The Role of Ultrasound in Orthopedics: A Review of the Literature

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Abstract

Many medical imaging professionals assume that because ultrasound waves cannot penetrate bone, ultrasound is not useful in orthopedics. Recent articles in medical literature describe the use of ultrasound in diagnosing fractures and other orthopedic pathologies. Ultrasound has been used successfully in orthopedic trauma settings by emergency physicians. Specialized applications of ultrasound have even proven useful in orthopedic surgery and bone densitometry. There are advantages and drawbacks to the use of ultrasound in the place of other imaging modalities in orthopedics. Implications to be considered are the impacts on the cost of health care, overall patient safety, and diagnostic accuracy. If orthopedic ultrasound is implemented more fully in the future, medical imaging professionals should be prepared for the ensuing reforms.
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Introduction

In the right hands, ultrasonography can be a tremendously versatile diagnostic tool. It has long been used to evaluate fetuses, breasts, hearts, blood vessels, glands, neonatal brains, and organs of the abdomen and pelvis. Musculoskeletal Ultrasound, or sonography of joints and soft tissues of the musculoskeletal system, is currently gaining popularity in fields such as sports medicine, rheumatology, physiatry, podiatry, anesthesiology, and pain medicine. The American Registry of Diagnostic Medical Sonographers made the first registry examinations for Musculoskeletal Ultrasound available on September 12, 2012. Training to read musculoskeletal sonograms is now more widely included in radiological curricula than it has previously been. As new radiologists enter the work force, and as veteran radiologists chose to learn this new specialty, Musculoskeletal Ultrasound will become a more common imaging examination (Fessell, 2011).

Some would say one of the very few tissue types left which ultrasound cannot evaluate is bone. Ultrasound waves cannot penetrate bone at the frequency range used in diagnostic imaging. The high acoustic impedance inherent in bone-soft tissue interfaces causes ultrasound waves to be strongly reflected from bone surfaces (Arbona, 2010). Because of the lack of signal deep to the bone-soft tissue interface, all that is visible beyond the cortical surface is a dark, homogenous area termed by sonographers as acoustic shadowing. Acoustic shadows hold no diagnostic information. Yet the use of ultrasound in bone studies has been steadily increasing over the last decade. As it turns out, the inability of ultrasound waves to penetrate bone does not rule this modality out as a valuable tool in orthopedics.

Literature Review
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According to Backhaus et al. (2001), orthopedic ultrasound is possible because of the hyperechoic reflection of the superficial cortex of bone in ultrasound images. Valuable diagnostic information can be obtained from the ability to view bone surfaces. For example, Blankstein (2011) observes that fractures can be seen as disruptions in the cortex. (See Figures 1 and 2) Many types of pathology can be identified as cortical irregularities including Hill-Sachs disease, osteolytic lesions, exostoses, and osteophytes. Bone tumors have been evaluated with ultrasound. Ultrasound is particularly advantageous in this case because blood flow to the tumor can be assessed in the same exam using Doppler settings. (See Figures 3, 4, and 5)

Pathologies wherein tendons pull a portion of cortical bone away from the bone surface, such as Osgood-Schlatter disease and avulsion fractures, are often well depicted with ultrasound. (See Figure 6) Stress fractures too small to be seen on radiographs can often be directly seen with ultrasound. Ultrasound is also a valuable tool for diagnosing and monitoring rheumatic diseases (Backhaus et al., 2001). The orthopedic pathologies which can be diagnosed with ultrasound are numerous.

Ultrasound has a wide variety of uses in orthopedics that extend beyond routine diagnosis of bone irregularities. Ultrasound plays a role in orthopedic trauma, orthopedic surgery, and even bone densitometry. The following three article summaries demonstrate the versatility of ultrasound in its orthopedic applications.

Article #1

Sinha et al. (2011) conducted a study in which bedside ultrasound was used by emergency physicians, after brief training, to detect extremity fractures on patients admitted to the Emergency Department (ED). Radiography has long been the imaging modality of choice for detecting fractures in trauma patients admitted to the ED. One difficulty apparent with the
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current system is that the wait time for a radiograph often exceeds several hours in facilities with high patient flow. “Non-life-threatening skeletal injuries are often kept waiting for hours for treatment because radiographic examination is delayed. Bedside ultrasound has the potential to be a quick, noninvasive alternative for identifying bone fractures in the ED setting” (Sinha et al., 2011, p. 443).

Data were collected from the examinations of 41 patients aged 7-17 who presented to the ED with possible extremity fractures. Pediatric patients were used because the authors wished to demonstrate the usefulness of bedside ultrasound in detecting fractures in the population of patients who are at greatest risk when exposed to ionizing radiation. Patients were diagnosed by blinded physicians in separate radiography and ultrasound exams. Fractures were detected radiographically in nine of the 41 patients. Eight of these nine fractures were also detected with bedside ultrasound.

Sinha et al. found bedside ultrasound to be a legitimate tool for fracture diagnosis and a possible alternative to radiography in certain scenarios. Benefits to the use of bedside ultrasound for extremity trauma in the ED include shorter wait times for diagnosis in overcrowded facilities and the avoidance of patient exposure to radiation. This study was small in scale, but successfully demonstrated marked possibilities for the use of ultrasound for orthopedic diagnosis in trauma settings.

Article #2

Quantitative Ultrasound is a form of ultrasound that is useful for monitoring patients with degenerative orthopedic diseases. Osteoporosis is a degenerative orthopedic disease that affects many millions of people worldwide. Floter, Bittar, Zabeu, and Caneiro (2011) iterate the "great social and economic impact" of osteoporosis, particularly in impoverished countries where the
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direct costs of the disease are beyond what the general population can afford (p. 327). They compare Dual Emission X-ray Absorptiometry (DXA) and Quantitative Ultrasound of the calcaneus as alternate methods for detecting osteoporosis. Because Quantitative Ultrasound is the less expensive of the two exams, they point out the possible cost savings if Quantitative Ultrasound were proven to be as accurate as DXA.

DXA is the current gold standard for osteoporosis detection, and is the diagnostic method recommended by the World Health Organization. According to Floter et al. (2011), Quantitative Ultrasound is a recently-emerging method in which key points of the calcaneus are penetrated by ultrasonic waves and overall bone mineral density is estimated. They reviewed several recent studies and found that Quantitative Ultrasound is consistently less accurate than DXA in detecting osteoporosis, but is useful in determining the risk of fractures from osteoporosis. They assert that, unlike DXA, Quantitative Ultrasound is capable of providing information about the qualities of bone, such as trabecular micro-architecture. Trabecular micro-architecture accounts for up to 50% of total bone strength, and is a valid indicator for the risk of pathological fractures.

Though Quantitative Ultrasound cannot currently detect osteoporosis as accurately as DXA, the authors recommend that additional studies be conducted on this topic as Quantitative Ultrasound technology advances. They feel this technology has the potential to aid in lowering the cost of care for osteoporotic patients. In present times of economic hardship, lowering cost in any aspect of healthcare is very much in line with healthcare institution goals and, more importantly, patient interests.

Article #3

In a ground breaking 2006 study, Barratt et al. described the use of self-calibrating ultrasound to create models of the femur and pelvis sufficient to guide a total hip replacement in
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A Computer Aided Orthopedic Surgery (CAOS). CAOS is an emergent form of orthopedic surgery in which digital models of patients’ bones are referenced in order to increase surgical accuracy and minimize invasiveness. CAOS was initially CT guided, but to avoid unnecessary cost and radiation exposure, CT-free methods are being developed.

The first CT-free CAOS procedures involved incising soft tissues and exposing portions of a patient’s bony anatomy to a digital sensor to create bone models. Ultrasound guidance can negate such invasive measures. According to Barratt et al., a tracker can sense the location of an ultrasound probe during scanning and incorporate the data obtained into an algorithm to create a sufficient model. They state that, “a self-calibrating 3D-ultrasound-based algorithm provides a noninvasive and accurate method for registering bones during image-guided orthopedic procedures” (p. 321).

There are a number of difficulties inherent in the use of ultrasound guidance in orthopedic surgery. For example, ultrasound waves can only penetrate so deeply into a patient’s tissues, so hypersthenic patients may not benefit from these methods. However, this application of ultrasound expands the range of options orthopedic surgeons have to choose from for intra-operative guidance. Ultrasound is noninvasive, radiation free, relatively inexpensive, and according to this study, accurate in bone registration. Such qualities should make this modality attractive to orthopedic surgeons.

Case Study

A 31-year-old male serving military duty in a remote location presented to a physical therapist with pain in the area of the distal fibula. The physical therapist evaluated the patient using the Ottawa Ankle Rules. Based on the results of the evaluation, he determined there was a high likelihood of a distal fibular fracture. The nearest facility with radiography equipment could
only be reached by air medical evacuation. Rather than fly the patient out, the physical therapist examined the patient using a portable ultrasound machine. He was able to detect a fracture with ultrasound and sent the digital images to a reading radiologist. The radiologist confirmed the fracture diagnosis (Kardouni, 2012).

**Discussion**

According to an expanding body of professional literature, ultrasound can be used in the place of other modalities for certain orthopedic studies. The question of whether or not ultrasound *should* be used in the place of other modalities is widely debated and highly situational. The advantageous aspects of ultrasound are many.

Ultrasound is the safest of the medical imaging modalities. Patient exposure to ionizing radiation is a chief concern in medical imaging. Exposure to high levels of ionizing radiation has been linked to increased risk of cancer. Skin erythema and cataracts are also a concern with ionizing radiation. The long term biological effects of ionizing radiation at low levels are not fully understood at present, but most professionals agree that exposure should be kept as low as reasonably achievable. This is known as the ALARA principle. This principle is especially significant given that the effects of ionizing radiation are cumulative. Ionizing radiation is not utilized in ultrasound.

Ultrasound does not produce dangerous magnetic fields like MRI. There are many reported cases of injuries and deaths that occur when objects containing ferrous metal, such as oxygen tanks, knives, and scissors, are brought too close to an MRI machine and become projectiles. There have also been deaths and injuries caused when ferrous metal inside a patients’ bodies react to the magnetic fields in MRI units (Martin, Frauenrath, Özerdem, Renz,
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Niendorf, 2011). Such ferrous metal objects include surgical clips, aneurysm clips, shunts, and metal shards in eyes from welding.

Patient claustrophobia is a concern in MRI which is not a problem with ultrasound. Medical imaging technologists are faced with patient anxieties such as claustrophobia every day and may be disposed to make light of these anxieties. However, patient anxieties should be recognized and addressed whenever possible. Ultrasound is a superior modality when it comes to patient comfort. Patients are usually examined lying or sitting on a padded bed. Ultrasound allows for dynamic images. Ultrasound is also very portable. This makes it easy to transfer from Radiology to departments such as the OR, the ER, and Physical Therapy for orthopedic evaluations.

Ultrasound is a relatively inexpensive diagnostic imaging exam. The cost of health care is currently a major national issue, and was one of the most discussed topics in the recent 2012 presidential election. Using sonography in the place of more expensive modalities when appropriate is one clear way to lower the price patients pay for their care.

There are also a number of drawbacks to the use of ultrasound in the place of other modalities for orthopedic studies. Ultrasound has limited penetration abilities, so areas of bone that reside deep in soft tissue may not be well visualized. The bones of hypersthenic patients may be poorly visualized as well. Ultrasound is more operator dependant than other imaging modalities. If the operator is not sufficiently skilled in recognizing anatomy and pathology on ultrasound, the images may not be of diagnostic quality. In some cases pathology may be missed altogether.

Ultrasound has a smaller field of view than modalities such as MRI and radiography, which limits the amount of anatomical context available in each image. At the present time,
specialists in orthopedic ultrasound are few. Because of this, orthopedic ultrasound studies often require an additional study in another modality to confirm findings. The detection rates of some orthopedic pathologies are currently not as high in ultrasound as in the traditional orthopedic modalities.

Another drawback of orthopedic ultrasound is that some aspects of the bony skeleton are impossible to view on ultrasound. For example, a man in his mid fifties presented to his doctor with shoulder pain. An MRI showed a full thickness tear of the supraspinatus. Ultrasound is excellent for detecting tears of the rotator cuff. One might say that this patient should have had an ultrasound instead, since ultrasound is far less expensive than MRI, and also advantageous if the patient is claustrophobic or has any ferrous metal in his body. However, the MRI also revealed a factor that likely contributed to the supraspinatus tear was a bone spur on the underside of the acromion, which ultrasound would not have detected. Ultrasound can only be used to view bone surfaces and is not able to detect anatomy past the first bone-soft tissue interface encountered.

As applied in orthopedics, it is clear that ultrasound has limitations. Ultrasound has a limited ability to penetrate deeply into tissue, is highly operator dependant, and cannot be used to view anatomy beneath or behind cortical bone. However, it also has unique diagnostic abilities and benefits that no other modality can offer to this field. Ultrasound is safe, portable, noninvasive, and relatively inexpensive. Ultrasound has a wide variety of possible uses in orthopedics, from detecting fractures in an emergency department, to evaluating the risk of fractures in osteoporotic patients, to creating bone models for Computer Aided Orthopedic Surgery. In the hands of a skilled operator, ultrasound can accurately detect many orthopedic pathologies.
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If these relatively new applications of ultrasound are implemented in future, there are reforms to be made and learning curves to be ascended. It is commonly noted across all health care professions that patient interests transcend all other concerns. If Orthopedic Ultrasound proves to be in line with patient interests, one would hope that hesitancy of health care professionals to change routines and learn new skills will not impede the progression of this specialty. Medical imaging professionals who familiarize themselves with new specialties and technologies in their beginning stages of development can serve to accelerate the evolution of their field. Those who drag their feet in the face of reform may hold their profession back with them. Sudden, far-reaching change may excite some and frustrate others, but such has always been the nature of medical imaging technology.
Figures

Figure 1. Normal bone surface

Figure 2. Fractured bone


Figure 3. Bone Tumor on x-ray

Figure 4. Bone Tumor on ultrasound

Figure 5. Blood flow to tumor with Doppler ultrasound

Figure 6. Osgood-Schlatter disease

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