TEXTBOOK ON MUSCULOSKELETAL ULTRASOUND

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*– for beginners and trained*

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Munksgaard Danmark

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# PREFACE

Diagnostic ultrasound has developed considerably since the early B-mode scans in the beginning of the 1970s. Ultrasound and MR-imaging has revolutionized musculoskeletal imaging. The focus has been on MR-imaging, but modern, high resolution ultrasound can produce similar results, and in many applications perform even better than MR-imaging. High-frequency linear transducers (from 7.5MHz to > 20MHz), color Doppler and new techniques like elastography have dramatically improved our ability to assess soft tissue involvement in musculoskeletal disease around or inside joints, tendons, bursae, muscles, nerves, skin, glands, and vessels.

The main advantages of ultrasound include multiplanar imaging capability, the unique possibility of dynamic imaging, permitting diagnoses that cannot be made with other modalities, high resolution (a 20MHz transducer has an axial resolution of 0.038 mm), absence of radiation, low running costs, and fully transportable equipment. Ultrasound is an interactive modality: The examiner is with the patient, and therefore the examination can be focused precisely on the symptomatic area. This direct correlation of clinical symptoms and imaging findings is invaluable, not least because modern diagnostic imaging reveals a high incidence of asymptomatic pathology.

Ultrasound-guided injection and aspiration or biopsy from synovium, tendons, or erosions are other advantages. Studies have shown that nearly half of all unguided, intra-articular injections of steroids are placed outside the joint cavities, which significantly affect the clinical outcome and increases the risk of local tissue damage.

Unfortunately, ultrasound is an operator-dependent modality with a long and steep learning curve. Proper training and a standardized technique are therefore crucial. Musculoskeletal ultrasound is also highly equipment-dependent. Demonstration of subtle abnormalities of small soft tissue structures requires a good ultrasound unit and high-resolution transducers. In fact, the greatest danger of ultrasound is not the possible bioeffects, but inaccurate diagnoses due to technical or operator limitations.

A "gold" ultrasound examination requires 1) an in-depth knowledge of the clinical settings and of the specific questions that need to be answered, 2) a deep knowledge of sectional anatomy, 3) a high quality ultrasound equipment, and 4) a knowledge of the limitations and pitfalls of ultrasound.

The aim of this book is to give an introduction to practical musculoskeletal ultrasound and in pictorial form to present ultrasound-appearances of normal musculoskeletal structures (marked in blue) followed by commonly encountered abnormalities (marked in red) in well defined standard projections. Of course, dynamic ultrasound cannot be reduced to a few standard projections. The many projections between the standard longitudinal and transverse projections can be even more informative and ought to be an integrated part of the examinations.

Today, ultrasound is the "extended finger" of the clinicians, and the continuous, rapid advances in technology will make the modality even more interesting in the future.

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The ultrasound is indeed the sound of the future.

*Lars Bolvig*
*Ulrich Fredberg*
*Ole Schifter Rasmussen*

# ULTRASOUND PHYSICS

Musculoskeletal ultrasound uses high-resolution linear transducers where an array of Piezo-electrical crystals is activated by the beam-former of the ultrasound unit. Piezo-electricity, the foundation of diagnostic ultrasound, was discovered in 1880 by two French scientists, Jacques and Pierre Curie. The Piezo-electrical crystals in the transducer transform a voltage to mechanical energy: ultrasound. The activation sequence of the crystals determines the form and direction of the wavefront and makes it possible to steer the beam electronically.

Diagnostic ultrasound is not a continuous beam of sound, but extremely short pulses. The interval between the pulses is of much longer duration, enabling the transducer to receive resounding echoes before the next pulse is generated. When a sound pulse crosses an interface between two different types of tissue, a fraction of the sound energy is reflected, depending on the differences in tissue impedance (tissue density). If the difference is significant, as in the soft-tissue/cortical bone interface, most of the sound energy is reflected, resulting in acoustic shadowing behind the interface.

Most of the ultrasound energy is absorbed by the tissues, thereby generating heat.

The reflected sound energy is transformed in the Piezo-electrical crystals of the transducer into a voltage. The voltage pattern along a scanline contains the information required to fill-in each image pixel in the line with an appropriate gray-shade. High echo amplitudes are displayed in bright gray-shades, low echo amplitudes in dark gray-shades. The information from each scan line is stored in the memory of the scanner unit, and a matrix of pixels is displayed in real-time on the screen as 2-dimensional, gray-scale pictures.

With cine-loop or image review, the ultrasound unit can read out a scan sequence, making retrospective viewing possible.

The Time Gain Compensation (TGC) corrects for the attenuation of the ultrasound pulse caused by increasing depths by amplifying returning signals in proportion to the depth.

The axial resolution depends on the pulse length and the applied transducer frequency. The shorter the pulse and the higher the frequency, the better the resolution. Unfortunately the sound-energy of high-frequency transducers is absorbed rapidly into the tissue causing reduced penetration. Therefore, a compromise must be made between resolution and penetration. In musculoskeletal ultrasound, where most of the structures are superficially located, frequencies of up to 20 MHz are used as a routine. The lateral resolution in the ultrasound image depends on the number of transducer elements and the ability of the transducer to narrow the beam width by electronic focusing at any chosen depth.

A number of technical developments have improved musculoskeletal ultrasound. Multi-frequency mode makes it possible to adjust the transducer frequency upwards or downwards. Tissue-harmonic imaging produces a picture of an improved contrast, enhanced near-field resolution, and better far-field penetration. Speckle-reduction reduces the inherent graininess of the ultrasound image. Cross-beam or sono-CT combine multiple images from different steering angles into a single frame. Panoramic view provides the user with the ability to construct a wide, static image from individual frames by moving the transducer across larger structures.


Longitudinal panoramic view showing a total Achilles tendon rupture (1). Calcaneus (2). Soleus (3). Proximal (4) and distal (5) part of the Achilles tendon.

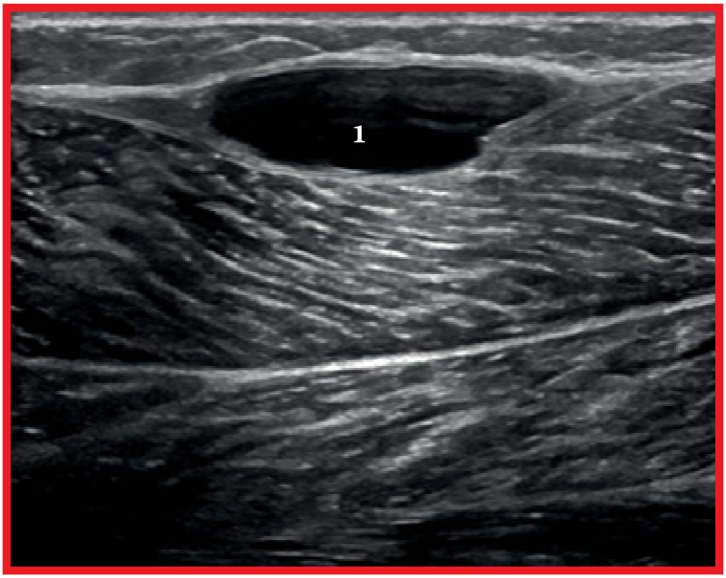
## Ultrasound artefacts

The term artefact is used to describe any unwanted image information generated in the process of image formation. Understanding artefacts is important to avoid interpretative errors. On the other hand, artefacts can often provide important diagnostic information.

**Shadowing:** A dark band behind a region of higher than average attenuation of the sound beam. The typical example is the shadow behind the cortical bone, or behind a soft-tissue calcification.


Acoustic shadowing behind the cortical bone (1).

**Enhancement:** The opposite of shadowing. A bright band behind a region of lower than average attenuation, e.g. the acoustic enhancement behind a cystic structure.

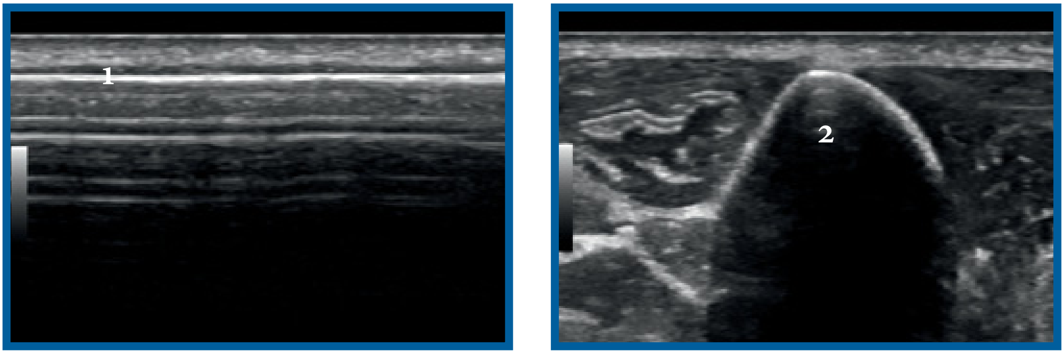



Enhancement behind an anechoic cyst (1) in the fascial plane superficial to the gastrocnemius muscle.

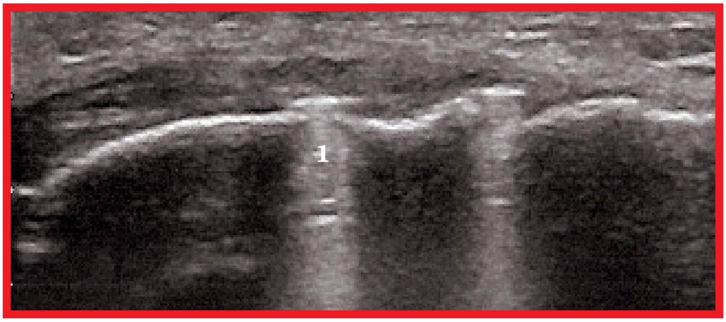
Longitudinal and transverse scan of the ulna. The cortical bone is seen in the longitudinal plane (left) as a hyperechoic line (1) with a hypoechoic layer representing the periosteum. Multiple repeat echoes are depicted behind the true image of the bone. In the transverse plane (right), the repeat echoes can only be seen where the ultrasound is insonated perpendicular to the bone surface (2).

**Reverberation:** Multiple echoes are generated between strong reflectors lying parallel to each other. The commonest example is a bony surface parallel to the skin/transducer interface. Ultrasound reflected from the bone to the transducer generates a true image, but a proportion of the sound-energy is re-reflected to the tissues, thereby creating a new reflection from the bone. This produces a second image at twice the depth of the first one.

Metal structures can produce white shadows or **comet tails**. The cause is reverberation between the layers in the metal.




Metal implants can be easily located on the basis of typical artefacts (white shadows or comet tails) (1).




**Mirror artefact:** This artefact displays a repeat image of a structure behind a strong reflector, as cortical bone. It may be produced in both gray-scale and color Doppler. When an object is located between the transducer and a bony surface, sound is reflected from the object and the bone, creating a true image. If echoes from the bone strike the object, they will retrace the original path and return to the transducer indirectly. This results in a phantom image of the object behind the reflecting surface of the bone, in addition to the correctly positioned virtual image of the object.