the closed eyelids of supine patients, bilaterally. Based on prior literature, an ONSD above 5 mm on ultrasound was considered abnormal. Computed tomography (CT) findings defined as indicative of EICP were the presence of mass effect with a midline shift 3 mm or more, a collapsed third ventricle, hydrocephalus, the effacement of sulci with evidence of significant edema, and abnormal mesencephalic cisterns. For each patient, the average of the two ONSD measurements was calculated and his or her head CT scans were evaluated for signs of EICP. Student's t-test was used to compare ONSDs in the normal and EICP groups. Sensitivity, specificity, and positive and negative predictive values were calculated. **Results**: Thirty-five patients were enrolled; 14 had CT results consistent with EICP. All cases of CT-determined EICP were correctly predicted by ONSD over 5 mm on US. One patient with ONSD of 5.7 mm in one eye and 3.7 mm in the other on US had a mass abutting the ipsilateral optic nerve; no shift was seen on CT. He was placed in the EICP category on his data collection sheet. The mean ONSD for the 14 patients with CT evidence of EICP was 6.27 mm (95% CI = 5.6 to 6.89); the mean ONSD for the others was 4.42 mm (95% CI = 4.15 to 4.72). The difference of 1.85 mm (95% CI = 1.23 to 2.39 mm) yielded a $p = 0.001$. The sensitivity and specificity for ONSD, when compared with CT results, were 100% and 95%, respectively. The positive and negative predictive values were 93% and 100%, respectively. **Conclusions**: Despite small numbers and selection bias, this study suggests that bedside ED US may be useful in the diagnosis of EICP. **Key words:** emergency ultrasonography; ocular ultrasound; head injury; emergency medicine; elevated intracranial pressure; subarachnoid hemorrhage. ACADEMIC EMERGENCY MEDICINE 2003; 10:376–381.

Elevated intracranial pressure (EICP) may be present in emergency department (ED) patients with head trauma and in those with spontaneous intracranial hemorrhage.[1,2] Both groups often present acutely to the ED and may require rapid intervention. EICP in either patient group suggests serious pathology.[1,2] In most ED settings, cranial computed tomography (CT) is readily available; in other situations, CT scanning may be unavailable, making the detection of early EICP difficult. Such settings include long-distance patient transportation, disaster scenes, and multi-casualty occurrences, where many patients require rapid triage (i.e., the Armenian earthquake when more than 700 blunt trauma patients were triaged by one hospital in two days).[3] Under any of these circumstances, where CT scanning is unavailable to detect early EICP, a noninvasive method would be useful to determine whether a patient's ICP is elevated or is changing.

In recent years, emergency medicine has seen the growth and expansion of emergency ultrasound (US). This expansion has been in the form of not only the proliferation of ultrasound technology to more and more EDs, but also the expansion of different ED ultrasound applications. Emergency physicians (EPs) have explored the use of echocardiography, endovaginal sonography, and high-resolution linear transducers.[4–6] Linear transducers have been used to evaluate long bone fractures, abscesses, lower-extremity venous thrombosis, testicular torsion, and ocular pathology.[6–10]

The eyes often reflect disease states elsewhere in the body. This may be seen with retinal changes due to

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hypertension, or papilledema secondary to increased intracranial pressure.[11] Similarly, ocular US can detect pathology reflecting disease states outside of the eye. Altered flow patterns in the central retinal artery may in some cases suggest carotid occlusion or dissection.[12] Although not extensively investigated, evaluation of the optic nerve sheath diameter (ONSD) can detect EICP.[13]

We sought to determine whether dilation of the optic nerve sheath, as detected at the bedside by emergency US, could reliably correlate with head CT findings suggestive of EICP in patients with acute head trauma, and those with suspected acute spontaneous intracranial hemorrhage, such as from a ruptured cerebral aneurysm.

METHODS

Study Design. This was a single-blinded, prospective observational study of patients suspected of having intracranial hemorrhage either from trauma, or spontaneously, presenting to our ED. The study utilized a convenience sample of patients. The institutional review board approved this research. Patients or proxies provided informed consent prior to enrollment.

Study Setting and Population. The study was conducted in a large suburban teaching ED with an emergency medicine residency program. The ED has a census of approximately 70,000 visits per year and full specialty backup. All patients presenting to the ED with suspicion of intracranial hemorrhage, as described above, during the six-month study period were eligible for the study.

The ED is staffed by board-certified emergency medicine attending physicians as well as residents. An intradepartmental credentialing system is in place to allow EPs to make clinical decisions based on the results of their US examinations. EPs are credentialed to perform US examinations by the hospital as consistent with resolution 802 by the American Medical Association. Residents and attending physicians perform all bedside US examinations in the ED. The radiology department performs CT of the head 24 hours per day, but does not perform ocular US examinations. Neurosurgical consultation is available on a 24-hour basis from private neurosurgeons.

Patients presenting to the ED were eligible for study enrollment if they suffered from blunt head trauma with loss of consciousness or change in mental status. Non-trauma patients with focal neurological changes and history suggestive of a possible spontaneous intracranial hemorrhage were also included. Intubated patients were included when family was available to consent for the performance of the ocular US examination. Unstable patients who required immediate intervention and those less than 18 years of age were excluded from the study. It is the ED policy that bedside testing should not interfere with patient care and no US examinations can be performed that would delay formal testing or surgical intervention. Only patients who received an ocular bedside US and then a confirming study (CT of the head) were enrolled into the study. There were five enrolling physicians whose US experience ranged from approximately 100 to more than 1,000 scans performed. Training for the study physicians consisted of a one-hour lecture on ocular US as well as five proctored ocular US examinations during which they were observed to measure the optic nerve sheath in volunteer patients.

Study Protocol. Patients suspected of having acute intracranial hemorrhage and EICP from either blunt head trauma or spontaneous aneurismal rupture, and were to undergo head CT, were enrolled when a study EP was available. The diameters of the optic nerve sheaths were measured by US. The EPs scanned both eyes through closed eyelids, using a high-resolution 10-MHz linear array transducer (Figure 1). Ultrasound examinations were performed following a protocol previously described in the literature.[10] The power output and gain were turned down to the minimum possible settings to achieve acceptable imaging. Each eye was then scanned in both saggital and transverse planes.

The ONSD was measured 3 mm posterior to the globe for both eyes in each patient (Figures 2 and 3). The two measurements were averaged. Patients were then sent to radiology for head CT. Radiology consultants were not informed of US examination results. An average ONSD of 5 mm or greater was

Figure 1. A high-resolution linear array ultrasound transducer is being applied to the closed lid to perform an ocular examination. In actuality, much more gel is used so that the transducer does not need to make direct physical contact with the eyelid.

considered abnormal (Figure 4). Once completed, head CT scans were evaluated for signs of EICP. These signs were defined as any of the following, as documented in previous literature: midline shift from mass effect of 3 mm or greater, a collapsed third ventricle, hydrocephalus, effacement of sulci with evidence of significant edema, and abnormal mesencephalic cisterns. Acute injury or neurologic deficits were defined as having occurred within 12 hours of presentation. All examinations were recorded on a standardized US log and taped on SVHS tape for review by the department US quality assurance (QA) committee. The QA committee met on a weekly basis to review all US examinations performed by EPs.

Measures. Resident and attending EPs saw all patients. Bedside ultrasonography was performed immediately after initial physical examination. Radiological testing consultation was not delayed for bedside scanning. Initial complaint, bedside US results, head CT study results, and diagnosis upon leaving the ED were recorded. All US examinations were performed with a 10-MHz linear array US probe using a closed eye technique. The US machine used was an Agilent Image Point Hx (Phillips, Andover, MA). Confirmatory radiology testing consisted of thin section CT of the head.

Data Analysis. All patient information was entered into a Microsoft Excel 5.0 spreadsheet (Microsoft Corporation, Redmond, WA). Data were analyzed

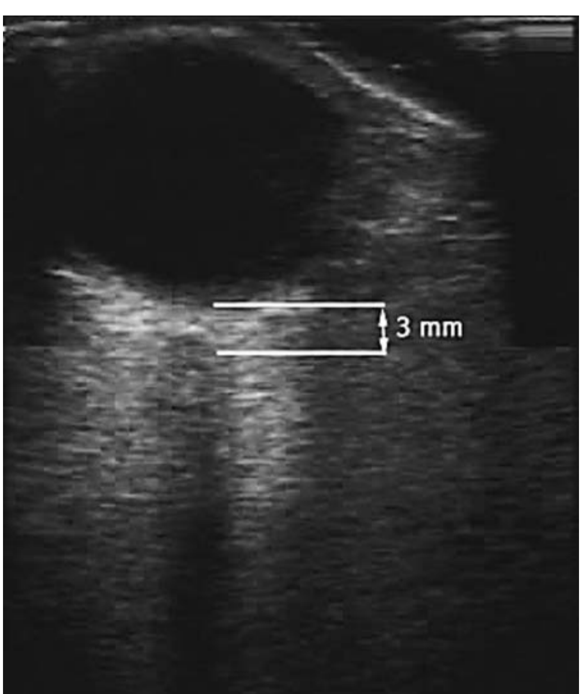

Figure 2. Shown is a 3-mm measurement behind the globe. This is where the optic nerve sheath was measured.

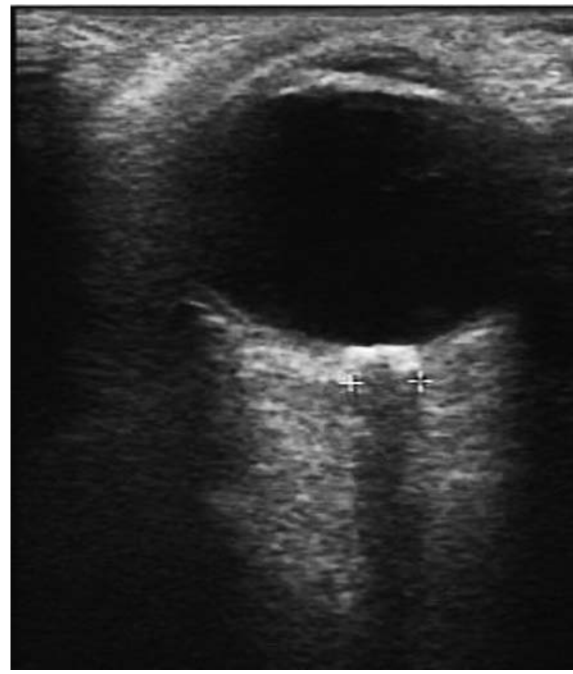

Figure 3. A normal optic nerve sheath being measured.

using statistical calculators from a commercially available software package (Analyse-it 1.44, Analyse-it Inc., Leeds, Great Britain). Sensitivity, specificity, and positive and negative predictive values with 95% confidence intervals (95% CIs) were calculated.

RESULTS

Thirty-five patients with suspected EICP from intracranial hemorrhage were enrolled into the study, nine of whom were intubated at the time of ultrasonographic evaluation. Of these, 14 patients with CT evidence of EICP had CT results consistent with EICP as determined by attending radiologists on the neuroradiology service (four of these patients were intubated at the time of US performance). EICP was predicted for all 14 patients by averaged US measurement of ONSD over 5 mm. One patient with ONSD of 5.7 mm in one eye and 3.7 mm in the other on US had a mass abutting the ipsilateral nerve. His CT, however, revealed no evidence of EICP. This patient was placed in the EICP category by the study physician due to the marked dilation of the optic nerve sheath on one side and was thus counted as a false positive. The mean ONSD for the 14 patients with CT evidence of EICP was 6.27 mm (95% CI = 5.6 to 6.89). The mean ONSD for those patients found to have no evidence of EICP on head CT was 4.42 (95% CI = 4.15 to 4.72). The difference of 1.85 mm (95% CI = 1.23 to 2.39) in the ONSD between the normal and elevated ICP groups was statistically significant ($p = 0.001$).

Using the head CT scan results as the criterion standard for EICP resulted in a sensitivity of 100%

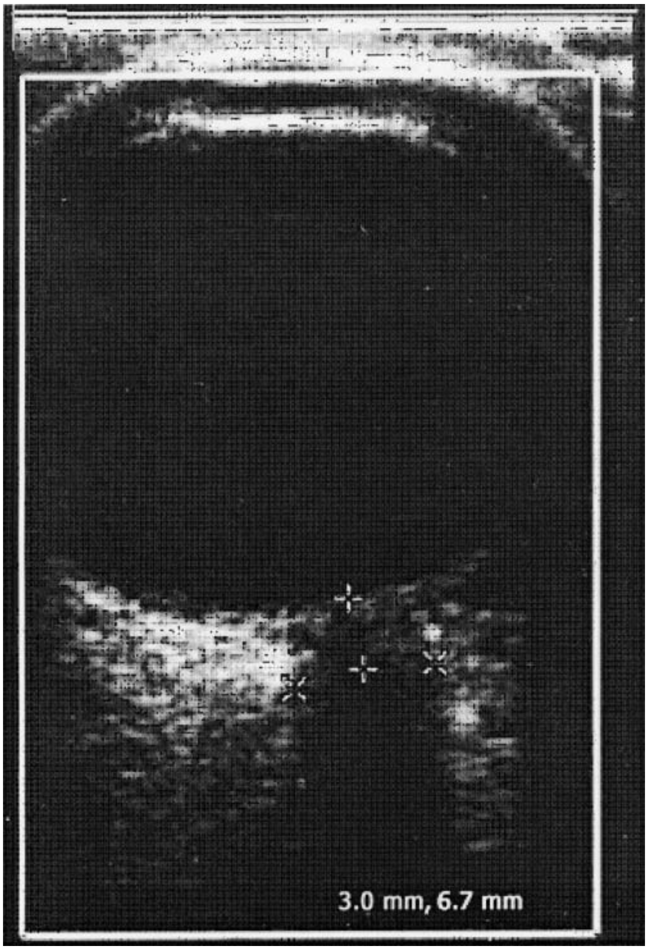

Figure 4. A dilated optic nerve sheath measuring 6.7 mm in a patient with intracranial hemorrhage is shown. One set of calipers measures 3 mm behind the globe and the second measures the diameter of the optic nerve sheath.

when comparing ONSD measurement with radiology results. The specificity was 95%. The resulting positive predictive value was 93%, with the negative predictive value being 100%. There were no complications from ocular US examination. No patients complained of discomfort or pain. Time between US examination and head CT was not controlled for.

DISCUSSION

Of the various traditional means for detecting EICP in an acutely ill patient, none except physical examination can be performed rapidly and noninvasively at bedside. However, the physical examination has significant limitations if the patient is unconscious, or intubated and paralyzed. Papilledema from EICP is delayed in its appearance after ICP elevation, by up to several hours. Performing a lumbar puncture to measure pressure on a patient with potentially elevated ICP may be dangerous. Thus, for most patients in the ED setting, head CT scanning is often the best option for detection of EICP.

Although many EPs practice in an environment where head CT is readily available, there are a number of circumstances where alternative, reliable, noninvasive testing for EICP could be beneficial. Such situations include a disaster scene where multiple casualties are being triaged, and the ability to detect elevated ICP in one out of several unconscious patients may help select the patient requiring the most rapid care. Conversely, in times of scarce resources, the opposite may be true, when a decision has to be made regarding which trauma victim is most likely to survive. With the advent of hand-held, portable, and battery-powered US units, it is not unreasonable that rescuers could arrive to a remote location with an US machine in hand to detect EICP. Other uses of noninvasive EICP detection could include the monitoring of increasing ICP during a long transport, such as by airplane or helicopter, where a decision may have to be made to divert to a closer location. Even monitoring in an intensive care unit setting may benefit if ocular US of the optic nerve sheath proves a reliable screening method.

The optic nerve attaches to the globe posteriorly and is wrapped in a sheath that contains fluid. In 1968, Hayreh established the presence of a constant communication between the subarachnoid space of the optic nerve sheath and the intracranial cavity by studying rhesus monkeys.[14] He further documented the variability of the ONSD under changing CSF pressures by placing rubber balloons into the subarachnoid space and carefully manipulating pressures. As he inflated the rubber balloon, Hayreh noted that increasing pressure caused a dilation of the optic nerve sheath, which resolved once the balloon was deflated.

The relationship between the ONSD and ICP has been observed before in a clinical setting as well. Normal ONSD measured by ultrasound ranges from 4.7 to 5.0 mm in previous studies.[15,16] Several reports have noted widened optic nerve sheaths on ultrasound in patients with intracranial hypertension, such as in those with pseudotumor cerebri.[17,18] In a prospective interventional study by German researchers in 1997, patients presenting for regularly scheduled lumbar puncture to remove CSF underwent spinal needle placement at two levels.[13] The researchers were able to remove and infuse liquid in the subarachnoid space and measure CSF pressure changes while performing ultrasound examinations of the optic nerve sheath. The study found a direct relationship between increasing ICP and dilation of the optic nerve sheath. The effect seemed to plateau at an ONSD of just over 7 mm. This phenomenon was reversed when ICP was lowered by removing excess CSF.

Our use of head CT as a comparison for EICP came out of necessity, as few patients at our facility receive immediate invasive intracranial monitoring. Although CT cannot match an invasive monitor for detection of EICP, there is considerable literature arguing that certain findings correlate well with EICP when seen in the acutely injured patient. One of the earliest studies to look for correlation between CT findings and actual cerebrospinal fluid pressure measured invasively was performed in 1980 in Glasgow, where researchers examined findings and actual pressures in 37 acutely injured patients.[19] They found excellent correlation with CT signs, such as obliteration of the third ventricle, or the collapse of the basal cisterns. Data from the National Institutes of Health Traumatic Coma Data Bank published in 1990 indicates that among 753 patients with severe head injury, head CT findings such as mass effect with midline shift of 3 mm or greater, and abnormal mesencephalic cisterns, correlated highly with EICP on invasive pressure monitoring.[2]

Our study shows a strong relationship between signs of EICP on head CT and dilated optic nerve sheath on ocular US. The only confounding finding was the patient with unilateral compression of the optic nerve with a focal mass that did not appear to cause hydrocephalus, midline shift, or any other sign of EICP. This patient was noted on the data collection sheet as having optic nerve sheath dilation and was thus a false positive. A number of rare etiologies can lead to dilation of the optic nerve sheath, which can lead to false-positive findings. These include optic neuronitis, arachnoid cyst of the optic nerve, optic nerve trauma, and an anterior orbital or cavernous sinus mass.[16]

This ED ultrasound application may have utility as a noninvasive test of ICP in patients when CT is not available. This technique may also be useful in settings other than in the ED. For example, evaluating for changes in ICP in the intensive care unit setting, and even in the operating room, where it is inconvenient to transport the patient to CT, and invasive monitoring may not be possible or convenient.

LIMITATIONS

The study has several limitations, including its small size. However, to the best of our knowledge, it is the first study of its kind and suggests an additional application of ED US, despite the modest number of patients entered. The criterion standard used as follow-up to the US examinations is not ideal since head CT appearance is not a true measurement of ICP. However, in the acute trauma setting, CT has good reliability for signs of EICP in a number of previous studies. Intravenous fluid administration was not controlled for and could have affected formation of edema on CT after US was performed. However, most CT examinations were performed within 20 minutes of the US examination, and none of the CT signs suggested that EICP in these patients was solely edema. There was no follow-up performed on the EICP patients or those without EICP as we focused the study on patient evaluation in the ED. No attempt was made to correlate our US findings with Glasgow Coma Scale results or papilledema findings. The vast majority of our patients did not have papilledema on US or physical examination, probably as a result of the time lag between EICP and the development of papilledema.

CONCLUSIONS

Our study demonstrated a close correlation between optic nerve sheath dilation on ocular ultrasound and evidence of elevated intracranial pressure on head computed tomography in patients with intracranial hemorrhage from head trauma or aneurismal bleeding.

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