

Clinical applications

Ultrasound imaging of sports-related musculoskeletal injuries

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Integrating high-frequency Tissue Harmonic Imaging ultrasound with MRI and CT provides the best opportunity for diagnosing specific injuries.

Sports-related injuries of the musculoskeletal system affect millions of individuals every year. In the U.S., for example, it is estimated that nearly 4 million musculoskeletal injuries suffered each year are sports related [1].

Accuracy in imaging of individuals with sports-related injuries is critical. To aid in early diagnosis of injuries, the technology involved in musculoskeletal imaging is evolving and, with a renewed emphasis on the early diagnosis, appropriate treatment can be started much earlier.

Imaging is necessary when the clinical diagnosis is uncertain, or if the clinical diagnosis is clear but the extent of an injury or the presence of complications is unclear. Under these circumstances, imaging affects the decisions made in treating an injury. Imaging is also necessary when previous treatment has failed, the reasons for the treatment failure are unclear, or to assist in surgical planning to treat the injury.

Choice of modalities

Cross-sectional imaging modalities used in sports medicine include MRI, CT, and ultrasound. Determining the most appropriate imaging modality depends on a variety of factors, not all of which are readily apparent. Choices are often made based on the expected diagnostic outcome, availability of radiological equipment, and patient-related considerations such as cost, safety, convenience, and compliance. In an increasingly cost-conscious society, reimbursement issues also affect decisions related to the patient's examination. To an outsider, it often seems as if decisions are always made on a case-by-case basis. In general, ultrasound is best for a focal pain or injury, while MRI is typically the best modality for diagnosing an injury in which pain is vague.

MRI

MRI provides a comprehensive, multiplanar image of both superficial and deep soft tissue structures. Because MRI is superior in its contrast differentiation of tissues, it is preferred to CT for imaging in which it is necessary to discriminate between bone and soft tissue.

MRI is also an ideal modality when radiologists seek detail in the tissues contained within the bone shell, for example in bone marrow characterization, and proves optimal for evaluating bone bruising, bone stress, transient osteoporosis of the hip, osteochondral injuries, or osteonecrosis. With MRI's ability to delineate deep and superficial tissues, it is the ideal modality for evaluating knee injuries.

However, MRI has its limitations. Its use is limited in patients suffering from claustrophobia, in neonates, in young children, and in patients with a variety of implants including arthroplasties. Cardiac pacemakers, cochlear implants, and certain aneurysm clips represent absolute contraindications.

CT

CT uses X-rays to obtain image data from different angles around the body, which are then processed to show cross-sections of body tissue and organs. It is the ideal method when bone anatomy or joints need further assessment, and provides a better option for viewing fracture lines, small calcifications, loose bodies, subtle bone erosions, and bone mineral loss. CT can also assist in guided injections into structures that lie too deep for ultrasound resolution to reach. However, due to the exposure to radiation, patient safety and hospital personnel protection should always be considered when deciding on whether to use CT.

Ultrasound

Sports medicine has benefited from ultrasound, which provides a safe and powerful modality for viewing superficial soft tissue lesions such as tendon injuries. Ultrasound's high resolution

► **Accuracy in imaging individuals with sports-related injuries is critical.**

► **Ultrasound provides a safe and powerful imaging modality.**

provides an excellent view for diagnosing ruptures, adhesions or tendonitis of the Achilles tendon, proximal and distal biceps tendon injury, and tears in the quadriceps tendon, patellar tendon, or rotator cuff.

Ultrasound is also ideal for evaluating sports hernias and assessing sports-related hip pain. The ability to look closely at the moving tendons in the hand is of significant clinical benefit to orthopedic and hand surgeons preparing surgical repair of a specific injury. Foreign bodies in the hand have been localized routinely by ultrasound; even though some were so small that surgeons needed optical lenses to localize them during surgery.

Musculoskeletal ultrasound in the clinic often proves a valuable extension of a good physical examination. Additionally, musculoskeletal ultrasound can be used to evaluate joint and tendon dynamics and can estimate synovitis or fluid in joints. Because of its unique real-time capabilities, ultrasound allows identification of the exact site for therapeutic intervention and facilitates needle placement for aspiration or delivery of local pain control.

Tissue harmonic imaging in sports-related diagnostic ultrasound

Tissue Harmonic Imaging (THI) on an ultrasound transducer was introduced to help clinicians obtain the optimal views necessary for diagnosing specific musculoskeletal injuries. It is based on the principle of Harmonic Imaging, which was originally developed for microbubble contrast agents in the early 1990s. At that time it was assumed that under ultrasonic imaging conditions, tissue behaves linearly, and that all harmonic echoes would be generated by bubbles [2]. In fact, however, just like fluid containing bubbles, tissue is a nonlinear medium. Thus, harmonic echoes from tissue are the result of nonlinear propagation.

The clinical benefits of THI include reduced reverberation noise and reduced overall clutter level, improved border delineation, increased contrast resolution, and reduced phase aberration artifacts.

Since its introduction, THI has been routinely used in diagnostic imaging. It addresses some of the challenges encountered in diagnostic ultrasound imaging, including blood flow measurement in the microcirculation at the capillary level, reduction of the reverberation artifacts resulting from awkward acoustic windows, reduction of the phase aberration and beam distortion caused by the passage of the

ultrasound through inhomogeneous tissue, and improved contrast resolution.

Tissue harmonic imaging on a high frequency transducer

In ultrasound imaging, THI provides the best results in obtaining optimal border delineation and contrast resolution. Different acoustic pulse lengths, together with various pulsing schemes, may be used in THI, depending on the clinical application and the transducer being used. In musculoskeletal imaging, the challenges for THI relate to the common use of high-frequency transducers.

Figure 1. A long transmit pulse corresponds to a narrow bandwidth.

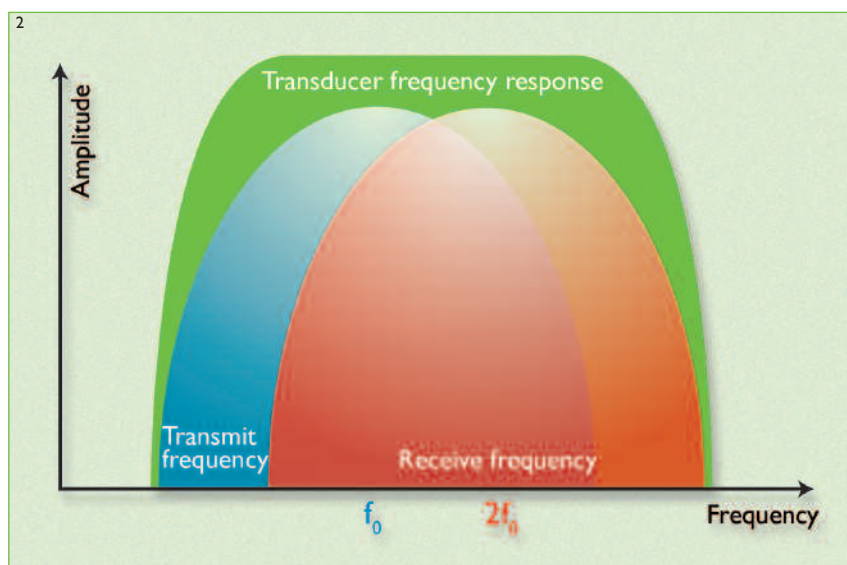
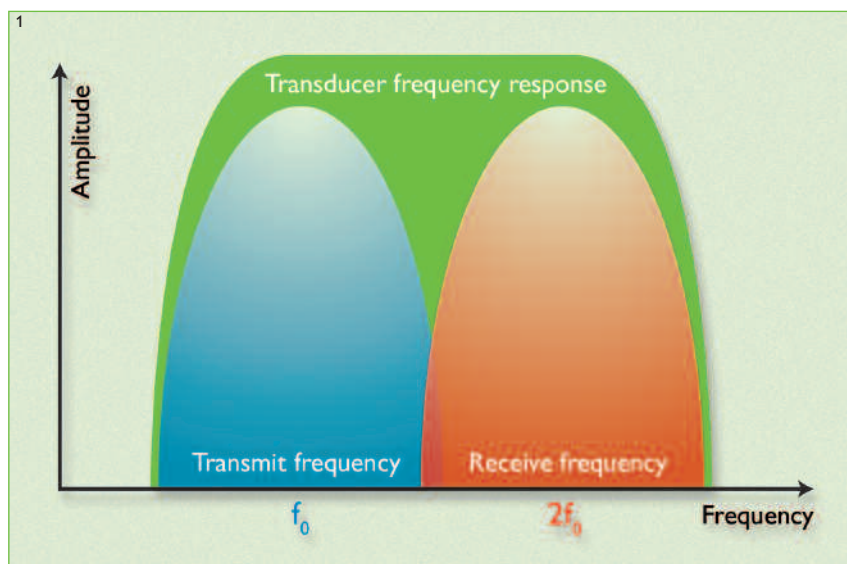


Figure 2. A short transmit pulse corresponds to a broad bandwidth.

Traditionally, fairly long acoustic pulses have been used to implement THI on high-frequency transducers. As an example, a linear transducer dedicated to superficial vascular imaging may feature a $1.5 \mu\text{s}$ pulse in fundamental imaging, while $4 \mu\text{s}$ pulses would be used to implement Pulse Inversion THI [3]. In Pulse Inversion, the receive echoes are combined in such a way that

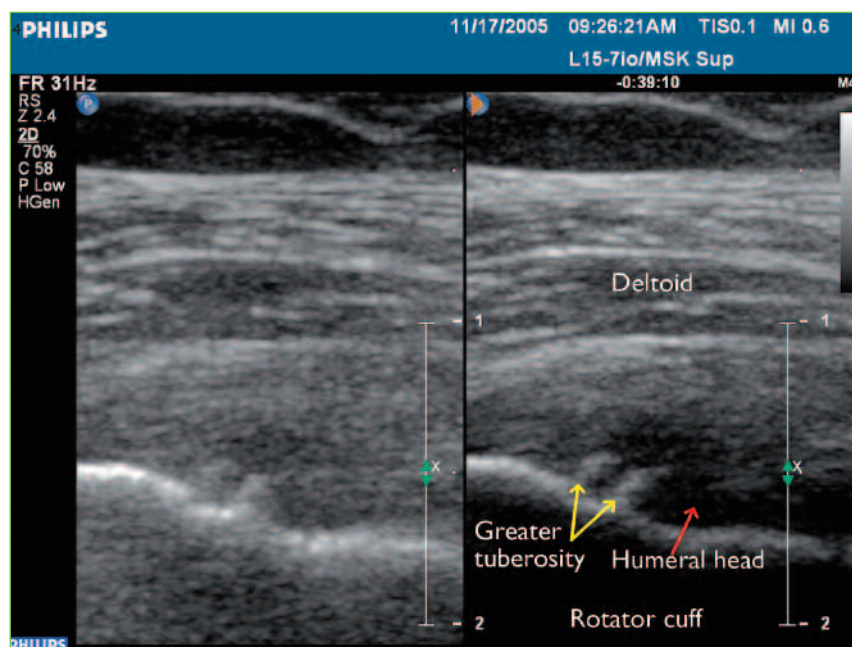


Figure 4.

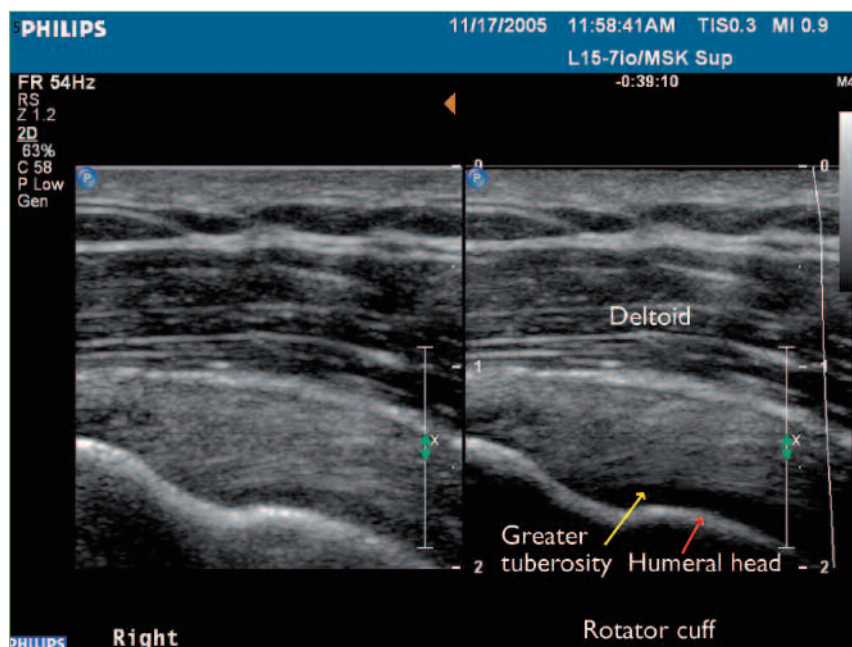


Figure 5.

all linear responses are cancelled out, while certain nonlinear responses are emphasized. The result is a 2-pulse scheme that allows for broadband harmonic imaging using shorter pulses with better axial resolution. Consequently, Pulse Inversion THI preserves axial resolution while benefiting from the usual image quality improvements provided by THI. We have found that this algorithm provides superb image contrast in musculoskeletal anatomy and pathology.

Given these considerations, implementation of Pulse Inversion THI on the high frequency transducer L15-7io was designed to maximize its

use of the transducer's bandwidth (i.e. to use the shortest possible pulses). We chose this imaging solution in preference to the use of increased transmitted energy (i.e. using a sequence of longer pulses). Figures 1 and 2 demonstrate how minimizing the transmitted pulse's duration corresponds to optimizing the use of the transducer's bandwidth in Pulse Inversion THI.

Achieving appropriate harmonic separation would not be possible without implementing Pulse Inversion, in order to avoid undesirable artifacts such as axial duplication of borders.

The L15-7io transducer



Figure 3. The Philips L15-7io intra-operative transducer.

The L15-7io transducer (Figure 3), soon to be available with Philips' premium iU22 and iE33 ultrasound systems, is a dedicated transducer for musculoskeletal imaging, allowing access to notoriously difficult-to-image areas such as ankles, fingers, wrists etc.

To successfully implement THI, the transducer bandwidth must be wide enough for the second harmonic to fit. This is especially difficult for high-frequency transducers, but has been successfully addressed in the L15-7io transducer.

As described above, THI has the ability to achieve a significant improvement in image quality. In musculoskeletal applications, THI addresses issues associated with clutter level by providing excellent contrast resolution, which leads to better delineation of the borders of the various structures.

The following clinical cases illustrate the multiple benefits of THI in musculoskeletal imaging. The images are presented side-by-side in order

to demonstrate the added benefits of THI over conventional fundamental imaging.

All these clinical images are reproduced by courtesy of Professor van Holsbeeck, Henry Ford Hospital, Detroit MI, USA.

Case 1.

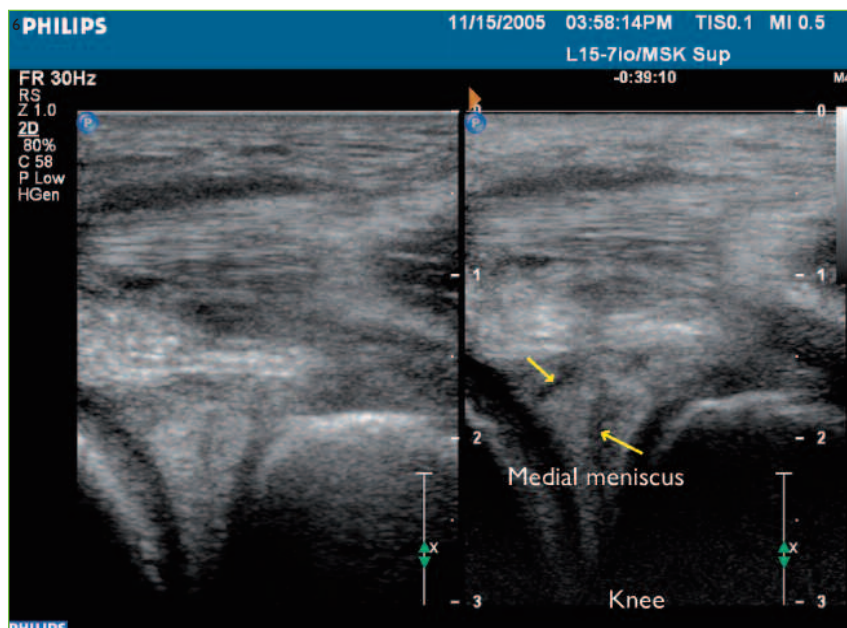
In Case 1 (Figure 4) Tissue Harmonic Imaging (right) provides better detail resolution (yellow arrows) and reduced clutter (red arrow) throughout the entire image. The bony surface is better delineated by harmonic imaging, particularly in the demonstration of the two protuberances (yellow arrows) of the bony pathology.

Case 2.

In Case 2 (Figure 5) Tissue Harmonic Imaging (right) helps decrease the amount of clutter for better visualization of the cartilage (yellow arrow). The bony interface is also sharper and better delineated (red arrow). Due to Tissue Harmonic Imaging, there is also an increase in resolution resulting in better demarcation of the tendon fibers.

Case 3.

In Case 3 (Figure 6) Tissue Harmonic Imaging (right) demonstrates better contrast and detail resolution to help visualize the small tears in the meniscus (yellow arrows).



▲
Figure 6.

Conclusion

As demonstrated in the foregoing examples, ultrasound offers important benefits for musculoskeletal imaging in sports medicine. For best practices, an integrated approach to imaging is recommended, in which ultrasound, MRI, and CT modalities fit together like the pieces of a puzzle. The techniques complement each other in imaging areas in which a single modality may encounter significant limitations.

References

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