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We are in the midst of a major phase in the evolution of patient assessment in emergency medicine. Ultrasound is changing the way we evaluate and approach patients in a manner that may be as significant as the clinical application of X-ray in the early 1900s. As an example of how ultrasound can become an integral part of the patient assessment, consider the following physical exam presentation by one of our third year residents: "BP 164/105, HR 110, RR 22, T 99°. HEENT—normal. Neck—supple, no venous distension. Chest—clear and equal *with no pleural effusion.* Heart—regular rate and rhythm, no murmur, ectopy, *or pericardial fluid.* Abdomen—soft, bowel sounds present, moderate epigastric tenderness, *gallbladder normal, no free fluid, cysts on both kidneys, aorta normal.*"

Ultrasound machines are becoming easier to use, less expensive, more lightweight and maneuverable, and their image quality is constantly improving. The emergency medicine literature suggests that there is a broad range of applications that emergency physicians can quickly and accurately utilize to facilitate patient evaluation and medical decision making. The Institute of Medicine and the Agency for Healthcare Research and Quality (AHRQ) have identified ultrasound as a significant means to decrease procedure-related complications.[1-2]

Although the initial learning curve for ultrasound technique is steep, patient satisfaction may be improved, and patient time spent in the emergency department (ED) may be decreased.[3-5] As important as the physical examination is, it often cannot compete with the images and perspectives afforded by ultrasound. The one potential downside to this evolution may be the further erosion of physical exam skills that have already suffered from the increasing use of imaging technology of the past twenty years.

Over the past ten years, battles to increase the acceptance of emergency medicine ultrasound have been waged, and these struggles continue even today. Nevertheless, growth and acceptance of emergency medicine ultrasound has been rapid. Virtually all residencies now teach ultrasound applications as part of their basic curricula, and their graduates are taking these skills into community emergency departments around the country.[6] As our literature continues to document the advantages of using ultrasound and the list of applications continues to expand, the costs of implementing ultrasound will come down, the quality of patient care will continue to improve, and the speed of this evolution in the use of ultrasound will accelerate.

Ultrasound can quickly and effectively evaluate multiple key parts of the body (chest, heart, abdomen) in clinical circumstances such as undifferentiated hypotension.[7] As emergency physicians become more comfortable with this modality, the benefits of decreased costs, decreased radiation exposure, and decreased use of other confirmatory tests will make ultrasound an indispensable ED tool. Table 1 lists potential ultrasound applications based upon a patient's chief complaint.

A guideline document for emergency ultrasound published in *Annals of Emergency Medicine* in 2001 lists the standard ED applications of ultrasound: trauma, ectopic pregnancy, abdominal aortic aneurysm, pericardial effusion, determination of cardiac activity, biliary disease, renal tract disease, and procedure guidance.[8] This document also

Table 1. Diagnoses made with and clinical application of ultrasound categorized by chief complaints.

Abdominal pain	Gallbladder disease, AAA, ascites, bowel obstruction, hernia, renal disease, bladder distension
Unexplained hypotension/ tachycardia/dyspnea	Pericardial effusion, DVT, pleural effusion, AAA, ruptured ectopic pregnancy, intraperitoneal free fluid, pneumothorax
Chest pain	Pericardial effusion, poor ejection fraction, pleural effusion, pneumothorax
Skin infection	Abscess, cellulitis, necrotizing fasciitis
Laceration	Foreign body, tendon laceration
Swollen leg	DVT, Baker's cyst
Pregnancy with vaginal bleeding	Ectopic pregnancy, threatened abortion, viable pregnancy
Eye trauma/loss of vision	Ruptured globe, retinal detachment, lens dislocation, foreign body
Obese patient spinal tap	Location of the midline and spaces between vertebrae
Line placement	Deep brachial line in IV drug user, central vein location and patency
Is there ascites?	Very sensitive for fluid in the abdomen
Locating fluid during procedures	Thoracentesis, suprapubic tap, paracentesis, pericardiocentesis
Swollen painful knee	Patellar tendon rupture, fluid in the bursa, fluid in the joint
Testicular pain, swelling	Torsion, mass, hydrocele
Trauma	FAST, pneumothorax, fetal heart rate for fetal and maternal distress, fractures
Fracture reduction	Can confirm adequate reduction/realignment
Sore throat	Peritonsillar abscess
Headache/facial pain	Sinusitis

AAA = abdominal aortic aneurysm, DVT = deep venous thrombosis, FAST = focused assessment with sonography in trauma

discusses important topics such as credentialing. However, it does not mention any of the newer uses of ultrasound that are currently being applied and investigated by emergency physicians. In the remainder of this article we discuss several of these applications that are new to emergency medicine: diagnosis of deep vein thrombosis (DVT), investigation of soft tissue infections, ocular ultrasound, and diagnosis of sinusitis.

Deep Vein Thrombosis

Assessing for the possibility of DVT in the lower extremities is problematic for emergency physicians. DVT carries the risk of significant morbidity and mortality, but it is often difficult to obtain formal vascular studies of the leg on an emergent basis, particularly at night. Clinical suspicion may be low enough to make physicians reluctant to order a formal study, even though they have lingering concerns. The emergency medicine literature has demonstrated that compression ultrasound performed by emergency physicians is fast and reliable.[9]

The procedure is not difficult, requiring fewer than 25 exams to attain proficiency. Using a 5 to 10 MHz linear transducer (generally higher frequency is better for optimum resolution) with the patient lying supine, the probe is placed in a transverse plane to image the femoral vessels at the level of the groin. The common femoral vein is identified medial to the artery. In the absence of clot, the vein is easily compressible. An abnormal test is defined by one of three findings:

1. The inability to completely compress the vein;
2. The pressure needed to compress the vein is so great that the wall of the artery is deformed; or
3. The pressure to compress the vein is significantly greater than the pressure necessary to compress the vein of the opposite leg.

The appearance of a clot in the vein is a specific but insensitive finding. This exam should be continued distal to the inguinal ligament for several centimeters. Subsequently the patient should be rolled to a prone position, and the study should be repeated in the popliteal fossa; the frog-leg position with the patient supine is another option. Color Doppler may be useful to help identify the vessels in obese or edematous patients.[9]

Soft Tissue Infections

The distinction between cellulitis, abscess and necrotizing fasciitis may be difficult. Ultrasound is an excellent modality to look for the presence or absence of pus collections and other tissue distortions. In a mature abscess, in which the soft tissue completely surrounds the liquefied pus, the echogenicity is very similar to other fluids—black on ultrasound. In fact, the abscess may be as distinct as the fluid-filled gallbladder or the urinary bladder. A less mature abscess, in which the material in the center of the infected tissue has not become completely liquefied, may be less distinct. The ultrasound appearance will resemble the echogenicity of a mixture of solid and liquid material, very different from normal tissue but not like the black, well-circumscribed appearance of a mature abscess.

In a study presented as an abstract at the Society for Academic Emergency Medicine national conference in 2000, ultrasound was able to distinguish an abscess from the thick, indurated tissue of cellulitis in 95% of patients.[10] The benefit to patients was to eliminate the need to aspirate the tissue to determine if pus might be present. Another recent study suggests that high-resolution ultrasound may be able to distinguish cellulitis from necrotizing fasciitis.[11] If one looks at normal tissue or at tissue with cellulitis, there may be disruption of the normal architecture of subcutaneous tissue but the underlying fascia will remain intact. In patients with necrotizing fasciitis there may be distorted, thickened fascia surrounded by a layer of fluid and/or air (highly echogenic with a distinct shadow) deep in the tissue.

Ocular Pathology

Recently, we evaluated a patient who presented with 24 hours of painful, monocular loss of vision. She

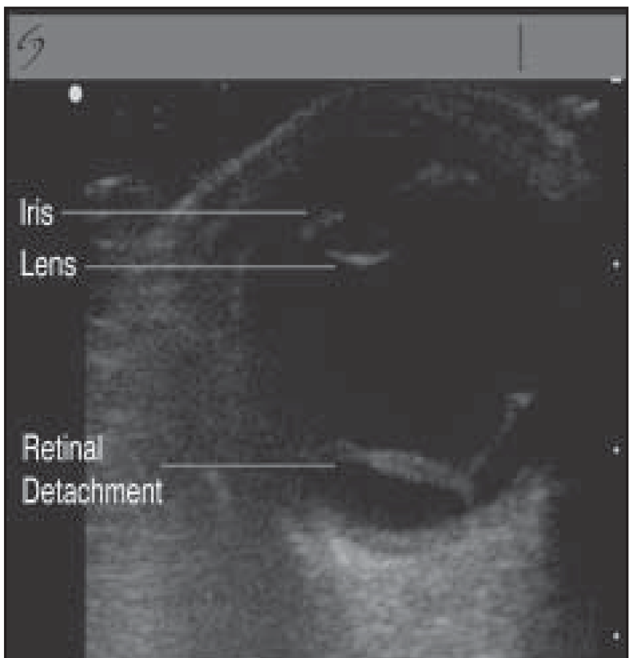

Figure 1. Retinal detachment. The retina is tethered by its connection with the optic nerve.

had a cataract in the affected eye, making the fundoscopic exam difficult. In addition to evaluation for domestic violence, we decided to augment her examination with an ultrasound evaluation of the eye. The image demonstrated the finding of retinal detachment (Figure 1). Ophthalmology was called and assumed care of the patient following consultation by the social worker.

Eye complaints are common in the ED, and vision-threatening pathology such as globe penetration, retained ocular foreign body, acute glaucoma, retrobulbar hematoma, lens dislocation, central retinal vein and artery occlusion, retinal detachment, and vitreous hemorrhage can be difficult to diagnose without sophisticated tools and training. Simply examining the eye can be complicated when the lids are swollen shut following trauma, or when the patient has a cataract blocking the view of the posterior chamber as in the case described above. Traditionally, we have been taught to pry open lids that are swollen shut in order to view the eye, but this maneuver tends to be difficult, painful, and potentially dangerous in that it increases intraocular pressure and can extrude ocular contents in the presence of a globe rupture. Furthermore, timely ophthalmologic consultation can be difficult to obtain, particularly at night, and may lead to delayed diagnosis and treatment.

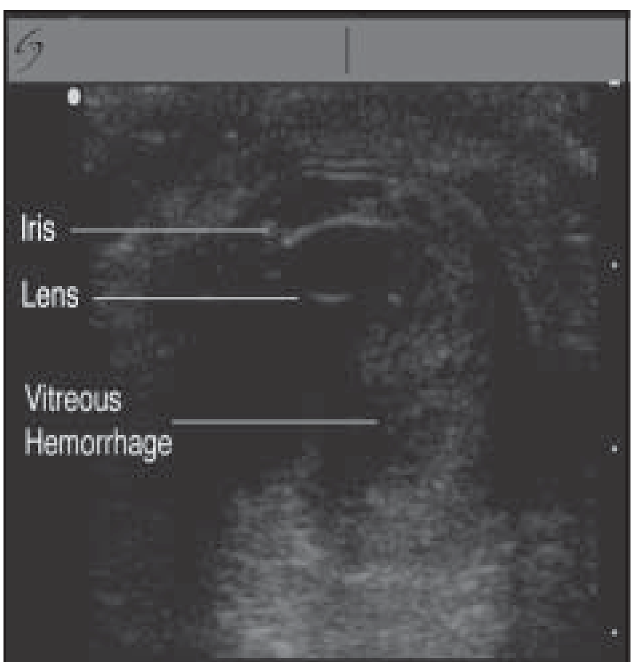

Figure 2. Vitreous hemorrhage. Note the echogenic material in the posterior chamber.

One of the most exciting new uses of ultrasound we have implemented in our emergency department during the past year is the ocular ultrasound exam. We have diagnosed cases of retinal detachment, vitreous hemorrhage, hyphema, and lens dislocation. As demonstrated in the case above, ultrasound can dramatically improve patient care by providing a rapid, accurate diagnosis leading to quicker treatment and disposition.

Emergency indications for ocular ultrasound include eye pain, trauma, and a sudden change in vision. In keeping with principles of emergency ultrasound, this exam is quick (three to five minutes or less) and relatively simple. The pathological findings are generally not subtle and are amenable to recognition by emergency physicians with basic ultrasound training. The eye is a fluid-filled structure and therefore provides a perfect acoustic window, producing images with excellent detail. Since only one eye is usually involved, the other eye can act as a normal control. The high frequency linear transducer is used to maximize resolution of detail. The close focal zone of this probe is perfect for a superficial structure like the eye. Most of these probes have adjustable frequencies ranging from 5 to 10 MHz, and the highest frequency should be used. With the patient sitting comfortably in an exam chair, or lying supine in the case of a trauma patient, the gel-coated probe is placed on the closed eyelid. When globe rupture is in the differential, care must be taken to brace the hand holding the transducer on the patient's face and forehead to minimize pressure to the eye, and a large quantity of gel should be applied to the closed lid so that the transducer does not actually press on the eyelid. Depth should be adjusted so that the image of the eye fills the screen, and gain should be adjusted to improve detail.

The anterior chamber will appear narrowed in a globe rupture or glaucoma. Hyphema will appear as echogenic white material in the anterior chamber. A dislocated lens is angled off-center. Vitreous hemorrhage appears as echogenic material in the posterior chamber (Figure 2). The ill-defined material of a vitreous hemorrhage may accompany a well-defined elevated flap of detached retina. With additional training and experience, central retinal artery and vein occlusions can be diagnosed using color and spectral Doppler.

Use of ocular ultrasound has been studied in the emergency setting. Blaivas and others evaluated the use of ocular ultrasound in 61 ED patients with eye trauma or acute change in vision.[12] They identified 26 pathologic findings, including nine retinal detachments, three globe penetrations, two lens dislocations, and one retinal artery occlusion. Their findings agreed with a gold standard of orbital computed tomography (CT) and/or complete evaluation by an ophthalmologist in 60 of 61 patients. The one discordant case involved a small vitreous hemorrhage that was not seen on examination by the ophthalmologist. However, the ultrasound tape was shown to a board-certified ophthalmologist with considerable experience in ocular ultrasound, who agreed the hemorrhage was present and thought it could have been missed on initial evaluation.

ED ultrasound provides a quick, accurate, safe, well-tolerated, noninvasive tool for evaluating potentially vision-threatening pathology at the bedside. The ocular ultrasound exam is easy to learn and has truly changed our approach to examining patients with eye complaints.

SINUSITIS

Ultrasound is a promising new imaging modality for diagnosis of acute maxillary sinusitis. In the past, A-mode ultrasound (a linear waveform without a two-dimensional image) was studied for the diagnosis of sinusitis and found to be an unreliable test. Recently, modern B-mode ultrasound (two-dimensional grayscale image) has been shown to be sensitive and specific for diagnosing radiographic maxillary sinusitis when compared to CT.[13,14]

Sinusitis is a common problem that was responsible for 25 million office visits in 1995.[15] Sinusitis is the fifth most common medical diagnosis for which antibiotics are prescribed and is responsible for approximately $2 billion in medical costs annually.[16,17] Physicians tend to think of sinusitis as an acute bacterial infection and prescribe an antibiotic in 85-98% of cases.[18] If left untreated, sinusitis can result in severe complications including orbital cellulitis, cavernous sinus thrombosis, intracranial abscess, and meningitis. Therefore, proper diagnosis and treatment of bacterial sinusitis with antibiotics is important.

The gold standard for diagnosing acute bacterial sinusitis is sinus puncture and culture. However, because of its invasive nature, sinus puncture is seldom performed in clinical practice. Instead, medical providers must rely on history and physical exam and imaging studies. According to Hickner et al., "the greatest barrier to efficient antibiotic treatment of acute bacterial rhinosinusitis is lack of a simple and accurate diagnostic test. Until a better test is widely available … diagnosis will continue to depend largely on clinical judgment and will remain imprecise."[18]
Guidelines for diagnosing and treating acute sinusitis recommend that for initial, uncomplicated, acute sinusitis, no imaging studies be obtained.[19] Diagnosis and subsequent treatment should be determined by history and physical exam. Unfortunately, clinical impression is accurate only 40-50% of the time when compared to punctures and imaging studies.[18] CT is a sensitive but costly test and therefore is not recommended as a routine imaging study. Sinus radiographs are not recommended because of poor sensitivity, with the presence of an air-fluid level or complete sinus opacification only present 60% of the time when compared to intra-operative and CT findings.[20] Thus, radiographs lend little additional information to history and physical exam.

Ultrasound has been shown to be both sensitive and specific for diagnosing acute maxillary sinusitis when compared to CT. Hilbert *et al.* examined 50 intubated patients (100 sinuses) thought to have acute nosocomial sinusitis.[14] Their objective was to compare bedside ultrasound with CT. A positive ultrasound was defined as the presence of an air-fluid level or complete opacification of a sinus. Ultrasound was 100% sensitive and 96.7% specific in diagnosing the 38 diseased sinuses. In a second study by Garioli *et al.*, 39 patients were seen in an outpatient setting

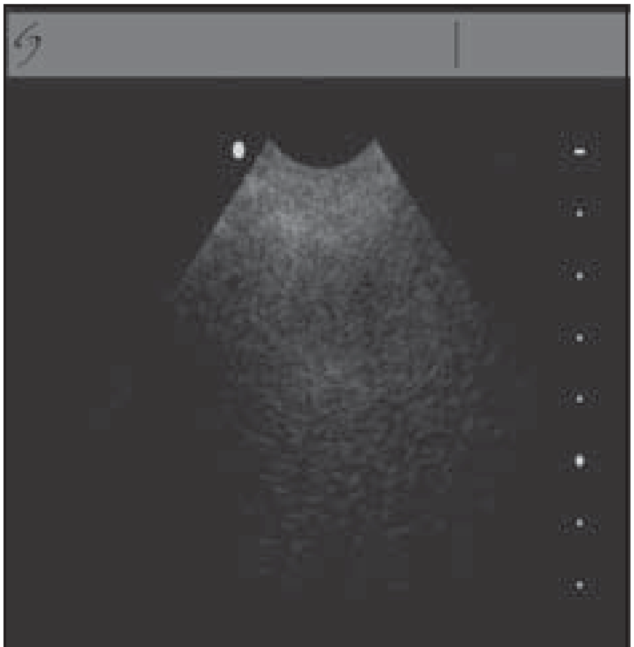

Figure 3. Normal maxillary sinus. Bony walls of the sinus cannot be distinguished because the sound waves are scattered by air in the sinus, producing an indistinct gray image.

for clinical suspicion of recurrent/chronic sinusitis.[13] When looking for an air-fluid level or complete opacification, ultrasound was found to be 100% sensitive and 98% specific when compared to CT.

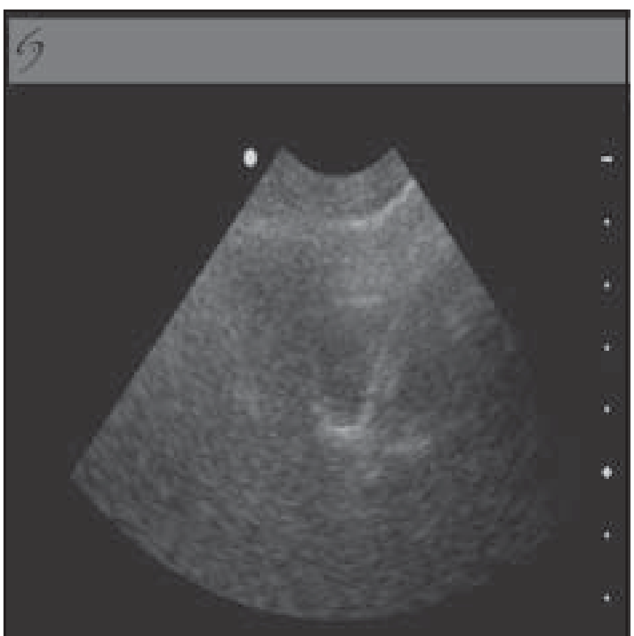

Figure 4. Maxillary sinusitis. Fluid in the sinus provides an acoustic window through which the walls of the sinus can be seen.

The ultrasound technique for sinus examination is straightforward and can be performed in minutes. An obvious question is, "how can ultrasound 'visualize' anything through bone?" The anterior wall of the maxillary sinus is a thin wall of cancellous bone. Using a low frequency 2-5 MHz small footprint transducer, one can see through this thin anterior wall. Higher frequency linear transducers are unable to penetrate the sinus wall. In a normal patient, there is no fluid and the sinus is filled with air. Air is an acoustic barrier; hence, there are no discernable sinus walls, only an acoustic shadow (Figure 3). If there is an air-fluid level or completely filled sinus, the fluid will act as an acoustic medium allowing complete or partial visualization of the posterior, lateral, and medial walls of the maxillary sinus (Figure 4).

The ultrasound exam is performed with the patient sitting upright. The patient's neck is flexed slightly so that any fluid in the sinus will become dependent and layer adjacent to the anterior sinus wall. After applying ultrasound gel, the transducer is placed on the patient's face over the maxillary sinus. The scan is done in both transverse and longitudinal planes by sweeping through the entire maxillary sinus. External landmarks include the inferior orbital rim, upper ridge of the maxilla, malar eminence, and nose.

Ultrasound's exact role in the diagnosis of sinusitis remains to be seen. Larger, prospective studies need to be done. However, if ultrasound is found to be both sensitive and specific for the diagnosis of acute maxillary sinusitis, it could change the diagnostic approach to this disease. It will likely not completely replace CT, which is the gold standard imaging modality for diagnosing sinus pathology and defining anatomy prior to sinus surgery. One author stated that "…possibly the most useful situation of ultrasound in sinus evaluation is the case of acute sinusitis."[13] In this study ultrasound was found to be very useful for diagnosing air-fluid levels and complete opacification (findings consistent with acute sinusitis). Since ultrasound is noninvasive, rapid, inexpensive, and available at the bedside, it could become the initial imaging modality of choice for the diagnosis of acute maxillary sinusitis.

Summary

In conclusion, ultrasound has found a unique niche in the specialty of emergency medicine, and its use is spreading as more individuals are trained. Ultrasound applications are evolving and exciting new uses are being investigated to address specific questions faced by emergency physicians. Most importantly, this technology is helping us to make more accurate and timely diagnoses and to improve patient care.

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