# Musculoskeletal Ultrasound

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## Anatomy and Technique

John O'Neill, MD
Editor

Springer

*Editor*
John M.D. O'Neill, MB, B.A.O, B.Ch, MRCPI, MSc, FRCR(UK)
Assistant Professor
McMaster University
Staff Radiologist, Musculoskeletal Imaging
Diagnostic Imaging Department
St. Joseph's Healthcare
Hamilton, Ontario
Canada

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*Dedicated to the memory of my father and*
*the love and strength of my mother.*

*Alva, Sam, and Sophie . . . Love . . .*

*. . . Always.*

# Preface

Ultrasound is an excellent imaging modality in the evaluation of the musculoskeletal system. It can, however, be intimidating due to the vast array of anatomy that is present and the different techniques and dynamic maneuvers required for a complete study. Many of the excellent musculoskeletal ultrasound texts have opening chapters on technique and anatomy, but the main aim of these texts is to describe the multitude of musculoskeletal pathology and its ultrasound appearance. Often it is necessary to use an anatomy reference text and atlas in addition to these texts. In this book we address the relevant anatomy of the musculoskeletal system by providing a detailed review of the anatomy relevant to that area followed by its normal ultrasound appearance. Anatomy is aided by multiple color illustrations, line drawings, magnetic resonance images, and anatomy review tables. Particular points of interest are highlighted in "Insider Information" boxes.

The normal ultrasound anatomy of structures is described in Section 1. The second half of each chapter details the ultrasound approach and the various techniques employed. This is supported by an extensive array of ultrasound images of the normal anatomy and the corresponding transducer positions. Ultrasound of the peripheral nervous system, including the brachial plexus, is gaining increasing interest, so we dedicated the third section of this text to the peripheral nervous system. Finally, the Appendix outlines the standard ultrasound imaging protocols for the major upper and lower limb joints, including dedicated protocols for assessment of mass lesions, synovitis, and assessment of the hands and feet.

The accompanying DVD, more than 2 hours in length, details the examination of the major joints of the upper and lower limbs. These examinations are presented by many of the individual chapter authors and follow the same imaging guidelines described in the text. All the authors use a structured approach to perform their examinations that is based on anatomy and anatomical landmarks. The evaluation of each joint is presented with a side-by-side arrangement of transducer position and the corresponding ultrasound image. Key anatomical structures and surface anatomy are highlighted throughout the demonstrations.

We hope that this book will encourage and stimulate all those interested in musculoskeletal ultrasound including radiologists, clinicians, sonographers, residents, and medical students.

# ACKNOWLEDGMENTS

We would like to extend our gratitude to all who have supported and contributed to this endeavor: Mr. Michael Szabo, St Josephs Healthcare audiovisual department, has gone above the call of duty, devoting numerous hours to editing the DVD and images. Terry Popwich provided expertise and guidance in ultrasound technique. Mike Huska and Michael Lintack from GE Healthcare Canada provided the technical expertise and state-of-the art imaging equipment; Julie Turcotte modeled endlessly for both images and DVD. I thank Toni Cormier and Naveen Parasu for their help in the acquisition of the MRI images, Catriona Kerr and Simon Barrick from Primal Pictures, and Magda Dobranowski for her detailed illustrations. Thanks to my editors who have supported this endeavor, Merry Post and Sadie Forrester, and last, but not least, all my previous mentors for their outstanding teaching.

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# Contributors


*Julian Dobranowski, MD, FRCPC*
Associate Clinical Professor, McMaster University, Diagnostic Imaging Department, St. Joseph's Healthcare, Hamilton, Ontario, Canada

*Karen Finlay, MD, FRCPC*
Assistant Professor, McMaster University, Staff Radiologist, Diagnostic Imaging, Hamilton Health Sciences–Henderson Division, Hamilton, Ontario, Canada

*Lawrence Friedman, MBBCh, FRCPC, FACR*
Associate Professor, McMaster University, Radiology Department, Hamilton Health Sciences–Henderson Division, Hamilton, Ontario, Canada

*Gandikota Girish, MD, MBBS, FRCS, FRCR*
University of Michigan, Musculoskeletal Radiology, Ann Arbor, MI, USA

*Aaron Glickman, MSc, MD, FRCPS*
Musculoskeletal Radiologist, Toronto East General Hospital, Diagnostic Imaging Department, Toronto, Ontario, Canada

*Srinivasan Harish, MD, FRCR, FRCPC*
Assistant Professor, McMaster University, Department of Diagnostic Imaging, St. Joseph's Healthcare, Hamilton, Ontario, Canada

*Jon A. Jacobson, MD*
Associate Professor of Radiology, University of Michigan, Director, Division of Musculoskeletal Radiology, Ann Arbor, MI, U.S.A.

*John M.D. O'Neill, Editor, MB, B.A.O, B.Ch, MRCPI, MSc, FRCR(UK)*
Assistant Professor, McMaster University, Staff Radiologist, Musculoskeletal Imaging, Diagnostic Imaging Department, St. Joseph's Healthcare, Hamilton, Ontario, Canada

# Section 1

## Introduction

# 1

# Introduction to Musculoskeletal Ultrasound

John O'Neill

Ultrasound is an effective and established technique in musculoskeletal imaging; its role in diagnostic imaging is continuing to expand with the development of further clinical applications and with the advancement of ultrasound technology. It is well established in Europe as a first line imaging modality in the investigation of musculoskeletal pathology and is rapidly gaining popularity in North America, as shown by the popularity of musculoskeletal ultrasound teaching courses. Ultrasound is, however, operator dependent and requires a detailed knowledge of the relevant anatomy, ultrasound artifacts, technique, and ultrasound appearance of both normal and abnormal structures for the conduction and interpretation of the study. This chapter will detail the anatomy and ultrasound appearance of the constituents of the musculoskeletal system. This is preceded by a brief overview of the history of musculoskeletal ultrasound.

Although musculoskeletal ultrasound may be considered as one of the later developments in ultrasound applications, it was first used, as far back as 1958, in the assessment of the acoustic attenuation of musculoskeletal tissues by K.T Dussik et al.[1,2] Dussik had also been the first to use ultrasound as a medical imaging modality in 1942.[1,3] Ultrasound developed slowly until 1960, when Donald and colleagues produced the first automatic scanner.[1] For the next decade ultrasound was predominantly limited to the evaluation of abdominal and pelvic diseases.

By 1972 the first B-scan image of a joint was reported in the differentiation of a Baker's cyst and thrombophlebitis.[4] Graf, in 1980, published his landmark paper on the use of ultrasound in the diagnosis of congenital hip-joint dislocation.[5] In 1988, L. De Flaviis described ultrasound of the hand in rheumatoid patients including erosions, 10 years after Cooperberg described features of synovial thickening and joint effusion in the rheumatoid knee.[6,7] Since this time, particularly in the past decade, there has not only been a rapid development in ultrasound technology, but also widespread use of ultrasound in the investigation of musculoskeletal disorders to the point where it is now firmly established as a key imaging modality. Ultrasound advances include high-resolution linear array transducers, extended field of view, tissue harmonics, compound imaging, and, recently, early forays into three- and four-dimensional (3-D and 4-D) imaging use in musculoskeletal imaging.

## Muscle

There are three different varieties of muscle found in the human body: skeletal, smooth, and cardiac. This description will focus on the structure and ultrasound appearance of skeletal muscle. Muscle is composed of individual fibers, cylindrical or prismatic in shape.[8,9] Each fiber, in general, measures up to 1.5 inches in length and 0.02 inches in breadth. The length of individual fibers is, however, highly variable; those of the sartorius measure up to 2 feet. Individual fibers are surrounded by a sheath: the sarcolemma. A bundle of fibers is called a fasciculus. The fasciculi are prismatic in shape and align parallel to one another, oblique or parallel to the longitudinal axis of the muscle. The endomysium, composed of connective tissue, separates individual muscle fibers. It is derived from the perimysium, which envelops the fasciculus, whereas the epimysium invests the entire muscle (Figure 1.1). Nerves and blood vessels are supported within this connective tissue framework.[8]

Muscles have an origin, a belly, and an insertion. The origin and insertion attachment sites can be multiple, including bones, cartilage, ligaments, and skin. By definition, the insertion is the attachment that has the greatest movement on muscle contraction. There are multiple different arrangements of fiber orientation with respect to the tendon (Figure 1.2). In the quadrilateral type, the fibers are parallel and run in the same longitudinal axis as the tendon, e.g., quadratus femoris, pronator quadratus. The fusiform type, a variation of the quadrilateral, is as the name implies, a fusiform arrangement of the fibers in which the fibers are curved with proximal and distal tapering to the tendon, e.g., biceps (Figure 1.3a). Triangular muscles, such as the infraspinatus, have a wide origin with convergence of fibers into a narrow point of insertion (Figure 1.3b). Feather-like or pennate muscles have a fiber orientation oblique to the tendon. They can be unipennate, bipennate, or multipennate. In unipennate muscles, the tendon lies on one side of the muscle and the fibers insert into it through the length of the muscle, e.g., the extensor digitorum longus. Bipennate muscles have a central tendon with oblique insertion fibers on both sides, e.g., the rectus femoris (Figure 1.3c). Multipennate muscles can have a central tendon with circumferential fiber insertion, e.g., tibialis anterior, or be composed of two or more series in a bipennate arrangement.

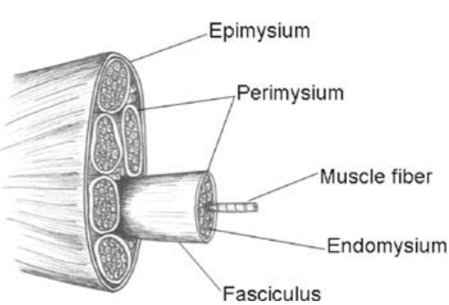



**Figure 1.1.** Muscle fiber: cross section.

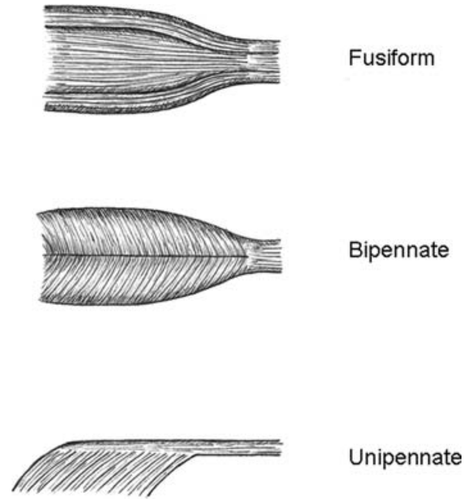



**Figure 1.2.** Muscle structure: some of the different arrangements of fiber orientation.

The fasciculi can be identified as separate structures on ultrasound.[10,11] They are best identified in the longitudinal plane as hypoechoic cylindrical structures, separated by the hyperechoic intervening connective tissue, the perimysium (Figure 1.4). Individual fibers and the endomysium are not individually discernible. The epimysium, fascia, and intermuscular fat are all thin, linear hyperechoic structures on ultrasound. Ultrasound can also differentiate the different arrangements of muscle fibers: quadrilateral, fusiform, triangular, unipennate, bipennate, or multipennate, as previously described.

During muscle contraction, there is a shortening of fibers and an apparent increase in muscle bulk (Figure 1.5). The hypoechoic fascicles appear thicker and give a more hypoechoic appearance to the muscle in the contracted state. When comparing the echotexture of the contralateral muscle, it is important

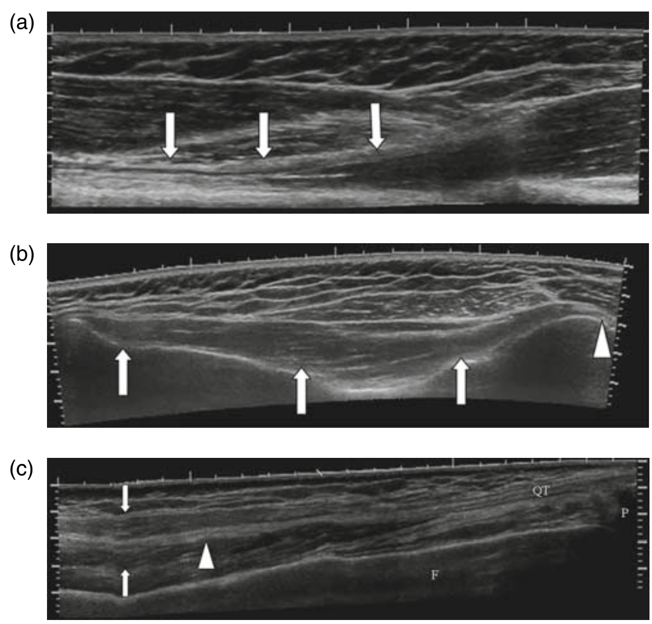



**Figure 1.3. (a)** Longitudinal ultrasound image of the long head biceps tendon at its musculotendinous junction (arrows) demonstrating the fusiform arrangement with proximal tapering of the muscle. **(b)** Extended field of view (EFOV) ultrasound image of the infraspinatus muscle (arrows); an example of the triangular configuration with a wide origin with convergence of fibers into a narrow point of insertion (arrowhead). **(c)** Bipennate: longitudinal EFOV ultrasound image of the distal anterior thigh demonstrating the rectus femoris muscle (arrows) as an example of a bipennate structure with a central tendon (arrowhead) and bilateral oblique insertion fibers. P, patella; F, femur; QT, quadriceps tendon.

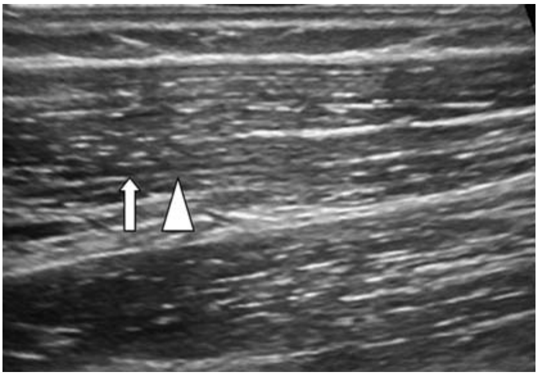


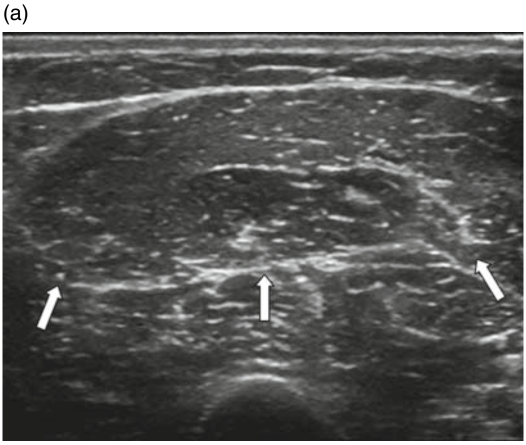
**Figure 1.4.** Longitudinal ultrasound image of the biceps muscle demonstrating multiple, linear, hypoechoic cylindrical structures: the fasciculi. A muscle fasciculus (arrow) is shown separated by the thin hyperechoic intervening connective tissue, the perimysium (arrowhead).

that they are in the same state of relaxation or contraction. Recent studies have assessed the role of dynamic evaluation in the contraction patterns of muscles in normal and abnormal states. Abnormal contraction patterns may explain different functional capabilities in patients with similar pathology.[12]

**Insider Information 1.1**
A bundle of muscle fibers, called a fasciculus, can be seen on ultrasound, in its longitudinal axis, as parallel hypoechoic cylindrical structures separated by the intervening hyperechoic connective tissue, the perimysium.

Individual chapters will outline the technical guidelines for specific regions, but, in general, linear array transducers are preferred with higher frequencies for superficial muscles.[10] Deeper muscles may require the use of a curvilinear probe with a frequency of 5 MHz to allow for deeper penetration. Extended field of view can allow for the full length of the muscle to be captured on

(a)



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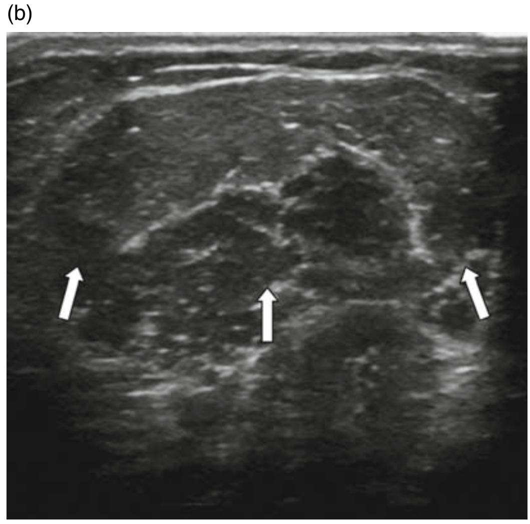

**Figure 1.5.** Muscle contraction: transverse ultrasound image of the anterior mid-arm biceps muscle, short and long heads (arrows) **(a)** pre- and **(b)** postmuscle contraction. In **(b)** there is an apparent increase in muscle bulk, and the hypoechoic fascicles appear thicker and slightly more hypoechoic.

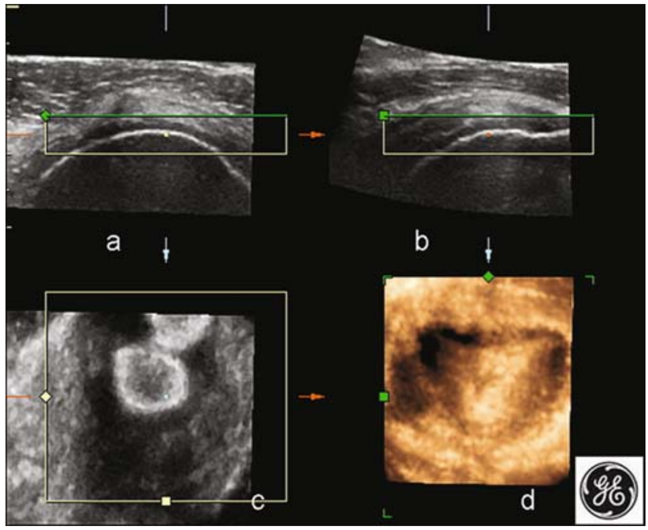


**Figure 1.6.** Supraspinatus tendon using 4-D transducer; **(a)** axial, **(b)** sagittal, **(c)** coronal, and **(d)** 3-D reconstruction.

one image. 3-D and 4-D are new applications that are in their early stages of development in musculoskeletal ultrasound (Figure 1.6). 3-D will allow multiplanar reformats and may allow better appreciation of the extent of pathology and surrounding anatomical relationships. This may be of particular benefit to referring clinicians not used to viewing ultrasound images.

The probe is held perpendicular to the axis of the muscle and scanned in the longitudinal and transverse planes. If the patient has significant point tenderness, we normally scan the area surrounding this point first until we identify a normal ultrasound appearance and then move slowly over the symptomatic region. Applying gel liberally and floating the probe over the area of interest to avoid compression are useful techniques in these circumstances. This allows the patient to relax and to tolerate a full study. Comparison to the contralateral side is helpful in delineating subtle abnormalities. If a muscle hernia is suspected, direct palpation over the suspected site of the hernia may allow the hernia to be felt as an intermittent soft tissue nodule that appears when the muscle contracts. On ultrasound, the hernia can be seen as a hypoechoic nodule extending through a defect in the fascia. Doppler may reveal the presence of a transversing blood vessel at the same point. Dynamic evaluation, with the patient actively contracting or the examiner passively moving and stretching the muscle of interest, can allow assessment of contraction patterns and aid in identifying the full extent of a muscle tear.

## Fascia

Fasciae are divided into superficial and deep fasciae. The superficial fascia lies deep to the skin and is composed of fibroareolar tissue. It is of variable thickness and connects the skin to the deep fascia. It contains adipose tissue of various quantities except in a few areas, such as the eyelid, where it is absent.[8] Beneath this subcutaneous fat is the layer containing subcutaneous vessels and nerves. Collagen fibers within the superficial fascia become dense in the palms, soles of the feet, and the scalp. The superficial fascia may

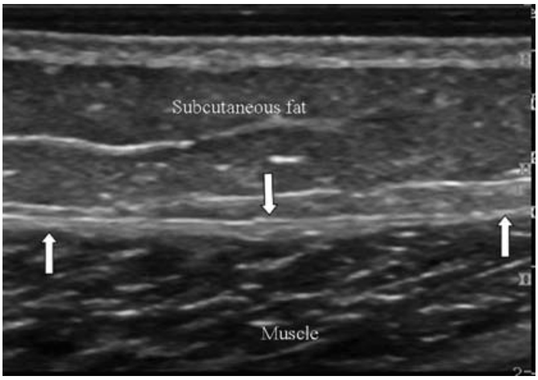


**Figure 1.7.** Fascia: longitudinal ultrasound image of the proximal thigh demonstrating the superficial fascia containing adipose tissue separated by thin hyperechoic linear bands. The deep fascia (arrows) is thin and hyperechoic, enclosing the deeper hypoechoic muscle.

contain superficial muscles or serve as attachment, e.g., platysma myoides. On **ultrasound,** the appearance of superficial fascia is determined by the content of adipose tissue. The latter is hypoechoic and separated by thin hyperechoic linear bands (Figure 1.7).

The deep fascia is a dense fibrous membrane that invests muscles and deeper structures. It is of variable thickness, becoming thicker on more exposed regions, e.g., it is thicker on the lateral aspect of the leg versus the medial aspect. It forms a sheath for muscles and occasionally as a site of attachment (Figure 1.7). It gives off the intermuscular septa, which separates various muscles and compartments and attaches to the periosteum. In the regions of joints, the deep fascia can become thickened to form retinaculae, as part of fibroosseous tunnels, maintaining the underlying tendons and nerves in place. On ultrasound, the deep fascia is hyperechoic with an identifiable fibrillar pattern of variable thickness. The hyperechoic intermuscular septae can be seen arising from the fascia.

**Insider Information 1.2**
The deep fascia helps form the muscle compartments and on ultrasound has a hyperechoic fibrillar pattern of variable thickness.

## Tendon

Tendons are composed of tightly packed type I collagen fibers with intervening fibroblasts. Bundles of parallel fibers form primary (subfascicle), secondary (fascicle), and tertiary bundles. They are loosely bound in a loose connective tissue sheath, the endotendineum, and the peritendinal connective tissue. The latter encloses several subfascicles to form a fascicle. The peritendineum also contains the supplying blood vessels and nerves. The epitendineum is a thicker fibroelastic sheath surrounding the whole tendon. At the musculotendinous junction the sarcolemma intervenes, i.e., there is no direct continuity of muscle and tendon fibers. At the attachment site to bone, the tendon fibers attach to periosteum, fibrocartilage, or directly to bone. Tendons can also insert onto fascia.[8,9]

Tendons can be round, (e.g., biceps), oval (e.g., Achilles), or flattened (e.g., patellar tendon) in cross section (Figure 1.8). They are surrounded

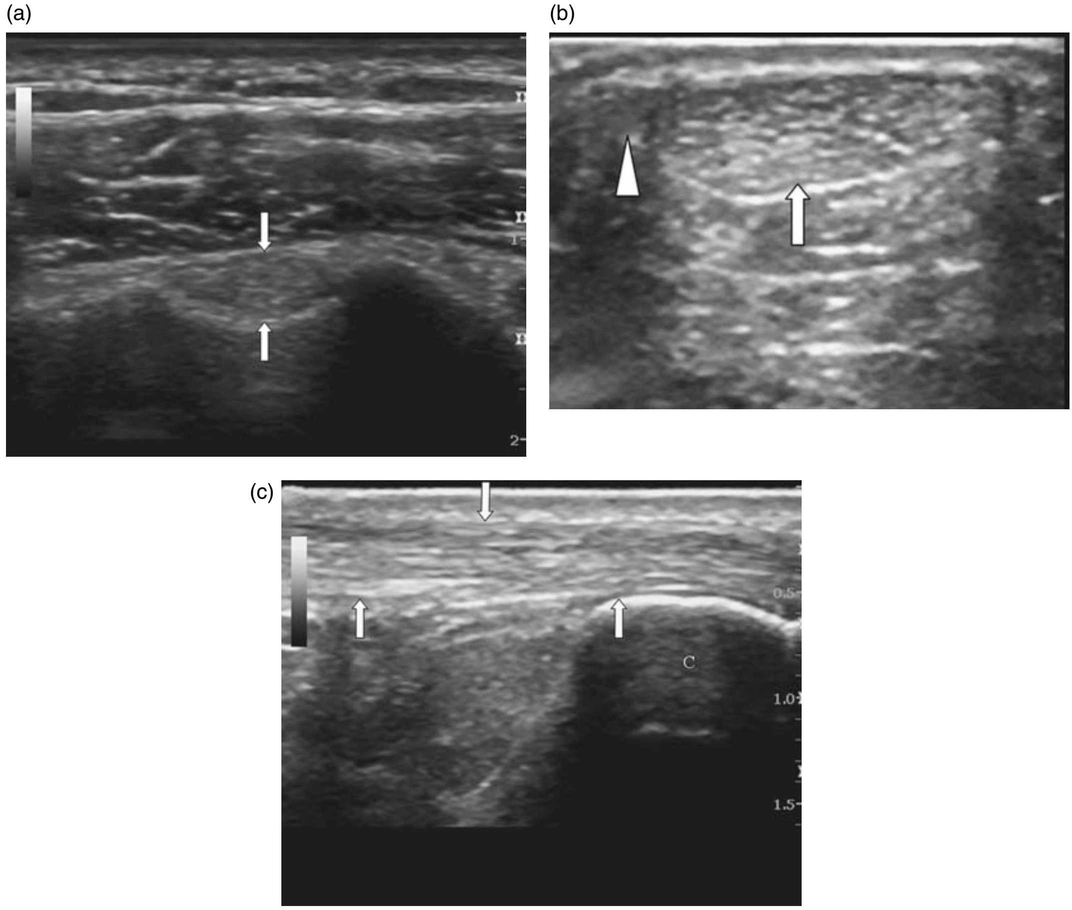


**Figure 1.8.** **(a)** Transverse ultrasound image of the hyperechoic round long head biceps tendon (arrowhead) within the bicipital groove. **(b)** Achilles tendon (AT) transverse ultrasound image of the oval AT: (arrows) and adjacent plantaris tendon (arrowhead) medially; the paratenon is identified as the thin hyperechoic rim surrounding the AT. **(c)** Longitudinal ultrasound at (arrows). C, calcaneus.

by a synovial sheath in areas where movement of the tendon would cause friction. The synovial sheath is composed of two layers, one of which is reflected along the surface of the tendon. The sheath contains synovium, which secretes a thick viscid fluid to reduce friction and encourage smooth gliding of the tendon. In areas where a synovial sheath is not required, the tendon is surrounded by the paratenon, a layer of loose connective tissue encasing the epitendineum (e.g., Achilles tendon) (Figure 1.8b).

On ultrasound, the tendon is composed of dense linear hyperechoic bands forming a fibrillar pattern when evaluated in the tendon's longitudinal axis (Figure 1.8c). On transverse images, the tendon is hyperechoic with multiple hyperechoic foci or dots (Figure 1.8b). The hyperechoic appearance is due to the specular reflections at the interface between the fascicles and the peritendineum.[10,11] Normal tendons are not compressible. Tendons are particularly prone to the artifact of anisotropy, discussed below, and the transducer must be maintained perpendicular to the axis of the tendon.

The paratenon is identified as a thin hyperechoic line surrounding the tendon (Figure 1.8b). The synovial sheath is best visualized when fluid is present between its layers. A small amount of fluid may normally be present. At the point of insertion, the tendon fibers often appear hypoechoic due to anisotropy as the fibers become curved. Realigning the transducer so it is perpendicular to the change in orientation will resolve most of the hypoechoic appearance in normal tendons; the remaining hypoechoic appearance is related to the interdigitating fibrocartilage.

**Insider Information 1.3**
On ultrasound, the tendon has a dense linear hyperechoic band pattern, fibrillar pattern, when evaluated in the tendon's longitudinal axis, and multiple hyperechoic foci or dots on the transverse axis. The hyperechoic appearance is due to the specular reflections at the interface between the fascicles and the peritendineum.

## Ligament

Ligaments are fibrous structures with a histology similar to tendons. They are usually, but not exclusively, situated around joints and attach bone to bone, helping to maintain correct joint position, stability, and alignment. Their attachment to bone, like tendons, is an enthesis. Ligaments can be well-defined structures easily visualized on ultrasound, e.g., medial collateral ligament of the knee, or represent focal thickening of the joint capsule and may not be discernible as separate structures on ultrasound.

On ultrasound, ligaments have a hyperechoic linear appearance. They are often better visualized when they are stretched, e.g., the anterior talofibular ligament is stretched by mild plantar flexion foot and medial orientation forefoot (Figure 1.9).[13] Linear array transducers with high frequency are optimal. Smaller footpads allow for better manipulation of the transducer along the path of the ligament.

**Insider Information 1.4**
On ultrasound, ligaments are best evaluated when taut and display a hyperechoic linear appearance.

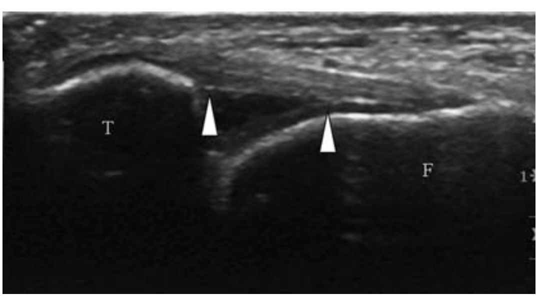


**Figure 1.9.** Transverse oblique ultrasound distal tibiofibular joint in the longitudinal axis of the anterior talofibular ligament.

## Nerve

A peripheral nerve is a cordlike structure containing a large number of individual nerve fibers. The nerve fibers are grouped together into bundles known as fascicles (Figure 1.10). The fascicles are enclosed in a connective tissue sheath or membrane known as the epineurium. Each fascicle is in turn covered by a sheath of connective tissue, the perineurium. The individual nerve fibers within the fascicle are also enclosed by a sheath of connective tissue, the endoneurium. Extending inward from the epineurium is the interfascicular epineurium, which are thin septae adding further support to the nerve bundles and their vascular supply. Similar septae extend inward from the perineurium. The individual nerve fibers are continuous and do not branch or coalesce. The nerve may branch giving off one or more fasciculi and unite with other fasciculi.[8,9]

Ultrasound, in the longitudinal axis of the nerve, demonstrates a fascicular pattern of uninterrupted hypoechoic bands with intervening linear interrupted hyperechoic bands (Figure 1.11a). The hypoechoic bands represent the fasciculi and the hyperechoic bands the supporting interfascicular epineurium. The epineurium is hyperechoic and of similar appearance to perineural fat and may not be separable on ultrasound. On axial study, the nerve is composed of fasciculi seen as multiple hypoechoic dots, which may be of varying size, intermingled in a hyperechoic background of the supporting connective tissue (Figure 1.11b). Identification of individual fascicles will depend on a number of factors, including the depth of the nerve and the frequency of the transducer. In general, the greater the depth and the lower the frequency of the transducer, the lower the resolution. Nerves may become more uniformly hypoechoic when they pass through narrow passages, such as fibroosseous tunnels, with the fascicles becoming tightly packed and less intervening hyperechoic connective tissue.[10,14–16]

Tendons and nerves can have a similar appearance and size. Tendons have a fibrillar pattern versus the fascicular pattern of nerves, are more prone to the artifact of anisotropy, are not normally compressible, and demonstrate more motion on active movement of the adjacent muscles.[14] Small, hypoechoic perineural vessels can be distinguished from the adjacent nerve with color or power Doppler. When nerves pass through fibroosseous tunnels, they are held in place by retinaculae. Dynamic assessment is important to

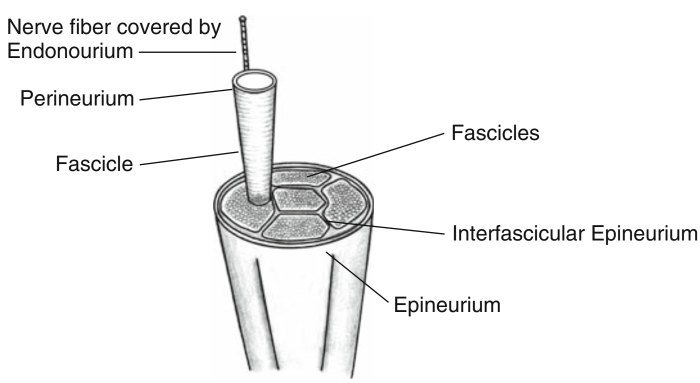


**Figure 1.10.** Peripheral nerve: cross section.

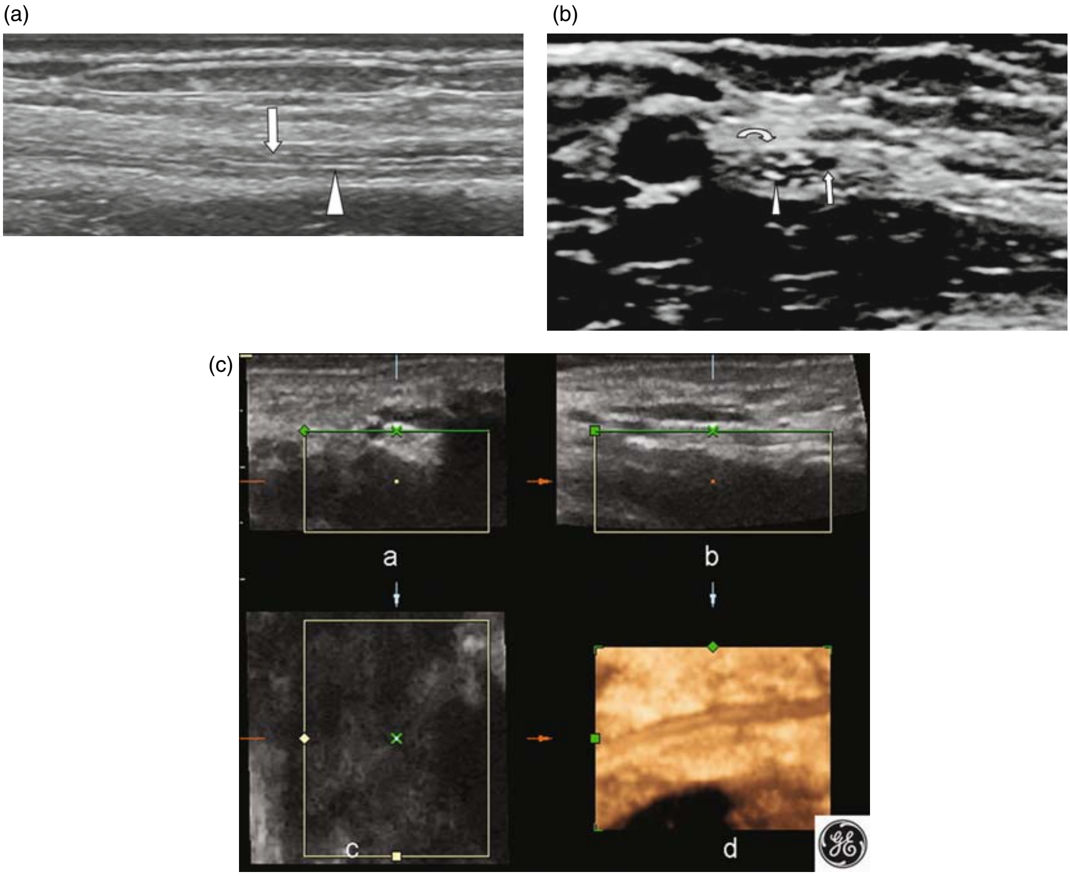


**Figure 1.11.** Peripheral nerve. **(a)** Longitudinal ultrasound of the medial nerve in the distal arm and **(b)** corresponding transverse image demonstrating the hypoechoic fasciculi (arrows) and the supporting hyperechoic interfascicular epineurium (arrowheads). The epineurium, seen on the axial image (curved arrow) as a thin hyperechoic rim of tissue around the periphery of the nerve, can be difficult to separate from perineural fat due to the same echotexture. **(c)** Ulnar nerve in Guyon's canal using 4-D transducer: (a) axial, (b) sagittal, (c) coronal, and (d) 3-D reconstruction.

exclude subluxation or dislocation of the nerve. A full discussion of dynamic maneuvers employed in this assessment is detailed in Chapter 12.

> **Insider Information 1.5**
> On ultrasound, in the longitudinal axis of a nerve, a fascicular pattern is composed of uninterrupted hypoechoic bands, the fasciculi, with intervening linear interrupted hyperechoic bands, the interfascicular epineurium.

## Bursa

Within the body there are three subdivisions of synovial membranes: articular, synovial sheath, and bursal. The bursal synovial membrane is further subdivided into mucosae and synoviae. The former is present within the

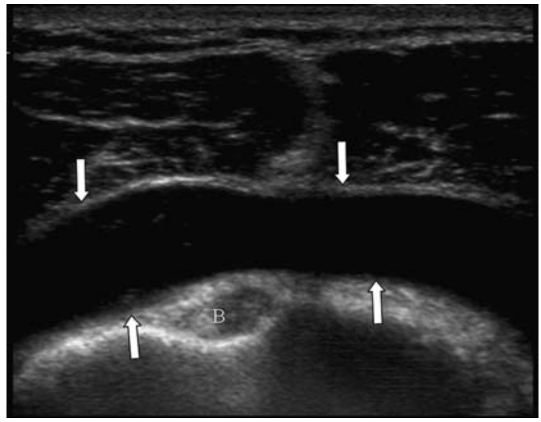


**Figure 1.12.** Bursa (B). Fluid distension of the subacromial-subdeltoid bursa, extending over the bicipital groove. The bursal capsule (arrows) and peribursal hyperechoic fat have a similar echogenicity and are difficult to separate.

subcutaneous tissue, between skin and underlying bony prominence (e.g., prepatellar bursa between the patella and skin). It becomes distended, for example, when there is increased friction between the bone and overlying soft tissue. Bursae synoviae are located deeper and lie between muscle or tendon and bone, and again serve to reduce friction. Occasionally, these deeper bursae will communicate with the joint, e.g., subscapularis bursa with the shoulder joint, and iliopsoas bursa with the hip joint.[8] Bursae are not usually discernible unless distended in part by fluid, with the fluid then appearing on ultrasound as anechoic between the hyperechoic tissue layers representing adjacent fat planes and capsule (Figure 1.12).

## Bone

Although ultrasound has limitations when imaging bone, it does offer excellent anatomical detail of the cortical surface of superficial bone. The high resolution provided by ultrasound allows for the detection and assessment of subtle cortical changes. Fractures, e.g., scaphoid or Hill-Sachs, and erosions of superficial bones that sometimes are not visible on plain radiographs can be demonstrated on ultrasound (Figure 1.13). The cortical surface, however, is highly reflective on ultrasound. This causes the cortex to be visualized as a well-defined hyperechoic continuous line, but obscures the deeper medullary cavity. Deeper cortical surfaces, e.g., the posterior tibia in the calf, usually require a lower frequency transducer. The overlying normal periosteum is not normally identifiable separate from bone and the adjacent soft tissues.

Knowledge of the bony anatomy is essential in the full ultrasound evaluation of the musculoskeletal system. Bony landmarks will often form an easily identifiable location to assess the overlying soft tissues, e.g., Lister's tubercle and the third extensor compartment on the dorsal wrist (Figure 1.14).

## Cartilage

Cartilage can be divided into hyaline cartilage, white fibrocartilage, and elastic or yellow fibrocartilage. The latter is present in only select regions, e.g., the auricle of the external ear. Articular cartilage, costal cartilage, and temporary

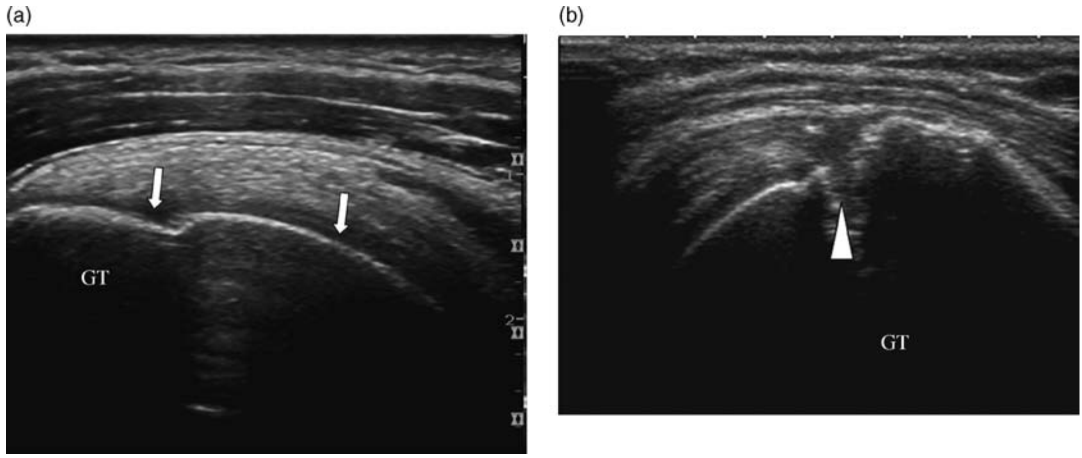


**Figure 1.13.** **(a)** Cortical bone: ultrasound of the normal greater tuberosity (GT) of the humerus demonstrating a smooth hyperechoic line consistent with cortex margin with posterior acoustic shadowing. **(b)** Fracture (arrowhead) GT with interruption of the normal smooth cortical line demonstrated in **(a)**.

cartilage are composed of hyaline cartilage. With the exception of articular cartilage, cartilage is covered by perichondrium. Articular cartilage is of varying thickness, being thicker in points of greater stress and on convex rather than concave surfaces. It provides a degree of elasticity and shock absorption, as well as helping to dissipate stress across a joint.[8,9]

On ultrasound, it has a smooth, well-defined surface and border and is uniformly hypoechoic (Figure 1.15). In children, cartilaginous centers prior to ossification are not visible on plain radiographs, but are clearly visible on ultrasound as hypoechoic structures with early ossification beginning centrally as a zone of hyperechogenicity (Figure 1.16).

Fibrocartilage is a variable mixture of white fibrous tissue and cartilaginous tissue with a large component of collagen fibrils. It provides elasticity and flexibility. The menisci of the knee, temporomandibular and sternoclavicular

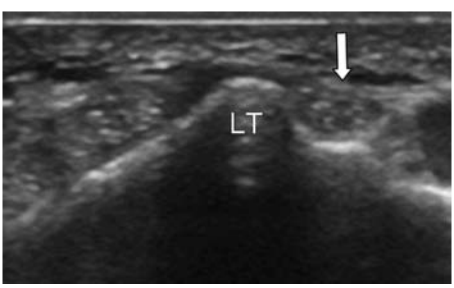


**Figure 1.14.** Lister's tubercle (LT) on the dorsal aspect of the distal radius is an important bone landmark in the assessment of the dorsal tendon compartments. The extensor pollicis longus tendon (arrow) lies on its ulnar aspect and is separated from the second compartment by LT.

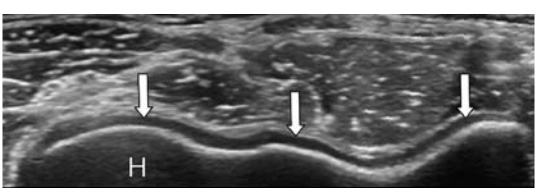


**Figure 1.15.** Articular cartilage: transverse ultrasound demonstrating the well-defined, uniformly hypoechoic normal articular cartilage (arrows) at the articulating surface of the distal humerus (H).

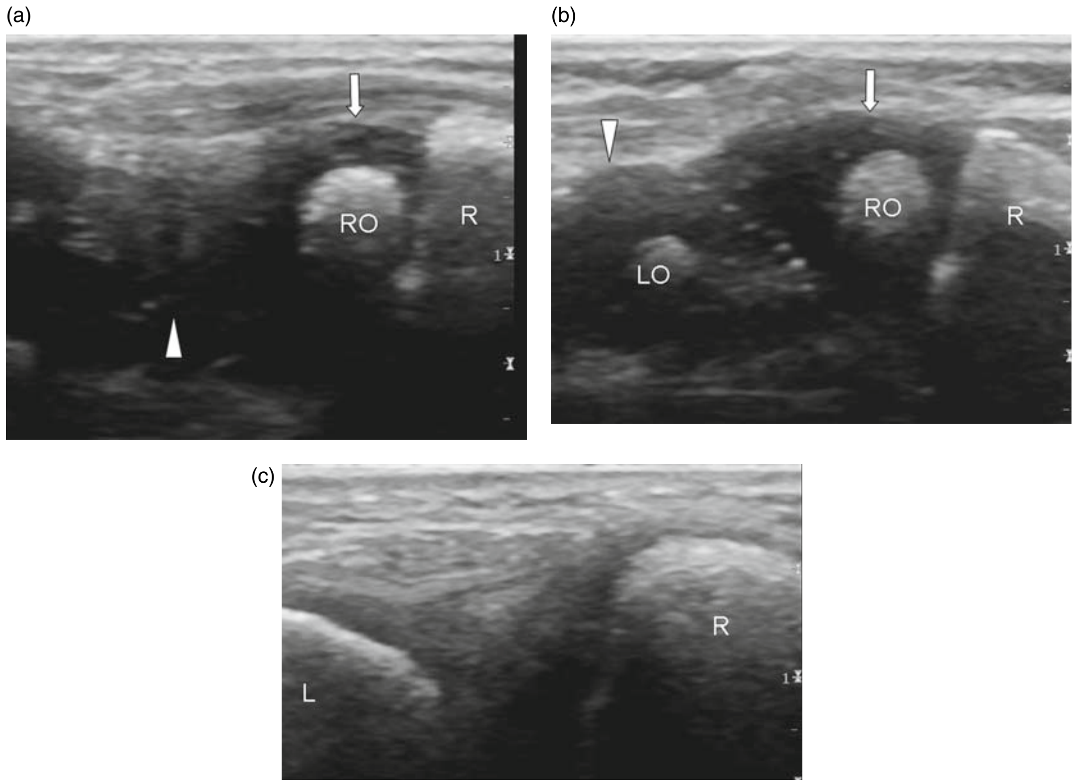


**Figure 1.16.** Cartilaginous centers prior to ossification are clearly visible on ultrasound as hypoechoic structures with early ossification beginning centrally as a zone of hyperechogenicity. **(a)** Longitudinal ultrasound of a 2-year-old girl demonstrating early ossification of the center distal radius (RO) surrounded by the hypoechoic cartilaginous center. No ossification has commenced within the lunate (arrowhead), which remains uniformly hypoechoic. **(b)** An early ossification center is now visible in the lunate (LO) in this 4-year-old boy. **(c)** Normal adult appearance.

joints, the glenoid and hip labra, and the triangular fibrocartilage of the wrist are composed of fibrocartilage. On ultrasound, fibrocartilage is hyperechoic with well-delineated borders. Because of its position within joints, it is not always fully accessible to a full ultrasound examination (Figure 1.17).

> **Insider Information 1.6**
> In children, cartilaginous centers, prior to ossification, are not visible on plain radiographs but are clearly visible on ultrasound as hypoechoic structures. Early ossification can be seen, beginning centrally, as a zone of hyperechogenicity.

## Anisotropy

Anisotropy is one of the commonest, and probably the most important artifact, in musculoskeletal ultrasound imaging. Anisotropy is the different ultrasound echogenicity of normal tissue when the angle of insonation is not 90° to the

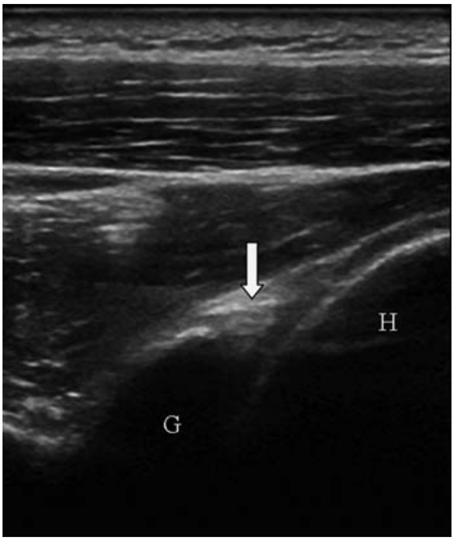


**Figure 1.17.** Fibrocartilage. The posterior glenoid labrum (arrow) is demonstrated here as a well-defined, hyperechoic triangular structure between the articulating surfaces of the glenoid (G) and humerus (H).

plane of the structure being imaged. It is best identified in tendons and is less pronounced in other soft tissues including muscles, ligaments, and nerves. A common site of occurrence is within the supraspinatus tendon because of its coronal oblique course and angulation. To separate anisotropy from pathology, the transducer is held in the same position but is angled until it is perpendicular to the tissue of interest, at which point the artifactual hypoechoic appearance will resolve in normal tendons and the tissue will be of homogeneous echogenicity (Figure 1.18).

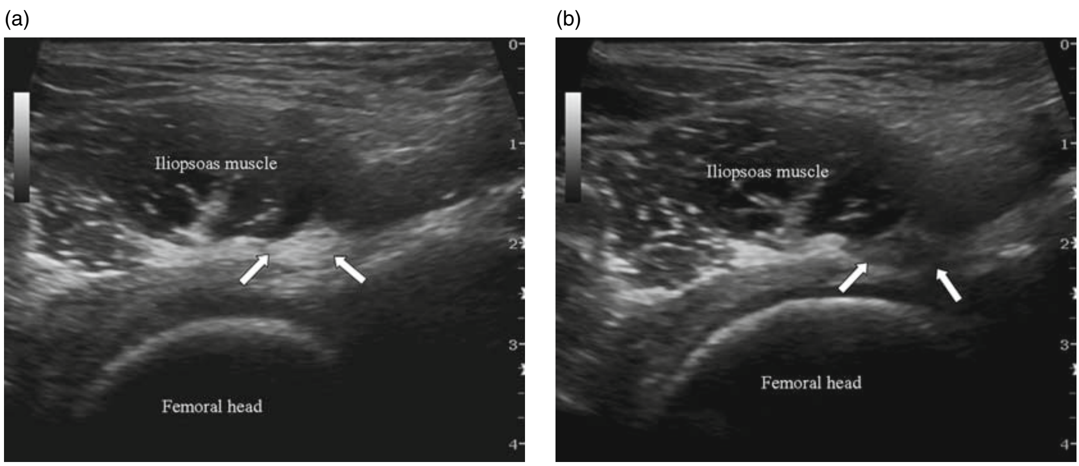


**Figure 1.18.** Anisotropy. The iliopsoas tendon (arrows) demonstrates a normal hyperechoic appearance in transverse ultrasound image **(a)**. By angulating the ultrasound beam 5° to 10°, so that the beam is no longer perpendicular to the hyperechoic tendon, the iliopsoas tendon becomes artifactually hypoechoic and simulates pathology **(b)**.

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# Section 2

## The Upper Limb

# 2

# The Shoulder

John O'Neill

The shoulder joint is the commonest joint examined sonographically, and is often the first joint on which most imagers are introduced to musculoskeletal ultrasound. The shoulder is superficial and readily accessible to ultrasound assessment and is excellent for assessing the normal anatomy and pathology of the shoulder joint; it has sensitivities and specificities in assessment of the rotator cuff that are comparable to magnetic resonance imaging (MRI). Ultrasound offers excellent resolution, is multiplanar, accessible, and cost efficient. One of ultrasound's main strengths is its ability to image in real time the normal dynamic motion of joints and surrounding soft tissues. This dynamic component of the study may expose pathologies not apparent in a static examination. This feature is particularly important in assessing for subluxation of the biceps tendon or impingement syndromes, e.g., supraspinatus or subcoracoid impingement. In addition, ultrasound allows for a more complete functional assessment of the structure. This chapter will outline the clinical indications for shoulder ultrasound, discuss the transducers suited to the examination, and then review the normal anatomy of this region. Anatomy will include a brief overview of surface anatomy, which will allow the imager to identify key landmarks that can then be used to formulate a structured and reproducible approach to the study as detailed in the section on ultrasound technique.

## Clinical Indications

The commonest indication is in the assessment of rotator cuff and biceps tendon pathology, including tendinosis, partial and full thickness tears, and impingement syndromes. Rheumatology referrals for joint effusion, synovial thickening, and erosions are increasing in number. Subtle nondisplaced fractures, particularly of the greater tuberosity, and Hill–Sachs defects, which may not be identified on plain radiographs, may be identified in a patient with persistent posttraumatic pain. Ultrasound can identify etiologies of nerve impingement, e.g., suprascapular nerve impingement and potential secondary findings such as atrophy and fatty infiltration of the supplied muscles. Labral injuries, particularly posterior labral tears with paralabral cyst formation, can be identified, although a full evaluation of the labrum requires MRI. Ultrasound is an important imaging modality in the primary imaging assessment of soft tissue masses, and is beneficial in assessing for solid/cystic components, internal and adjacent vascularity, and dynamic and functional components.

Interventional procedures include ultrasound-guided biopsy of soft tissue masses, arthrograms (e.g., in patients requiring MRI but who are allergic to iodine used in fluoroscopically guided injections), direct joint or tendon injections, joint aspiration, aspiration and dissolution of calcific tendinosis, and aspiration and injection of bursae and paralabral cysts.

The acromioclavicular joint can also be assessed at the same time for a wide range of local pathology including degeneration, inflammatory arthropathy, trauma, and joint sepsis. Interventional procedures include joint aspiration and injection.

## Technical Equipment

High-resolution linear array transducers with a broad-bandwidth frequency between 7.5 and 12 MHz are generally preferred, with frequencies lower and higher required for deep and superficial structures, respectively. Linear array transducers lack divergent beam geometry, which accentuates anisotropy. Color and power Doppler are valuable in assessing hyperemia in inflammatory or reparative tissue and the vascularity of soft tissue masses, as well as in differentiating cystic lesions from vascular structures. Evaluation of deeper structures, depending on the patient's habitus, including the anterior labrum, may require a low-frequency curved array transducer.

## Anatomy

### Surface Anatomy

The clavicle is palpable, throughout its length, at the root of the neck. At its distal end it forms the articulation with the acromion, the acromioclavicular joint, which is felt as a change in the smooth contour of the clavicle. The acromion is the superolateral bony projection from the scapula directly over the glenohumeral joint. Anterior, lateral, and posterior to the acromion is the smooth soft tissue contour of the deltoid muscle that covers the glenohumeral joint and the humeral tuberosities. Anteriorly, a triangular depression is formed between the medial border of the deltoid and the pectoralis major: the deltopectoral angle. Within the lateral aspect of this triangle, a bony prominence can be felt on deep palpation: the coracoid process of the scapula (Figure 2.1). The anterior and posterior axillary folds are formed by the pectoralis major and latissimus dorsi muscles, respectively.[1] Posteriorly, extending from the acromion, a palpable bony ridge—the scapular spine—separates the supraspinatus and infraspinatus fossae. The soft tissue contour of the posterior aspect of the joint is formed in part by the supraspinatus and infraspinatus muscles as well as the overlying musculature, which includes the deltoid, trapezius, and latissimus dorsi muscles. Patients with atrophy of these muscles may have a visible loss of mass in this region when compared with a normal contralateral side (Figure 2.1).

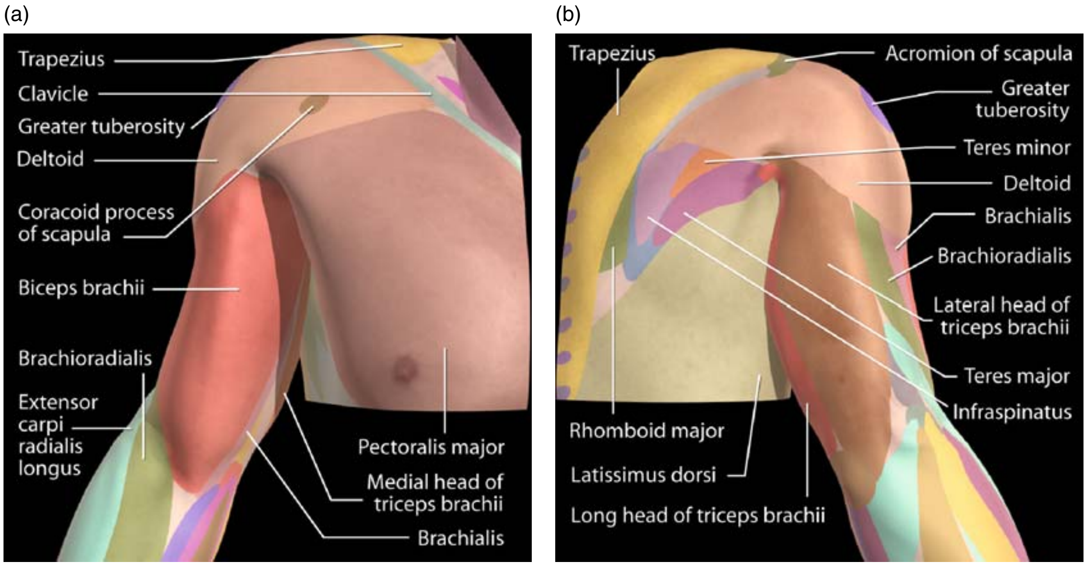


**Figure 2.1.** The surface anatomy of the shoulder: **(a)** anterior and **(b)** posterior views.

## Bones

The glenohumeral joint is an enarthrodial, or ball-and-socket, joint with multidirectional capabilities (Figure 2.2).[2] This wide range of motion is facilitated by the shallow glenoid fossa of the scapula articulating with the significantly larger humeral head. This anatomical arrangement, however, predisposes the joint to dislocation, which in turn is counteracted by the support mechanism of the glenohumeral ligaments, the rotator cuff tendons (Table 2.1), and the glenoid labrum. The articulating surfaces of the humerus and glenoid are covered by articular cartilage, which is thin at the center of

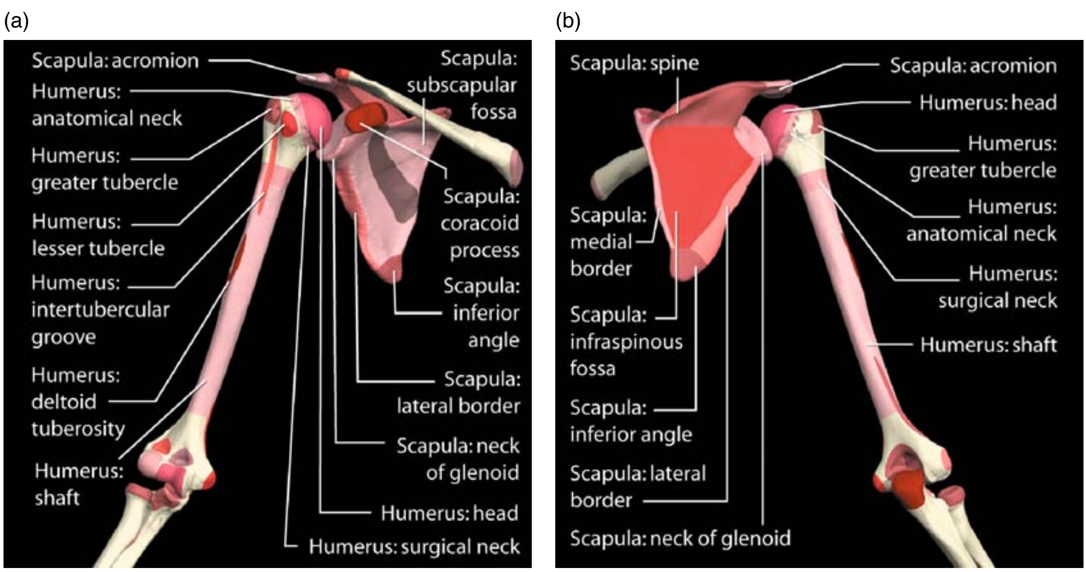


**Figure 2.2.** The important shoulder bony landmarks: **(a)** anterior and **(b)** posterior views.

**Table 2.1.** Rotator Cuff Muscles.

| |
|---|
| Supraspinatus |
| Infraspinatus |
| Teter minor |
| Subscapularis |

the glenoid and thick peripherally; the opposite holds true for the humeral head. The cartilage is continuous except for a focal spot on the posterosuperior aspect of the humeral head, known as the bare area. On ultrasound, the peripheral aspect of the humeral articular cartilage is identifiable as a continuous thin hypoechoic covering of uniform thickness with the deeper cortical bone visualized as a smooth uninterrupted hyperechoic line with posterior acoustic shadowing.

The rounded greater tuberosity is lateral to the humeral head and has three facets. The anterior and middle facets serve as sites of attachment for the supraspinatus tendon; the infraspinatus tendon also attaches to the middle facet and the teres minor tendon to the posterior facet and adjacent humeral shaft (Figure 2.3). The lesser tuberosity is smaller, anteromedial, and separated from the greater tuberosity by the bicipital groove. The subscapularis tendon attaches to the lesser tuberosity and the adjacent humerus (Figures 2.2 and 2.3).

The acromion, meaning shoulder summit, is the termination of the scapular spine. It may be oblong or triangular in shape and has a smooth concave undersurface. It has three centers of ossification that usually unite by 22 years.[3] If nonunion persists, it is termed os acromiale, and is important to identify when present. Os acromiale occurs in approximately 5% of the population and is bilateral in up to 20% of cases. The fibrous capsule of the joint is lax, which allows for the wide range of motion, and is lined by a synovial

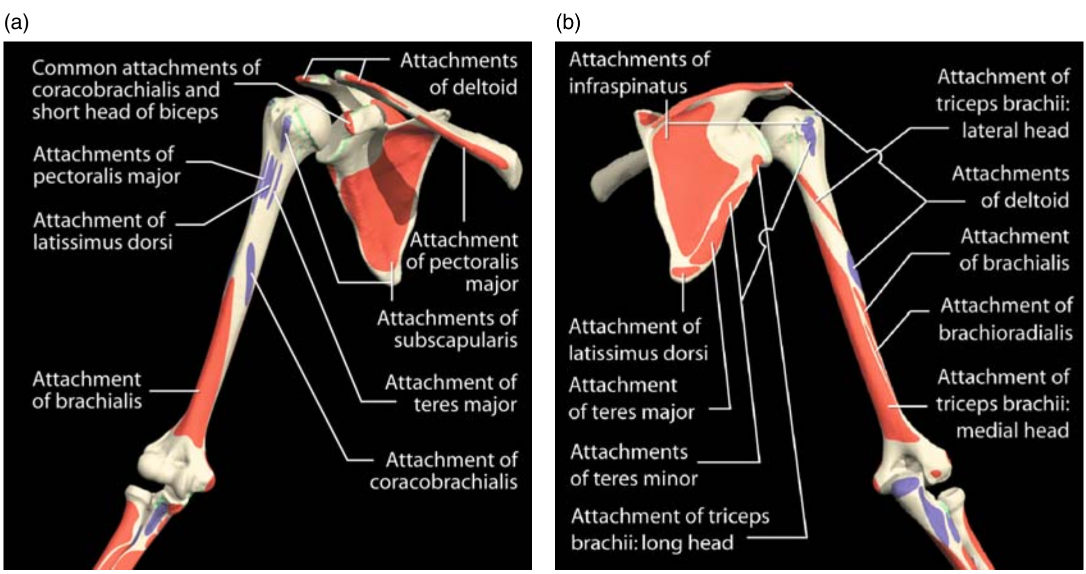


**Figure 2.3.** The muscle origin (red) and insertion (blue) points of the shoulder girdle muscles: **(a)** anterior and **(b)** posterior views.