A Rapid Noninvasive Method of Detecting Elevated Intracranial Pressure Using Bedside Ocular Ultrasound

Application to 3 Cases of Head Trauma in the Pediatric Emergency Department

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Abstract: Managing pediatric head trauma with elevated intracranial pressure in the acute setting can be challenging. Bedside ocular ultrasound for measuring optic nerve sheath diameters has been recently proposed as a portable noninvasive method to rapidly detect increased intracranial pressure in emergency department patients with head trauma. Prior study data agree that the upper limit of normal optic nerve sheath diameters is 5.0 mm in adults, 4.5 mm in children aged 1 to 15, and 4.0 mm in infants up to 1 year of age. We report the application of this technique to 3 cases of head trauma in the pediatric emergency department.

Key Words: optic nerve sheath diameter, ocular ultrasound, emergency ultrasonography, elevated intracranial pressure, traumatic brain injury

Managing pediatric head trauma with elevated intracranial pressure (ICP) in the acute setting can be challenging. Roughly 3000 deaths, 50,000 hospitalizations, and 650,000 emergency department (ED) visits per year in the United States can be attributed to traumatic brain injury, the leading cause of death and disability caused by trauma in children.[1,2]

In recent years, the applications of focused emergency ultrasonography have expanded in the practice of emergency medicine. Early applications explored by emergency physicians including the detection of free intraperitoneal fluid in the FAST (focused abdominal sonography in trauma) examination, limited echocardiography to detect pericardial effusions, and endovaginal sonography to confirm intrauterine pregnancies in the first trimester have become routine in many EDs.[3] Use of emergency ultrasonography has been recently explored in pediatrics as well.[4] Newer applications of focused emergency ultrasonography include extremity ultrasound for the detection of foreign bodies and real-time guidance in vascular access, testicular ultrasound in the evaluation of testicular torsion, and ocular ultrasound to detect ocular pathology such as retinal detachment, penetrating globe injury, and lens dislocation.[5,6]

Bedside ocular ultrasound for measuring optic nerve sheath diameters (ONSDs) has been recently proposed as a portable noninvasive method to rapidly detect increased ICP in ED patients with head trauma.[7] Early diagnosis of acute elevated ICP is essential to ensure prompt and effective treatment. The most precise method of measuring and monitoring ICP is by direct invasive measurement of intraventricular or subdural pressure, which is often not practical in the ED, and is typically established in a critical care or operating room setting.

We report 3 cases: one of an 8-month-old infant with severe head trauma from child abuse, a second case of a 12-year-old boy with altered mental status from head trauma, and a third case of a 4-month-old infant transferred to our facility for an epidural hematoma. Emergent bedside ocular ultrasound was performed in all these cases by a pediatric emergency physician in the pediatric ED.

CASE 1

An ex–35-week twin gestation 8-month-old female infant was brought in by emergency medical services to the pediatric ED in status epilepticus. In the pediatric ED, the infant was treated with intravenous lorazepam 0.1 mg/kg twice without effect and then loaded with intravenous phenytoin 20 mg/kg with cessation of the seizures.

On physical examination, the patient's initial vital signs were temperature, 100.8°F; pulse rate, 174 beats per

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minute; respiratory rate, 57 breaths per minute; and O_2 saturation, 99% on nonrebreather mask. The infant was obtunded; modified Glasgow coma score was 5 with flexor response to pain only. The right pupil was noted to be fixed and dilated at 6 mm, and the left pupil was not reactive to light at 2 mm with retinal hemorrhages and papilledema noted on fundoscopic examination. No deformities of the head, chest, abdomen, or extremities were noted, except for bruising and bleeding around the infant's vulva.

The patient was intubated; blood was obtained for cultures and laboratory tests, and the patient was then treated with cefotaxime and mannitol at 1g/kg intravenously.

While awaiting transportation for head computed tomography (CT), emergent bedside ocular ultrasound was performed by a pediatric emergency physician trained in sonography using a Sonosite 180 Plus with sterile endocavity transducer at 7 MHz (range, 4–7 MHz). Measurements were obtained through closed eyelids using water-soluble ultrasound gel. Transorbital ONSDs were measured in transverse and sagittal planes of 4.0 and 4.2 mm on the right and 4.4 and 4.4 mm on the left (Fig. 1). No retinal detachment or lens dislocation was noted in either eye on ultrasound and was later confirmed by ophthalmology consultation.

A noncontrast head CT revealed a large right subdural hematoma with subarachnoid blood and midline shift (Fig. 2). Cerebral edema was noted globally in the right hemisphere. Pediatric trauma, neurosurgery, neurology, and child protective service consultations were requested urgently. The patient remained hemodynamically stable in the pediatric ED and was admitted to the pediatric intensive care unit with the diagnoses of acute subdural hemorrhage with herniation, shaken baby syndrome, and child and sexual abuse. Neurosurgical intervention and ICP monitoring were declined because of the patient's coagulopathy from severe head injury. The patient's hospital course was notable for episodes of hypertension without bradycardia for the first few days that were controlled with labetalol and then stabilized. The patient's condition improved, and she was extubated and placed on nasal CPAP on the 15th hospital day. Ophthalmology examination at that time revealed resolution of the papilledema.

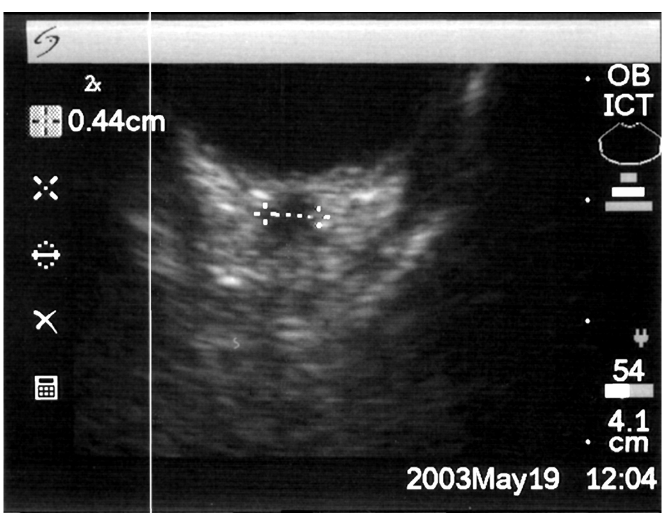

FIGURE 1. Ocular ultrasound at 7 MHz with increased ONSD at 4.4mm in an 8 month old infant.

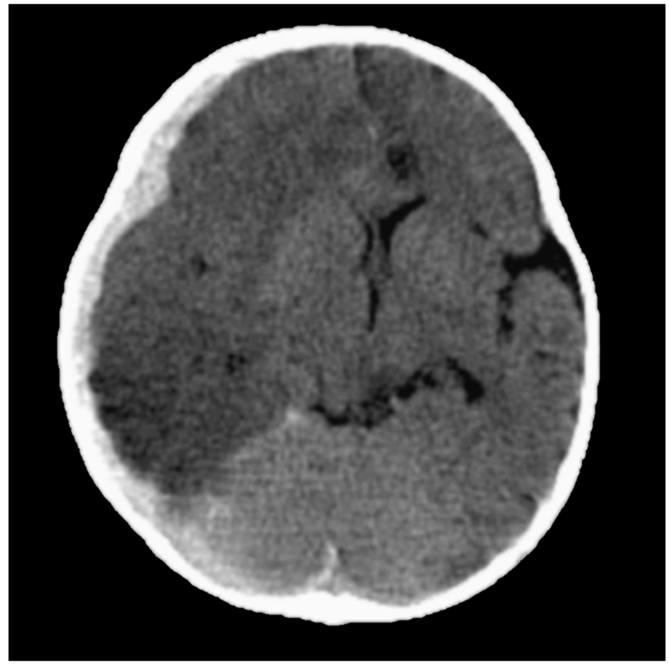

FIGURE 2. Head CT with right subdural Hematoma, subarachnoid blood and midline shift from case 1.

Follow-up measurements of the patient's transorbital ONSDs on the 16th hospital day were 2.8 mm transverse and 2.9 mm sagittally on the right and 3.1 transverse and 3.3 mm sagitally on the left.

CASE 2

A 12-year-old boy was brought to the pediatric ED by emergency medical services for altered mental status presumably after sustaining head trauma at school. In the pediatric ED, the patient's vital signs were temperature, 98°F; pulse rate, 69 beats per minute; respiratory rate, 18 breaths per minute; and O_2 saturation, 99%. His Glasgow coma score was 13, neurological examination was nonfocal, and pupils were symmetric and reactive to light, but the patient exhibited a fluctuating mental status—obtunded but easily arousable to vocal stimulus. The patient was too uncooperative to allow the performance of a fundoscopic examination. The remainder of the patient's physical examination was otherwise unremarkable. He vomited several times in the ED while awaiting CT scan of the head.

Before CT scan of the head, emergent bedside ocular ultrasound was performed using a Sonosite 180 Plus with sterile endocavity transducer at 7 MHz. Measurements were obtained through closed eyelids using water-soluble ultrasound gel. Transorbital ONSDs were measured in transverse and sagittal planes of 3.8 and 3.7 mm on the right and 3.8 and 3.8 mm on the left. No retinal detachment or lens dislocation was noted in either eye on ultrasound.

A noncontrast head CT was performed with lorazepam sedation which revealed no evidence of bleeding, skull fracture, or signs of elevated ICP. To rule out the possibility of an infectious encephalopathy as a cause of the patient's altered mental status, a lumbar puncture was performed, and the cerebrospinal fluid cell count was unremarkable. An opening pressure was measured at 12 cm H_2O, which confirmed that the ICP was normal. The patient was transferred to the pediatric intensive care unit for close neurological monitoring. Subsequent urine toxicology tests were negative, and the patient's mental status returned to baseline on the evening of admission and was discharged the following day. The patient had reported that he remembered wrestling with his friends at school during lunch when he hit his head and had no subsequent memories other than being in the hospital.

CASE 3

A 4-month-old male infant was transferred from another hospital to our facility for a right parietal skull fracture and epidural hematoma diagnosed by CT scan of the head 7 hours after the injury. The babysitter was carrying the patient up the stairs in a stroller when the babysitter became

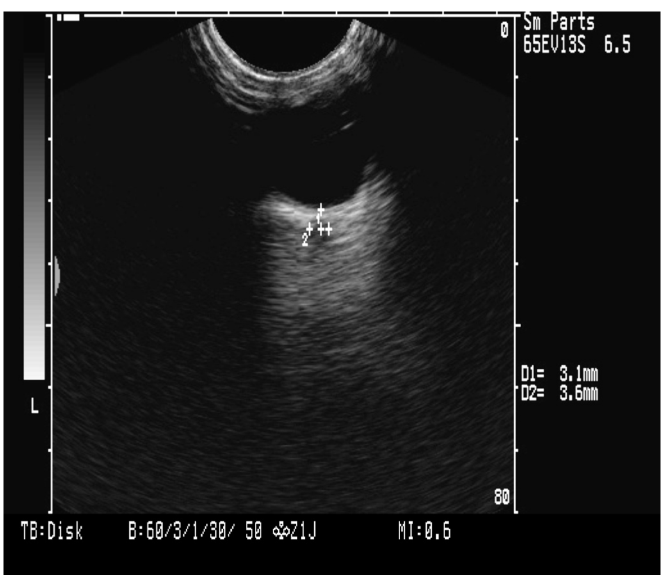

FIGURE 3. Ocular ultrasound at 6.5 mHz with normal ONSD at 3.6 mm in a 4 month old infant.

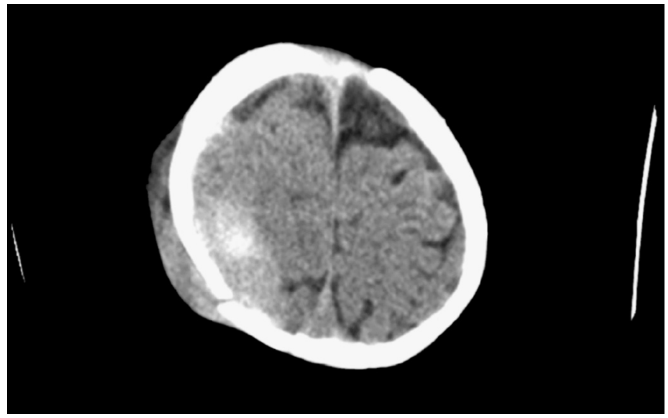

FIGURE 4. Head CT with right parietal skull fracture and epidural hematoma from case 3.

dizzy, fell down 3 stairs, and became unconscious; 911 was called, and the babysitter was taken the hospital by emergency medical services.

The event was witnessed by the uncle who reported no loss of consciousness for the patient, who was observed to be crying immediately after the event. The patient remained strapped into the stroller which had flipped over during the event. Afterward, the patient was taken home by the mother, who noted the infant to be alert, tolerating breast feeds without vomiting, lethargy, or irritability. However, the mother appreciated a growing swelling on the right side of the infant's head a few hours later and presented to an outside hospital. The infant was still asymptomatic except for right-sided scalp swelling, and CT of the head was performed which revealed a right parietal skull fracture and epidural hematoma. Patient was transferred to our facility for further neurosurgical evaluation.

On arrival to our facility, the infant was alert, smiling, and breast-feeding with no vomiting or altered mental status. Patient's vital signs were temperature, 97.1°F; heart rate, 140; respiratory rate, 20 breaths per minute; blood pressure, 80/50; and O_2 saturation, 100% on room air. Pupils were equal and reactive to light; fundi could not be assessed for papilledema. The patient's anterior fontanelle was open and flat, and a large right-sided parietal scalp hematoma was palpable with no bony step-off or crepitus. The remainder of the infant's physical examination was unremarkable.

The CT scanner was occupied by another critical trauma patient. While waiting for the CT scan, emergent bedside ocular ultrasound was performed using a Siemens Adara ultrasound machine with sterile endocavity transducer at 6.5 MHz (range, 4–8 MHz). Measurements were obtained through closed eyelids using water-soluble ultrasound gel. Transorbital ONSDs were measured in transverse and sagittal planes of 3.6 and 3.5 mm on the right and 3.4 and 3.4 mm on the left (Fig. 3). No retinal detachment or lens dislocation was noted in either eye on ultrasound.

Repeat CT of the head was performed and revealed a right posterior parietal skull fracture with an underlying large epidural hematoma (Fig. 4). Compression of the right lateral and fourth ventricles were noted with a widened sagittal suture. No midline shift or herniation was observed. There was no interval change from prior CT of the head, according to the neuroradiologist. Neurosurgical and ophthalmology consultations were obtained. Fundoscopic examination by ophthalmology revealed no papilledema or other abnormalities.

Neurosurgical intervention was deferred, and the patient was admitted to the pediatric intensive care unit for close neurological monitoring. A third head CT performed 24 hours after injury again revealed no interval change except for slight increased soft tissue swelling. The patient had an unremarkable hospital course and was discharged on the second hospital day in good condition.

DISCUSSION

Previous work has shown that patients with increased ICP have increased ONSDs.[8] Additional prior work has validated and demonstrated covariance of optic nerve sheath enlargement under ultrasound visualization with increased ICP during intrathecal infusion tests.[9] This method has been used to detect acute elevated ICP in children with hydrocephalus with measurements of ONSDs by ultrasound performed by radiologists.[10] Recently, it has been suggested that bedside ocular ultrasound may be useful in detecting elevated ICP in adult emergency patients.[7] Prior study data agree that the upper limit of normal ONSDs is 5.0 mm in adults, 4.5 mm in children aged 1 to 15 years, and 4.0 mm in infants up to 1 year of age.[10] In a small study performed on normal adult patients, emergency physicians trained in sonography were able to obtain ONSDs using ultrasonography with no significant difference measured (0.3 mm) between observers using the mean as the actual value.[11] Averaged measurements of ONSDs in children taken by radiologists produced a mean measurement that was within 0.08 mm of the true mean.[12] At present, no data exist on interobserver agreement of ONSDs measurements in children by emergency physicians trained in sonography.

In the case of the 8-month-old infant, the initial measurements of 4.1 mm for the right eye and 4.4 mm for the left eye average greater than the 4.0 mm upper limit of normal for infants consistent with the diagnosis of increased ICP. Averaged measurements on follow-up were 2.85 mm for the right eye and 3.15 mm for the left eye performed on the16th hospital day; these measurements were clearly within normal limits suggesting normal ICPs. This was consistent with the observation of resolution of papilledema by ophthalmology consultants and the patient's improved clinical status.

The presence of optic nerve sheath hemorrhage is a possibility in this infant's injury complex.[13–16] It is not known whether presence of optic nerve hemorrhage can increase ONSDs and confound the relationship of elevated ICP and measured ONSDs. However, it is unknown whether optic nerve sheath hemorrhage would have resolved in 2 weeks from initial presentation to follow-up measurements for the ONSDs to return to normal, as opposed to normalization of ICP. Furthermore, optic nerve sheath hemorrhage may be a possible explanation for the observation of the difference between left optic nerve sheath having a diameter that was consistently 0.3 mm larger than the right on repeated and follow-up measurements.

Although papilledema was observed in the patient on presentation, its appearance may lag the onset of increased ICP up to several hours. Furthermore, the accuracy of fundoscopic examination to assess papilledema or loss of retinal venous pulsation is limited in the acute setting, especially in children who may not be cooperative. Assessment of papilledema by nonophthalmologists under highly idealized conditions (stereoscopic images and dilated pupils) has been reported with a sensitivity of 84.5% and specificity of 59.3%[17] which translate to maximal likelihood ratios for a positive test at 2.07 and for a negative test at 0.25.

In the case of the 12-year-old boy, the averaged ONSDs of 3.75 mm on the right and 3.8 mm on the left were under the normal upper limit of 4.5 mm for his age. The normal CT scan of the head and the measured opening pressure of 12 cm on lumbar puncture provided further evidence of normal ICPs in the patient.

In the case of the 4-month-old infant, the averaged ONSDs of 3.55 mm on the right and 3.4 mm on the left were under the normal upper limit of 4.0 mm for his age. These ONSDs measurements were reassuring in addition to the infant's good clinical and neurological condition.

With higher quality ultrasound machines becoming more readily available, this application of emergent ultrasonography may be inexpensive and easy to adopt. However, specific ultrasound probes designed for ocular sonography are rarely available to physicians in the ED because of the lack of utility for other examinations. In these cases, probes with sufficiently high frequencies, such as linear transducers used for vascular access placement and soft tissue scanning, and endocavity transducers, as in our 3 cases, may be used.

Many of the conditions associated with increased ICP in the pediatric population, such as head trauma, brain tumors, cerebral edema in diabetic ketoacidosis, malfunctioning ventriculoperitoneal shunts for hydrocephalus, and pseudotumor cerebri, can be expected to present to the pediatric ED. Rapid noninvasive detection of elevated ICP would be valuable to facilitate treatment and care, especially if there are delays in obtaining definitive imaging such as

CT. In addition, measurement of ONSDs may be used to screen patients for elevated ICP before the performance of lumbar punctures and may obviate the need for CT scan of the head in otherwise neurologically normal patient.

CONCLUSIONS

Bedside ocular ultrasonography may be useful in the pediatric ED and other acute care settings to diagnose and monitor elevated ICP. Research in this technique as a diagnostic test is needed with large numbers of subjects to describe its test performance characteristics and to determine its clinical usefulness in a variety of acute conditions associated with elevated ICP in the emergent setting.

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