Musculoskeletal Ultrasound

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Chapter 1

Introduction

Ian Beggs

INTRODUCTION

Ultrasound is important for diagnosis and treatment in a wide range of musculoskeletal conditions and requires a firm grasp of anatomy, technique, and pathology. Ultrasound and magnetic resonance imaging (MRI) are complementary techniques. They are not competitive or mutually exclusive, and their use should be integrated. Technical advances in ultrasound[1] have improved image quality and capability, resulting in better understanding of anatomy and pathology, and the development of new therapeutic techniques. A further advantage is that ultrasound has returned the radiologist to the "bedside," providing the opportunity to examine the patient directly and garner more clinical information than is frequently available in a hastily scribbled requisition. Equally, many clinicians are beginning to perform their own specialty-specific ultrasound.

Ultrasound is best performed to answer specific questions. Symptoms that are located by a vague wave of the patient's hand are probably better investigated by MRI. In many instances, a "targeted" ultrasound examination detects the abnormality.[2] This is more likely with peripheral joints than with central joints, which benefit from a systematic examination. The shoulder is an example of a joint that should always be examined systematically. However, if the systematic approach yields no abnormality, it is worth completing the examination by reviewing the area that the patient points to as the site of pain.

Ergonomic issues are important. Repetitive strain injuries to the spine, shoulder, or wrist are common among sonologists.[3,4] This is especially true in musculoskeletal ultrasound, and the examination technique should be considered carefully. Good technique also optimizes imaging. The position of both the sonologist and the patient should minimize strain on the operator. The height of the examination couch or stool should be altered accordingly. The sonologist's arm should not be elevated or stretched, and twisting of the neck or trunk should be avoided. The transducer should be held close to its face to provide more control and reduce strain. The sonologist's hand can rest on the patient and provide support. The transducer cable should be held in the opposite hand to reduce strain.

Copious jelly is needed. This may need to be thick for very superficial structures, but a standoff is not usually needed. The transducer should be moved slowly. Beginners frequently fail to recognize pathologic changes and even normal anatomy because they move the transducer too quickly. Fine movement may be helped by using one hand to position and angle the transducer and the other to push and pull it. Transducer pressure should be light, although increased pressure may be needed to displace superficial fat. Heavy pressure may efface a muscle hernia, or Doppler signal in synovitis or tendinosis.

Ultrasound is a dynamic examination. For example, the shoulder is examined in various positions to bring the relevant tendons into view, and the examination may be performed during abduction to look for impingement. Transducer pressure may distinguish between fluid that can be compressed and displaced and incompressible synovial hypertrophy in a swollen joint. Pressure may displace echogenic fluid and debris in rotator cuff or Achilles tendon tears and show whether the tear is complete or incomplete. Dorsiflexion and plantar flexion of the foot show whether an Achilles tendon tear is complete or partial and whether conservative or surgical management is appropriate; if the tear edges do not come together on plantar flexion, conservative management with the foot plantar flexed in a cast will be suboptimal.

Variable frequency linear array transducers in the 7 to 14 MHz range are adequate for most purposes, although small footprint and higher frequency transducers may be valuable when examining fingers or very superficial structures. There is a trade-off, however, between the better resolution of high-frequency transducers and the depth to which they can penetrate. Adjustments to gain, frequency, and focal zone are critical to optimize images.

Anisotropy due to specular reflection is an artifact of major importance in musculoskeletal ultrasound. Specular reflectors reflect the ultrasound wave at the angle of insonation rather than producing a scattered reflection as, for example, does the liver. If the transducer is angled at 90° to a specular reflector, the sound is reflected back and detected; but if the ultrasound beam is not

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perpendicular, the sound will be reflected away from the transducer and the loss of reflected sound will result in a hypoechoic appearance. Tendons are the most important specular reflectors (Fig. 1.1), but ligaments, nerves, and muscles (Fig. 1.2) are also specular reflectors, and it is essential to ensure that the transducer is always perpendicular to these structures. Anisotropy is a particular problem with tendons that curve, for example, supraspinatus at the shoulder and tibialis posterior and the peroneal tendons at the ankle. Compound imaging produces sound waves at different angles and helps to overcome the problem of anisotropy and reduces noise and speckle.[5]

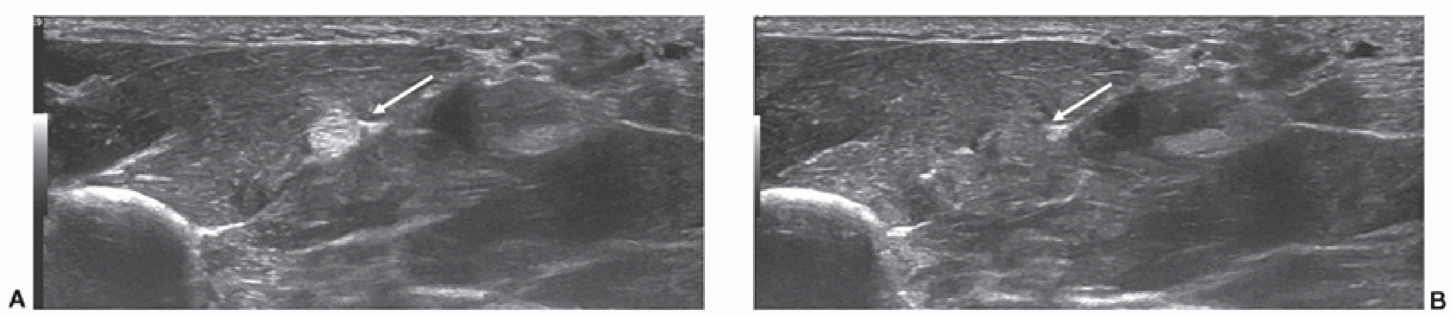

Figure 1.1. A: Transverse scan of the thenar eminence. The angle of insonation is 90° to the flexor pollicis longus tendon (arrow), which appears echogenic. B: The angulation of the transducer has been altered by about 5°, and the tendon (arrow) is no longer visible.

Beam steering also assists, although most experienced sonologists simply angle the transducer. Tissue harmonic imaging, which utilizes frequencies that arise within the tissue examined, helps to reduce other artifacts and improve contrast resolution.[6]

The effect of anisotropy can be harnessed profitably if a tendon is difficult to locate because it is surrounded by echogenic fat, for example, at the ankle. Altering transducer angulation to make the tendon hypoechoic (Fig. 1.3) will help locate the tendon. Then transducer angulation is corrected to examine the tendon.

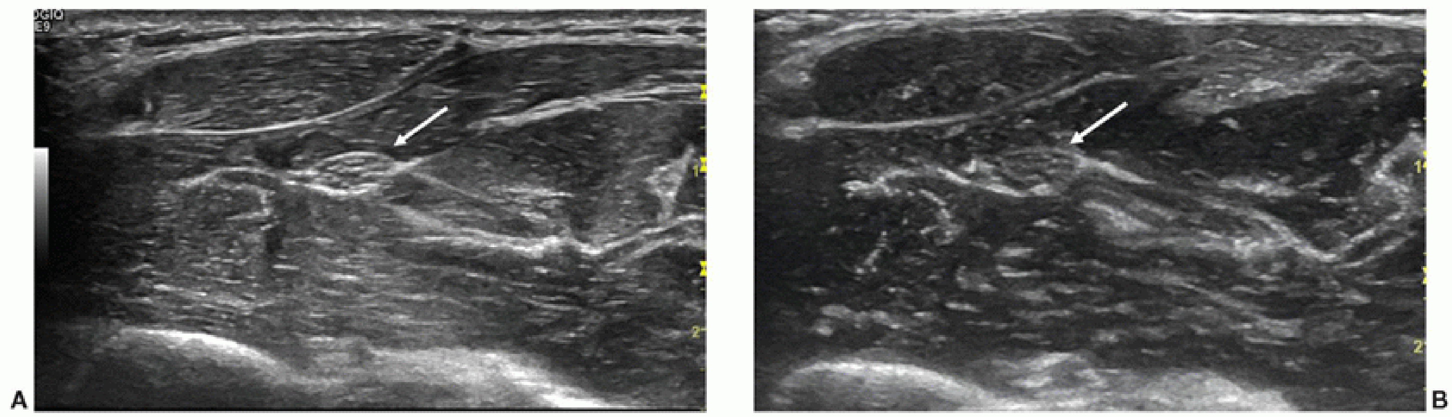

Figure 1.2. A: Transverse scan of the forearm showing the median nerve (arrow) between the flexor digitorum superficialis and flexor digitorum profundus muscles. The transducer is perpendicular to the muscles and nerve. B: The transducer is no longer perpendicular, and all structures, including the median nerve (arrow), are now poorly seen and appear hypoechoic.

Beam edge artifact (Fig. 1.4) is another artifact that can affect tendons, particularly large tendons. Loss of definition of the tendon edge and distal acoustic shadowing may simulate or obscure fluid in the tendon sheath.

Extended field-of-view imaging (Fig. 1.5) may improve diagnostic accuracy, for example, in assessing atrophy of the rotator cuff muscles, and has a valuable role in teaching and presenting findings.

Doppler examination is essential in assessing tendinopathy[7] and detecting (Fig. 1.6) or monitoring synovitis.[8] Neovascularity has been correlated with pain in tendinopathy (although the relationship between tendinopathy and neovascularity is controversial) and with active synovitis in inflammatory joint disease. Power Doppler is usually employed using low pulse repetition frequency, medium persistence, small color box, low wall filter, and appropriate color velocity scale. Doppler signal (Fig. 1.7) may be reduced or abolished by pressing too hard or if a tendon is under tension; therefore, a light touch should be employed and tendons should be relaxed while being examined.

The role of contrast-enhanced ultrasound (CEUS) is yet to be established. However, CEUS improves diagnostic
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sensitivity in inflammatory joint diseases, shows areas of relatively low vascularity that might predispose to tendinopathy, and demonstrates age-related changes in vascularity in the rotator cuff.[9],[10]

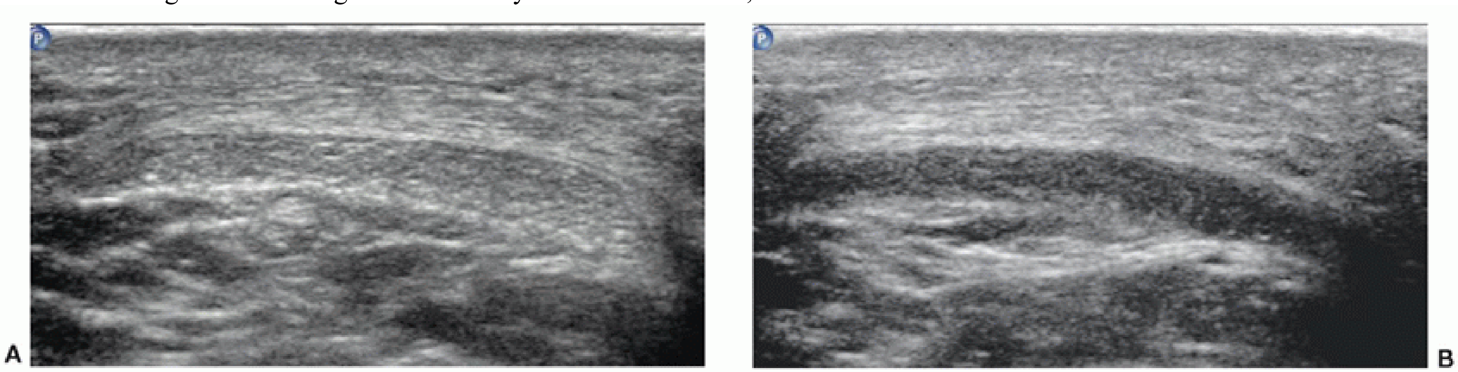

Figure 1.3. A: Short-axis scan of patellar tendon, with the angle of insonation at 90°. The tendon is correctly imaged and is echogenic, but the echogenicity is similar to that of the overlying subcutaneous fat. B: The altered angle of insonation results in a hypoechoic tendon that is clearly distinguished from the subcutaneous fat.

Elastography (Fig. 1.8) assesses tissue softening by measuring tissue displacement before and after compression, and has shown promising results in epicondylitis at the elbow and in Achilles tendinopathy.[1],[11],[12]

TENDON

Tendons are part of the musculotendinous unit and transmit force from muscle to bone to produce movement at joints. They are subject to tensile and compressive forces. Tendon strength depends on the size, number, and orientation of collagen fibers, thickness, and internal organization.[13]

Tendons are composed of collagen fibers, ground substance, and tenocytes. Collagen provides tensile strength. Ground substance provides structural support for collagen fibers and regulates collagen production. Tenocytes are scattered among collagen fibers and produce collagen precursors and ground substance. Collagen is arranged hierarchically and has a uniform appearance, which is distorted in tendinosis (Fig. 1.9). Tropocollagen, a triple-helix polypeptide chain, forms fibrils, which coalesce to form fibers, which in turn form the primary, secondary, and tertiary bundles that comprise the tendon. Most collagen fibers are parallel and run in the direction of the long axis of the tendon with a spiral element, but some fibers run transversely.[13]

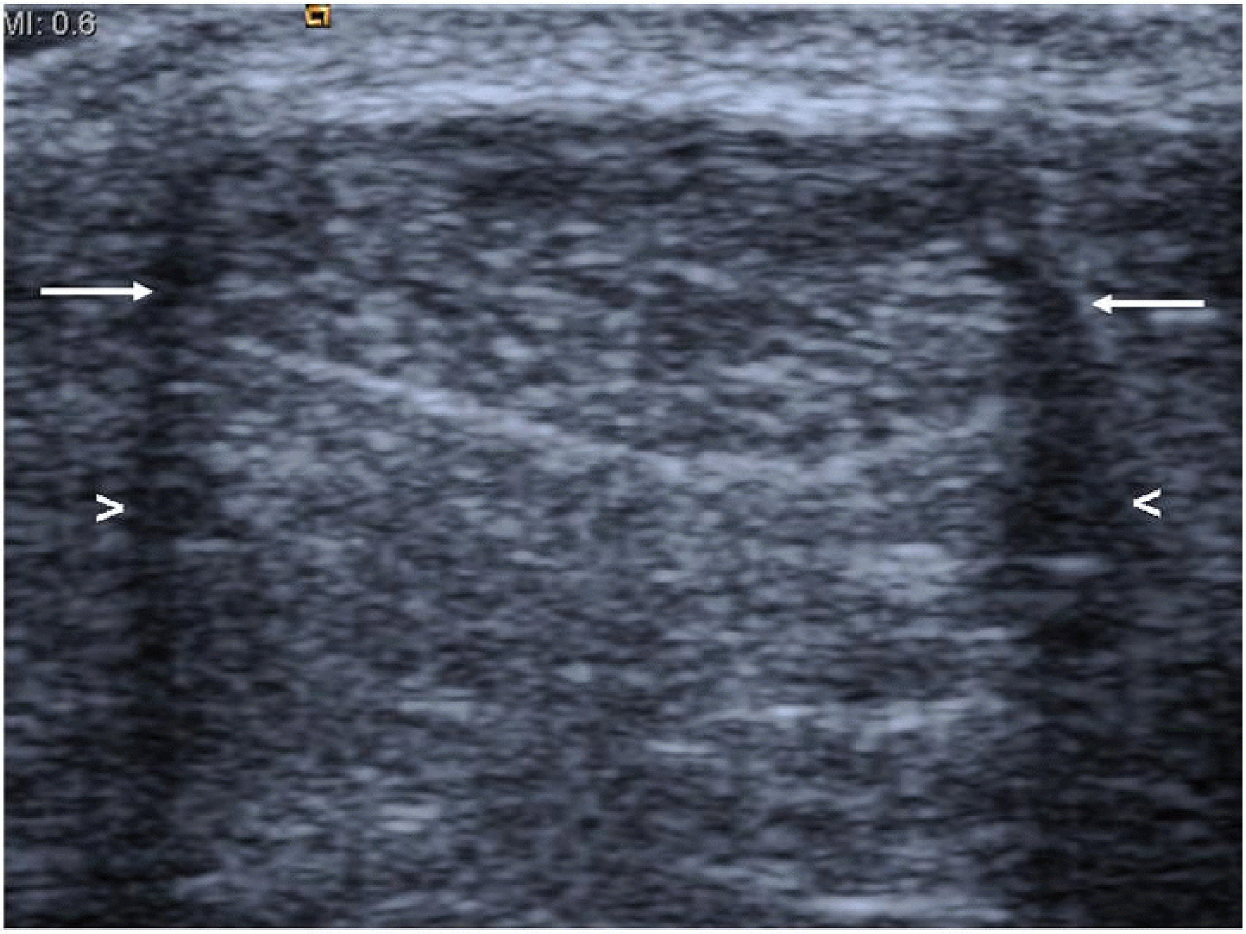

Figure 1.4. Transverse scan of tendo Achilles. Edge artifact (arrows) obscures the margins of the tendon and results in acoustic shadowing (arrowheads).

Tendons are covered by the epitenon, a loose connective tissue sheath that contains vessels, nerves, and lymphatics that supply the tendon. The epitenon extends deeply as endotenon between tertiary bundles of collagen, and blends externally with the paratenon or deep fascia when tendons have a straight course. Some tendons that alter direction with joint movement, typically those that run in osteofibrous tunnels at the ankle and wrist, have double-layered tendon sheaths that are lined by synovial cells and contain a thin film of fluid. Vessels cross the tendon sheath at the mesotendon. Curved tendons are held in position by fibrous retinacula (e.g., at the wrist and ankle) or pulleys (e.g., the flexor tendons of the fingers).

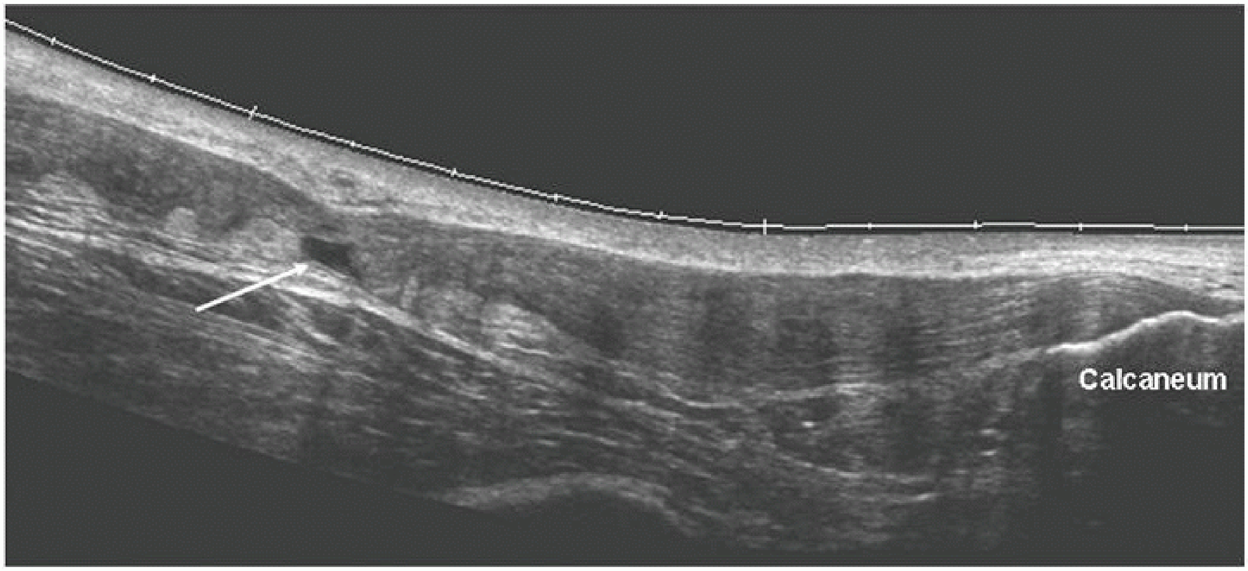

Figure 1.5. Extended field-of-view image showing partial tear (arrow) in tendo Achilles. The tendon distal to the tear is swollen. P. 4

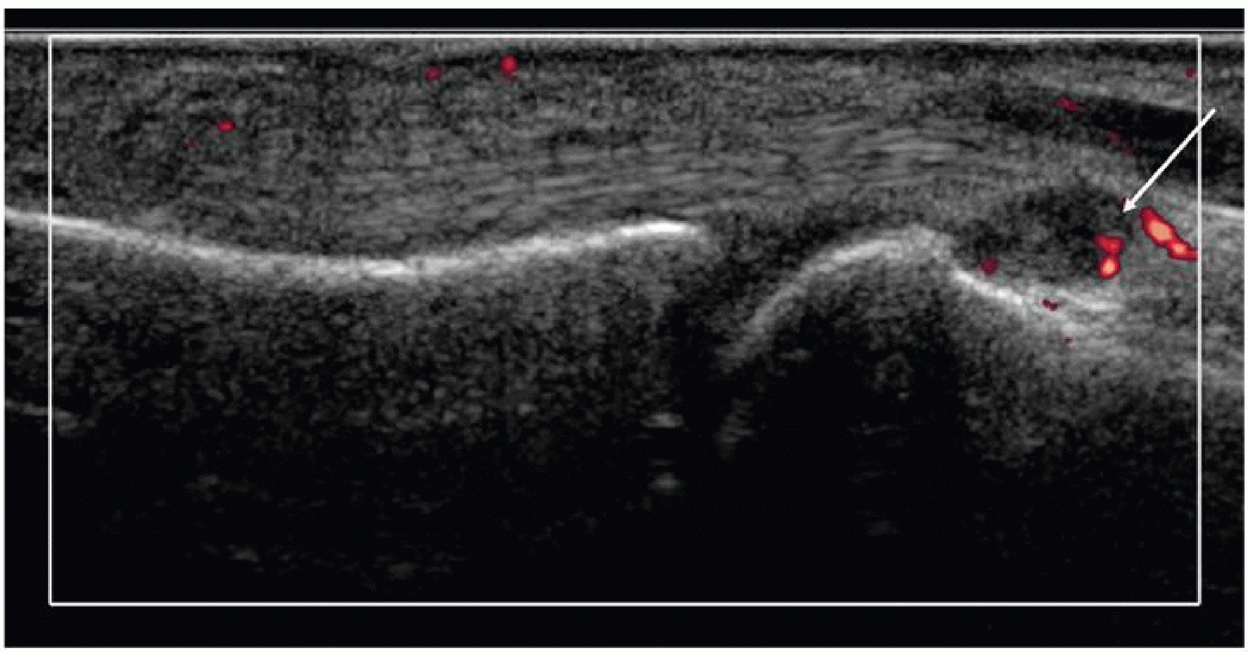

Figure 1.6. Power Doppler longitudinal scan of volar aspect of the fifth metacarpophalangeal joint. The proximal recess is distended and contains echogenic synovium and neovascularity in keeping with synovitis.

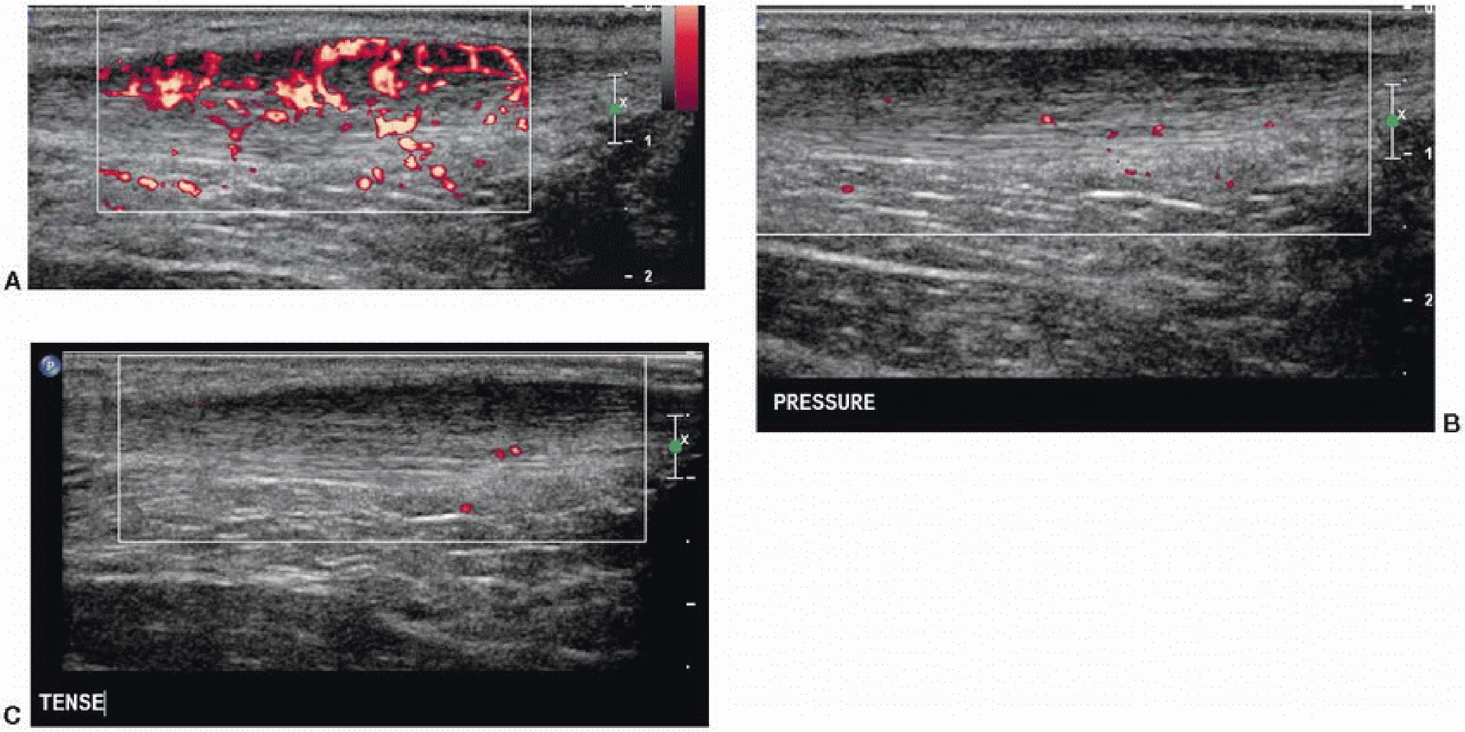

Figure 1.7. A: Power Doppler longitudinal scan showing typical Achilles tendinosis. There is fusiform thickening of the tendon, its superficial fibers are hypoechoic, and there is extensive neovascularity in the tendon and adjacent soft tissues. B: Heavy pressure has obliterated the Doppler signal. C: Putting the tendon under tension by dorsiflexing the foot has also abolished the Doppler signal.

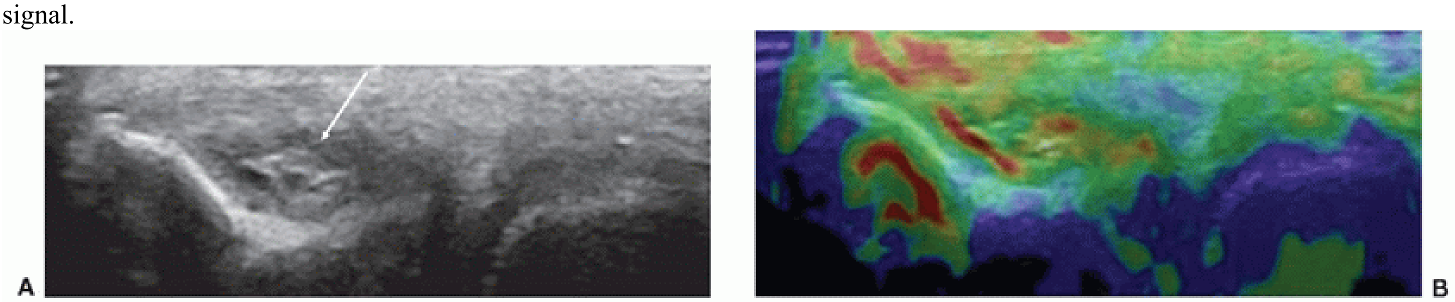

Figure 1.8. A: Swelling, reduced echogenicity, and cystic areas (arrow) in common extensor origin at elbow, consistent with lateral epicondylitis. B: Elastography of the same area shows red areas due to softening. The green areas are normal. (Both images courtesy of Professor A. Klauser.)

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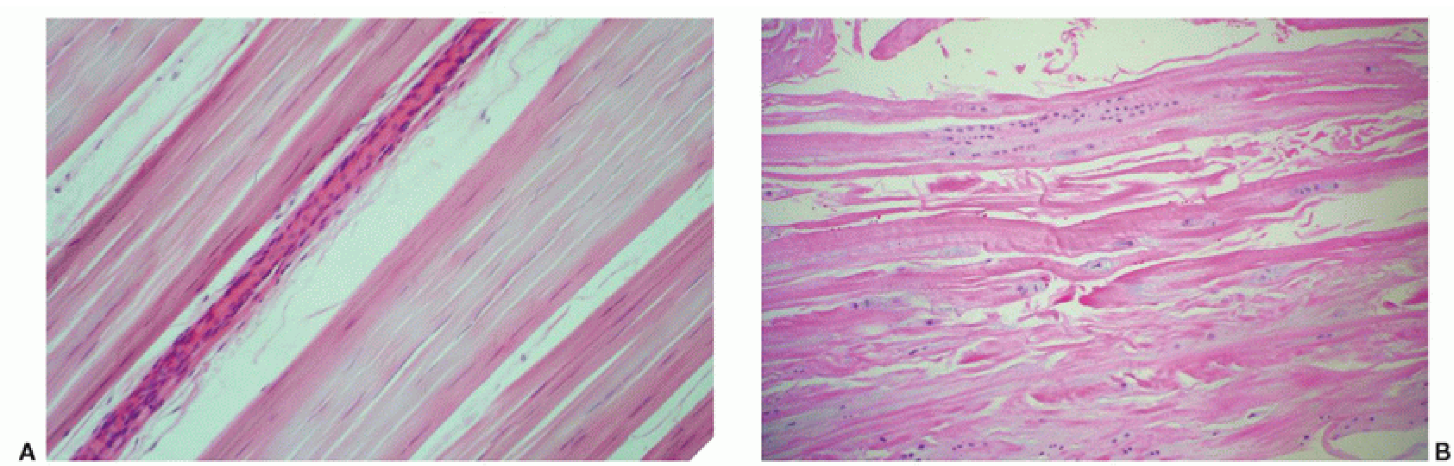

Figure 1.9. A: H&E preparation of normal tendon showing the highly uniform linear pattern. (Courtesy of Dr. F. Bonar. Reproduced with permission from Klein MJ, Bonar SF, eds. Fascicle 9: Non-neoplastic Disease of Bone and Joints. Silver Springs, MD: ARP Press; 2011.) B: H&E preparation of severe tendinosis showing disruption of the normal pattern and chondroid lacunae. (Courtesy of Dr. F. Bonar.)

Ultrasound (Fig. 1.10) demonstrates the internal architecture of tendons in greater detail than most conventional MRI scanners. Tendons have an echogenic, fibrillar pattern in long-axis scans and a speckled, echogenic appearance in short-axis scans, caused by the interfaces between the echogenic collagen bundles and the endotenon. Both tendon texture and caliber should be uniform, although some tendons narrow (e.g., supraspinatus) and others expand (e.g., distal patellar tendon) as they run to their insertions. Tendons normally show no flow on color or power Doppler scans, although contrast-enhanced scans can show vascularity. Epitenon, paratenon, and synovial sheath all appear echogenic, although a thin layer of anechoic fluid may be present in a tendon sheath. Pulleys and retinacula are usually thin and hypoechoic,[14,15] although the extensor retinaculum at the wrist is an exception and is thick (Fig. 1.11).

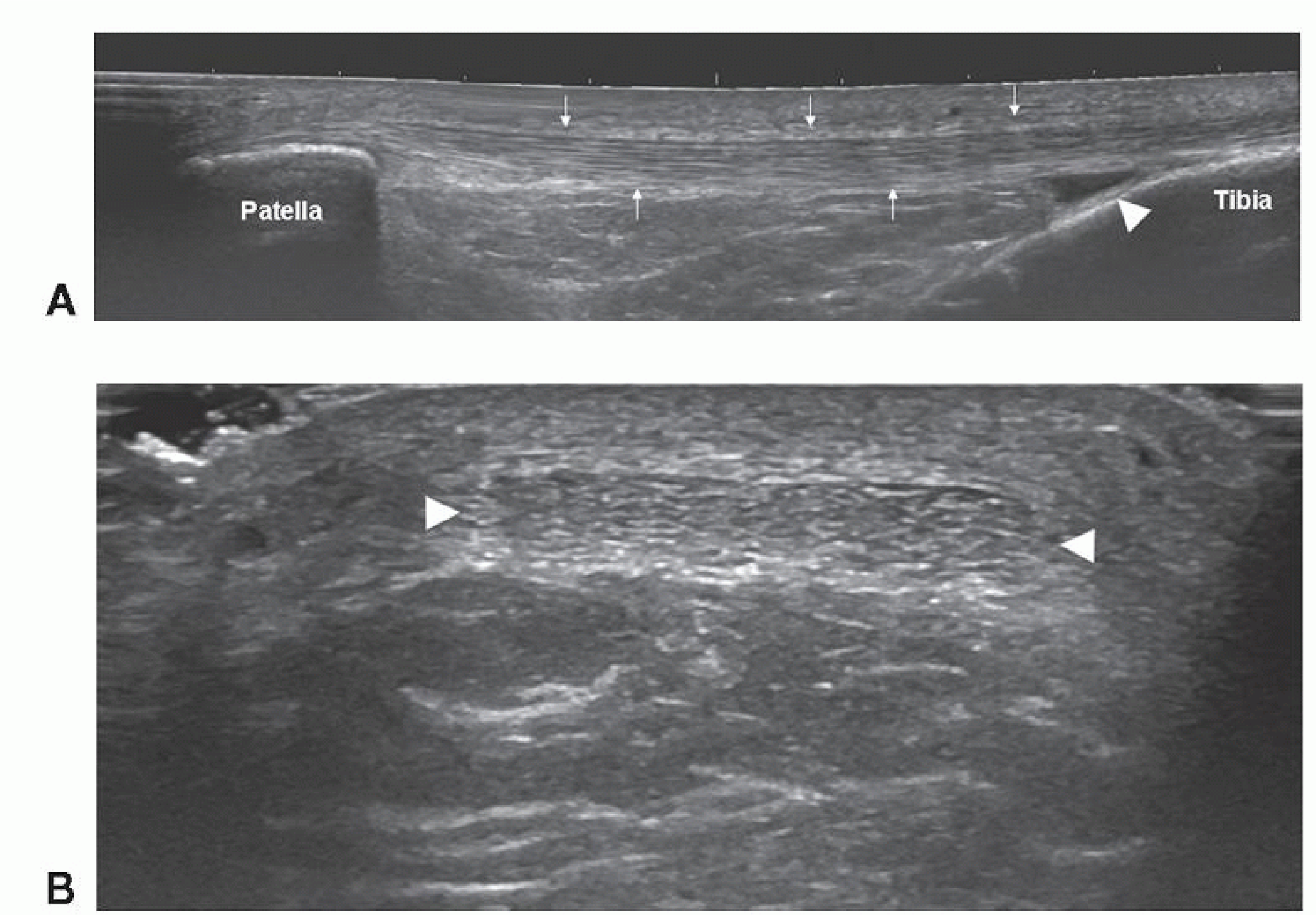

Figure 1.10. A: Long-axis scan of patellar tendon (arrows). The tendon has a fibrillar pattern and uniform caliber and texture. There is a small bursa (arrowhead) deep to the distal tendon. This is normal. B: Short-axis scan of the patellar tendon (between the arrowheads). The tendon has a speckled appearance and is well-defined and homogeneously echogenic.

As tendons are highly anisotropic, the transducer must be maintained at 90° to the tendon at all times. Altering the angle of insonation by as little as 5° may make a tendon hypoechoic and apparently abnormal.

MUSCLE

Muscles account for up to 50% of body weight. Muscle fibers are elongated structures (Fig. 1.12) that are uniform in size within a muscle, but vary from muscle to muscle. Groups of muscle fibers form fascicles. Aggregations of fascicles form muscles. Muscle fibers are surrounded by strands of connective tissue called the endomysium, fascicles are surrounded by a thicker perimysium, and muscles are surrounded by epimysium.

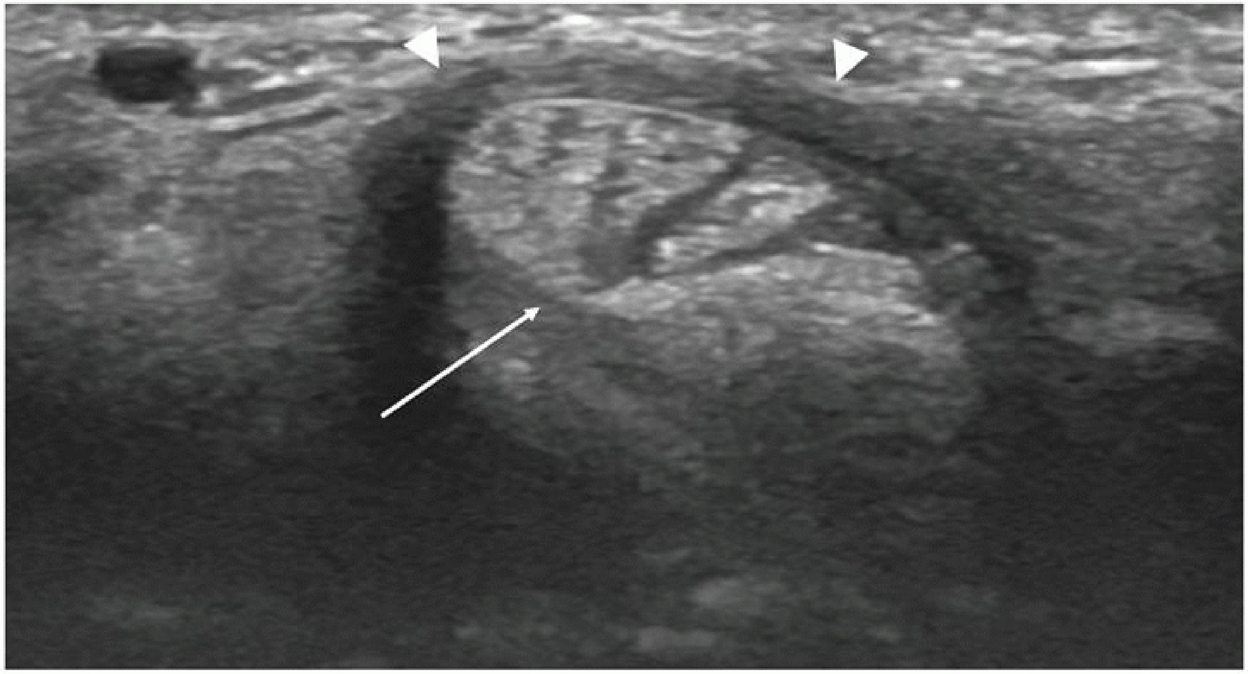

Figure 1.11. Thick (normal) retinaculum (arrowheads) overlying the extensor digitorum longus tendons (arrow) at the wrist.
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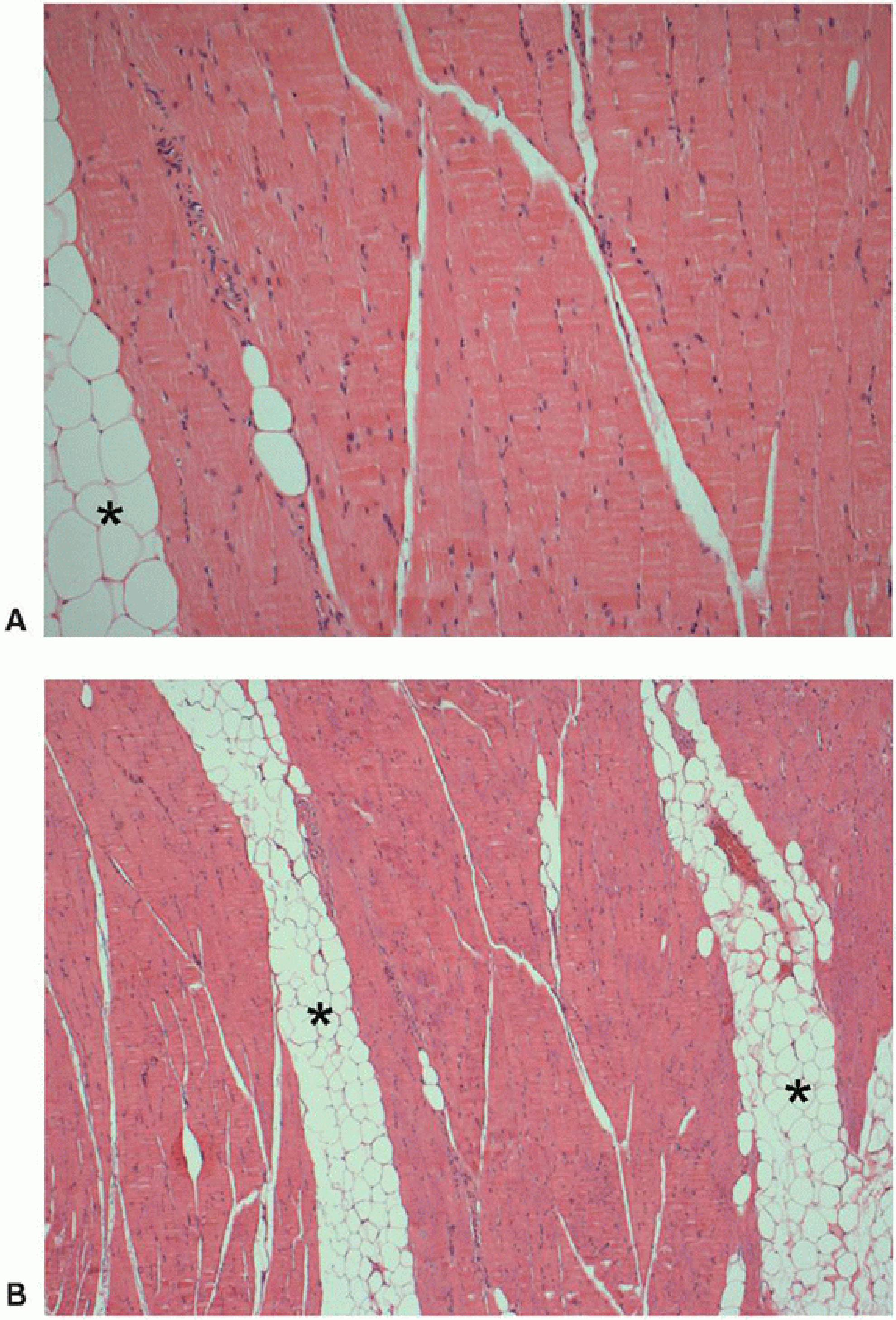

Figure 1.12. A: H&E preparation of normal muscle at high power showing the uniform distribution of the elongated muscle cells. Contraction of muscle cells results in contraction of the muscle. There is a fibroadipose septum (asterisk) at the edge of the image. B: Lower-powered H&E preparation showing fibroadipose septa (asterisks) separating muscle bundles. (Both images courtesy of Professor D. Salter.)

There are several muscle patterns. Flat (e.g., pronator quadratus) or strap-like (e.g., rectus abdominis) muscles have parallel fibers. Fusiform muscles (e.g., biceps brachii) have parallel fibers mid-muscle that converge on the tendon. Pennate muscles have oblique fibers and a feathery appearance and may be triangular (e.g., trapezius). In unipennate muscles (e.g., flexor pollicis longus), all fibers run obliquely in the same direction, while in bipennate muscles (e.g., rectus femoris), they converge on the aponeurosis, or intramuscular tendon, from two separate directions. Multipennate muscles (e.g., subscapularis) have several tendons. Spiral arrangements (e.g., pectoralis major) also occur.

Ultrasound (Fig. 1.13) reflects the anatomy of muscles: Muscle bundles and fascicles are hypoechoic, while the connective tissue structures are echogenic. In long-axis scans, fleshy, hypoechoic muscle bundles are separated by the parallel echogenic lines of fibroadipose septa or perimysium. In short-axis scans, the fibroadipose septa produce echogenic dots and dashes scattered uniformly between the muscle fascicles. The outer epimysium is echogenic in both long-axis and short-axis scans. Intramuscular tendons or aponeuroses are also echogenic. Vessels course through muscles. Muscles change shape and become hypoechoic on contraction, and the obliquity of the fibroadipose septa increases.[16]

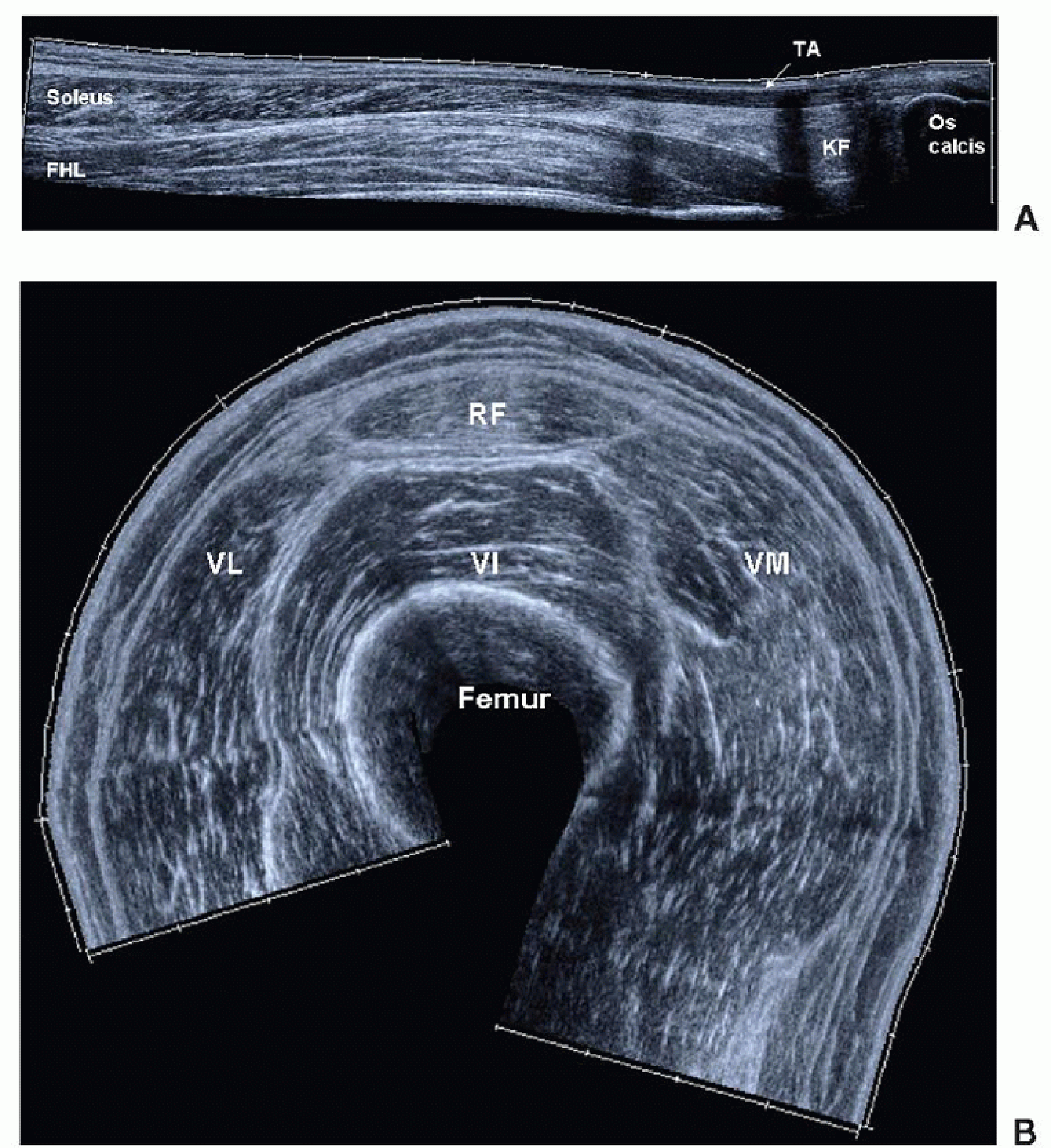

Figure 1.13. A: Longitudinal ultrasound scan of the lower calf showing the soleus and FHL muscles. The muscle boundaries are demarcated by echogenic fascia. Echogenic fibroadipose septa lie between hypoechoic muscle bundles and are oblique to the long axes of the muscles. FHL, flexor hallucis longus; KF, Kager's fat; TA, tendo Achilles. B: EFOV transverse scan of mid-thigh. Echogenic fascia outlines the muscle boundaries (of RF and VI, VM, and VL muscles). The fibroadipose septa are seen in cross section as echogenic dots and dashes. RF, rectus femoris; VL, vastus lateralis; VI, vastus intermedius; VM, vastus medialis. Muscles are anisotropic structures, and the appearance of a muscle will change with the angle of insonation. An individual muscle tends to be uniformly echogenic, but different muscles vary in echogenicity. Muscle echogenicity can be altered by pathology (e.g., fatty infiltration and infection cause increased echogenicity).

LIGAMENTS

Ligaments are very similar to tendons in structure, appearance, and acoustic properties. They consist of tightly bound parallel collagen bundles arranged hierarchically, although ligaments have slightly less collagen and more proteoglycan matrix than do tendons. Ligaments are covered by the vascular epiligament, which is indistinguishable from the ligament and merges with the periosteum where the ligament attaches to bone.[17] Ligaments are intra-articular (such as the cruciate ligaments at the knee),

capsular (such as the glenohumeral ligaments at the shoulder), or extra-articular and extracapsular (such as the lateral collateral ligament at the knee).[16]
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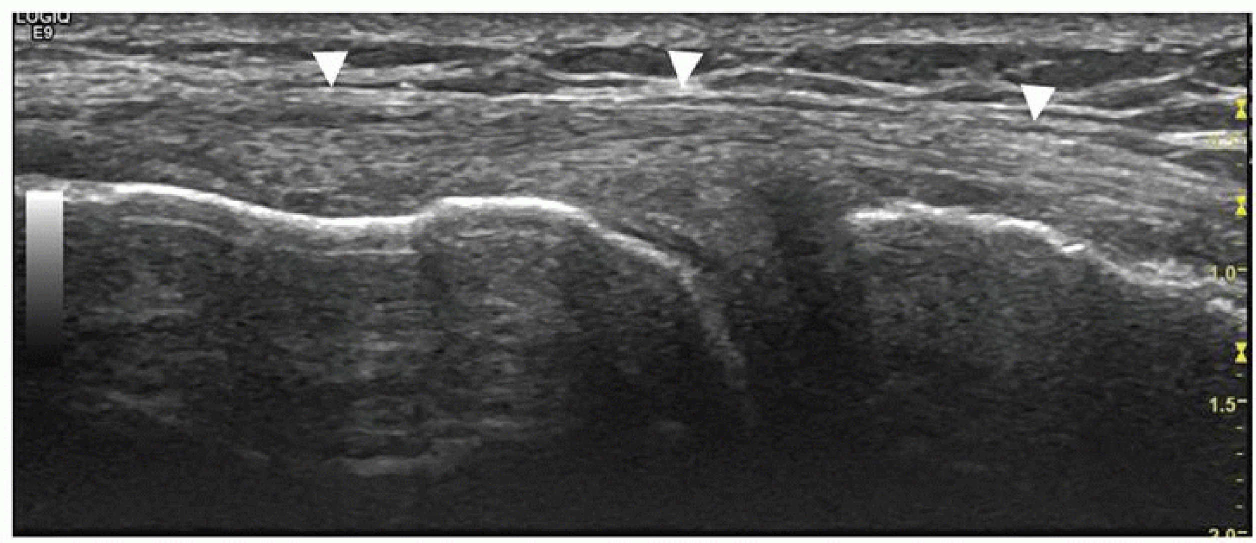

Figure 1.14. Long-axis scan of the medial collateral ligament of the knee (arrowheads).

Ultrasound (Fig. 1.14) shows echogenic, fibrillar structures, uniform in caliber and texture, running between bony joint margins and merging with the adjacent periosteum. Ligaments are echogenic and lamellar in long-axis scans and speckled in short-axis scans. The echogenic areas are the collagen bundles, and the hypoechoic areas are the supporting structures. Ligaments are anisotropic. Therefore, the incident sound beam should be at 90° to the ligament to demonstrate it adequately. This is best achieved if the ligament is stretched; for example, the calcaneofibular ligament is concave and not well seen with the ankle in neutral, but straightens and is well-demonstrated in dorsiflexion.

NERVES

Nerves are composed of multiple nerve fibers or axons, both myelinated and nonmyelinated, which are surrounded by the supporting connective tissue endoneurium. Nerve fibers are bundled together in fascicles, which are surrounded by connective tissue perineurium (Fig. 1.15). The nerve is enveloped by a sheath of connective tissue epineurium that may be focally thickened in fibro-osseous tunnels where the nerve is compressed or stretched. The connective tissue contains elastic fibers and vessels, but Doppler signal is not normally identified, and the Doppler signal in nerves is generally considered pathologic. Nerve caliber diminishes from proximal to distal as branches leave the nerve.

The ultrasound (Fig. 1.16) and histologic appearances of nerves are closely correlated.[18,19,20] The neural elements are hypoechoic or anechoic, whereas the supporting
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connective tissues are hyperechoic. In short-axis scans, nerves appear well-defined, round or oval, and speckled; the round hypoechoic fascicles are surrounded by echogenic connective tissue. In long-axis scans, nerves appear well-defined and tubular and contain alternating hyperechoic and hypoechoic lines. In contrast to tendons and ligaments, the hypoechoic components are much thicker and continuous in nerves. Loss of echogenicity and fibrillar pattern may occur where nerves are subject to pressure in fibro-osseous tunnels.

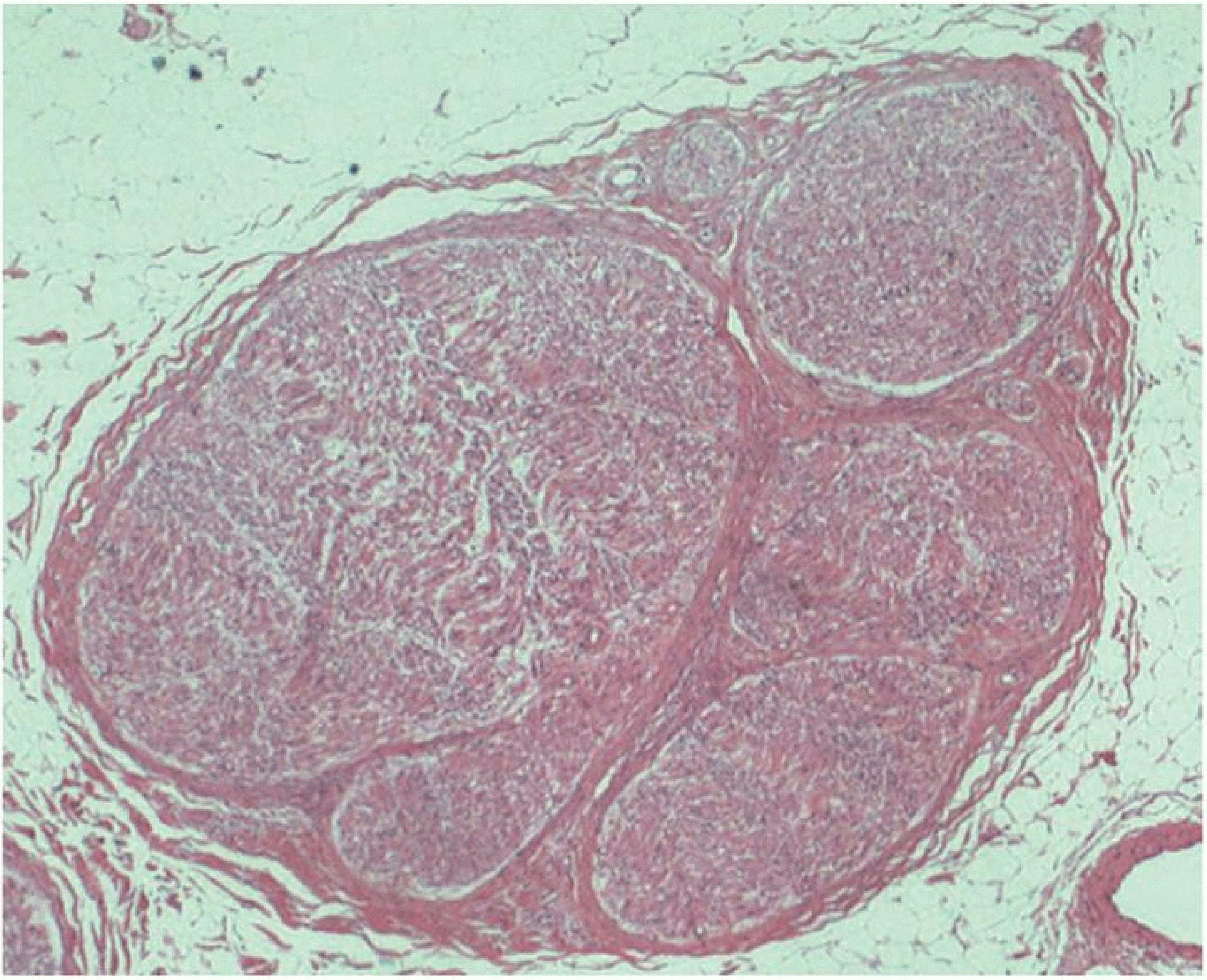

Figure 1.15. H&E axial section of peripheral nerve at high power. The plump nerve fascicles are surrounded by the connective tissue epineurium, and the whole nerve is enveloped by perineurium. (Courtesy of Professor D. Salter.)

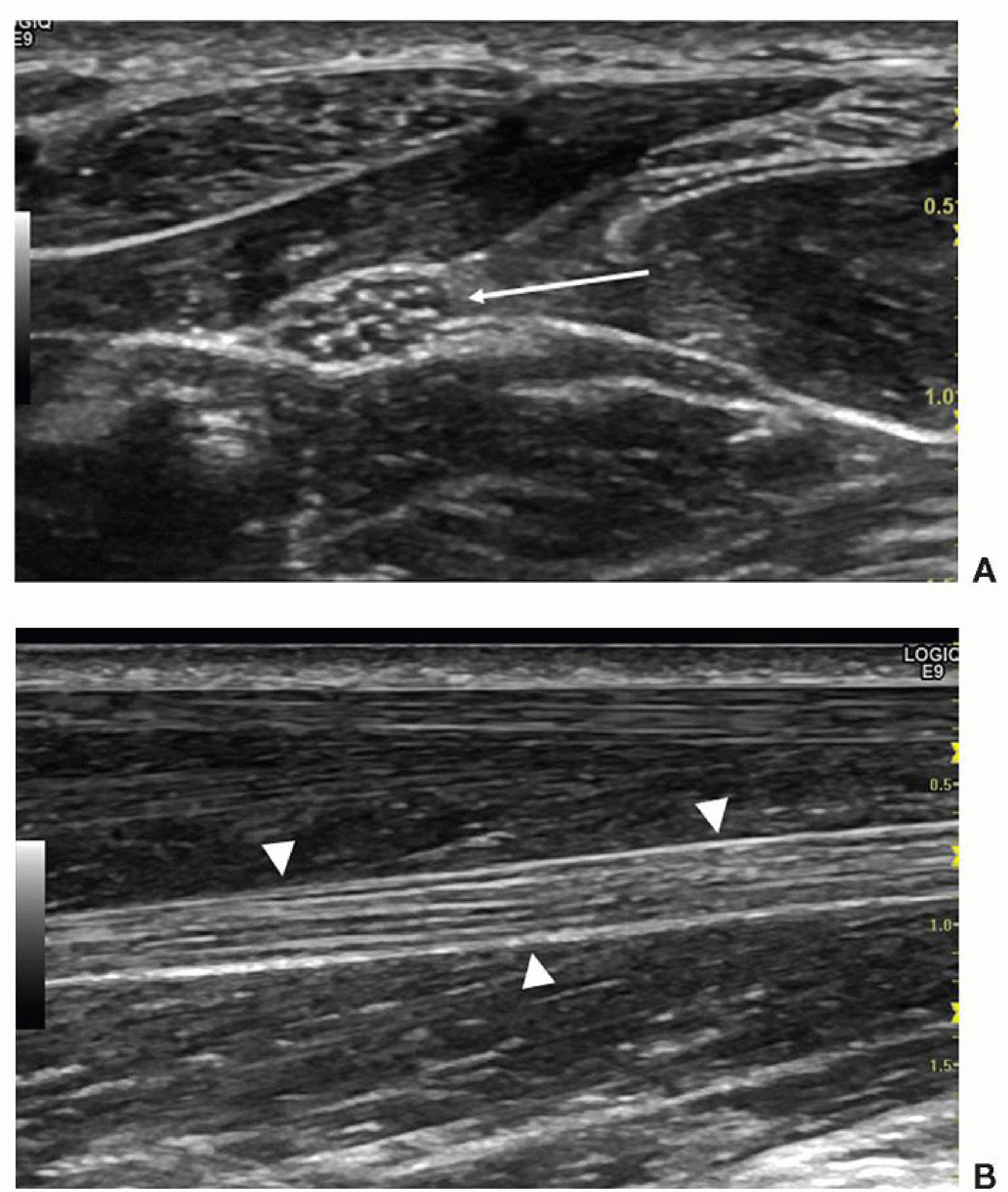

Figure 1.16. A: Short-axis scan of median nerve (arrow). The nerve is well-defined. The neural elements are hypoechoic, whereas the surrounding connective tissues are echogenic. B: Long-axis scan of median nerve (arrowheads). The nerve is of uniform thickness and texture. The neural elements are hypoechoic and continuous.

Nerves are easily examined on transverse images. Once the nerve is identified in an axial scan, an “elevator” technique may be employed, sweeping the transducer to and fro, proximally and distally, following the course of the nerve over quite long distances. Nerves are anisotropic structures, although not as strongly as tendons, and a nerve may appear hypoechoic if the incident sound beam is not perpendicular. Although nerves and tendons are not dissimilar in appearance, the distinction between them is easy. Anatomical position helps. Nerves are less echogenic and contain plumper hypoechoic areas than tendons. Nerves move, but not as much as tendons. This can be seen at the wrist when flexion and extension of the fingers produce much longer excursions in the flexor tendons than in the median nerve.

CARTILAGE

Normal hyaline or articular cartilage appears homogeneously hypoechoic on ultrasound (Fig. 1.17) and has a smooth superficial margin. A thin echogenic line may appear on the surface of the cartilage especially if fluid is present in the joint. The subchondral bone at the deep margin is echogenic and casts an acoustic shadow. Conventional ultrasound does not show the histological layers of cartilage. However, ultrasound can demonstrate cartilage ulcers, alterations in cartilage thickness, and increased echogenicity in and on the surface of the cartilage in crystal deposition disease.

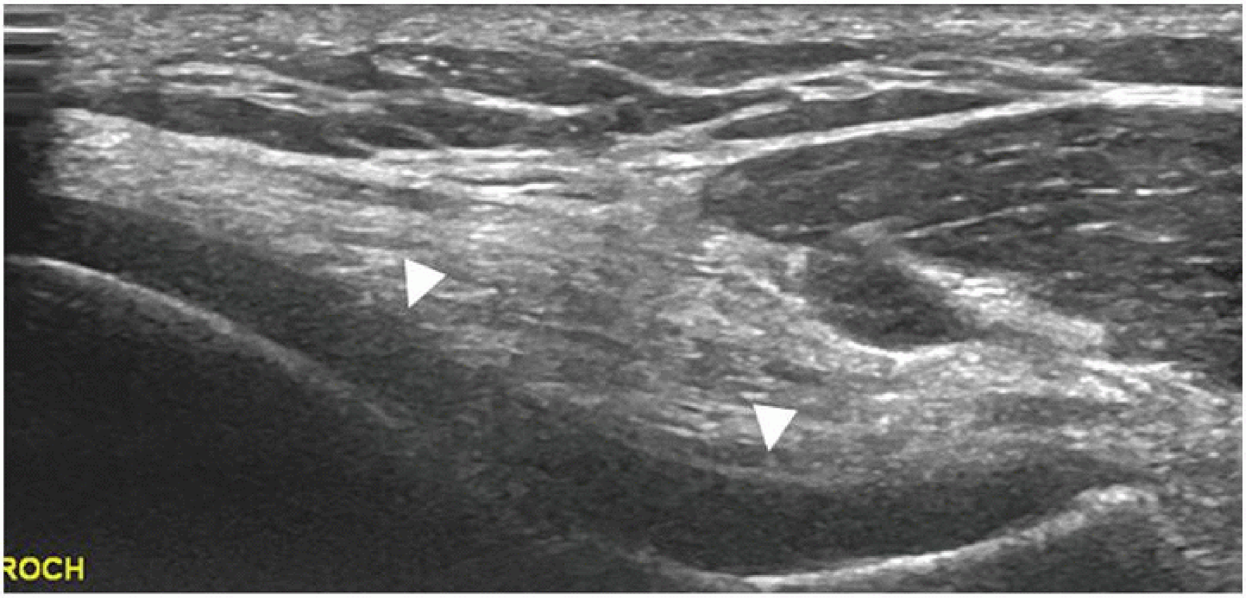

Figure 1.17. The articular cartilage (arrowheads) in the patellar sulcus is anechoic.

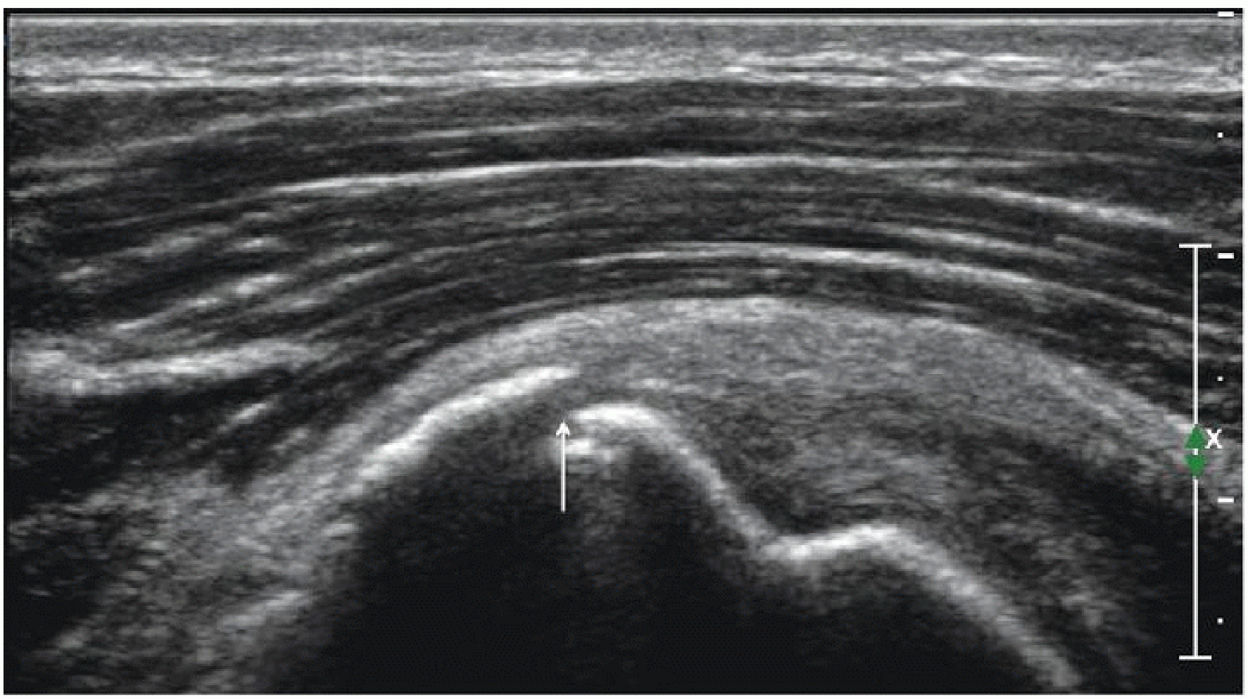

Figure 1.18. Sagittal oblique scan of shoulder showing a radiographically occult greater tuberosity fracture (arrow). The fracture fragment is elevated by <1 mm.

Fibrocartilage structures, such as the menisci at the knee or the glenoid labrum at the shoulder, are echogenic.

SYNOVIUM

Normal synovium is one to two cells thick, too thin to be seen with ultrasound.

JOINT CAPSULE

Joint capsules are thin and hyperechoic and merge with surrounding soft tissues.

BONE

Bone is highly echogenic and casts an acoustic shadow. Small depressions or pits in articular surfaces are frequently seen as normal variants and should be distinguished from erosions, which frequently show Doppler signal. Hyperostosis at tendon insertions is common and may be a manifestation of tendinosis. Periosteum is not usually distinguished separately from bone cortex, but ultrasound may show periosteal elevation early in infection, stress fracture, or tumor. Lytic tumors may destroy the cortex and extend into adjacent soft tissues. Fractures result in cortical defects, elevation, or depression that may not be visible in radiographs (Fig. 1.18). Ultrasound can also show echogenic areas typical of early osteogenesis or cystic changes that prevent bone healing following limb-lengthening surgery.

CONCLUSION

Ultrasound has a wide and increasing range of diagnostic and therapeutic roles in the musculoskeletal system. Careful attention to technique and good knowledge of anatomy and pathology are critical to success and develop with experience.
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