Some Strings Attached

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Objectives

• Describe the imaging appearance of normal and pathologic tendons on multiple imaging modalities.
• Describe common artifacts in tendon imaging.
• Describe some emerging techniques in tendon imaging.

Outline

I. Structural Components
II. Normal Imaging Appearance
III. Pathology
IV. Imaging Artifacts
V. Emerging Imaging Techniques
Structural Components

Collagen Biochemistry
- Type I collagen 66%
- Type III collagen 3%
- Soluble proteins 5%
- Cells 1%
- Proteoglycans 1%
- Other (lipid, insoluble protein) 24%

Cellular Composition
- 90-95% Tenoblasts and Tenocytes
- 5-10% Other (includes chondrocytes as well as endothelial, synovial and smooth muscle cells)

Extracellular Tendon Matrix
- Collagens
  - Mostly type I collagen
  - Collagen type II in cartilaginous zones, types III, IV, and V in vasculature, type X in mineralized fibrocartilage near entheses
- Proteoglycans, glycosaminoglycans (GAGs)
- Non-collagen proteins (Elastin and Glycoproteins)
- Lipids
- Inorganic components (ex. Calcium)
**Collagen Biochemistry**

**Tendon Microstructure**

**Tendon Histology**

**Variations**

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**Fibril**
- Consists of soluble tropocollagen molecules.

**Collagen Fibers**
- Consist of multiple fibrils oriented in multiple directions to improve strength in many different vectors.

**Subfascicle**
- (Primary Fiber Bundle)

**Fascicle**
- (Secondary Fiber Bundle)

**Tertiary Fiber Bundle**

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**Tendon**
There is marked variation from tendon-to-tendon and amongst various sites within a single tendon with regard to collagen composition and organization. These differences likely reflect the different functional demands of specific tendons. These differences may also effect the imaging appearance of these tendons as well as their susceptibility to various imaging artifacts.

The size of fiber bundles are proportional to the macroscopic size of the tendon. As seen above with increased size of fascicles associated with tendons which bear more weight.

The normal supraspinatus tendon seen above demonstrates increased heterogeneity within the structure of the tendon. This is seen in tendons which have developed a multilayered structure to better withstand increased shear and compressive loads.
Tendons on Radiographs

On radiographs, tendons appear as soft tissue density structures that are only visible when surrounded by or adjacent to fat. In such cases, tendons are apparent as a linear stripe of soft tissue density with uniform thickness, a sharply demarcated outer margin, clear uniform surrounding fat attenuation, and no adjacent soft tissue swelling.

Perturbation of this normal pattern is extremely nonspecific but could represent underlying tendon disruption in the correct clinical context.

A lateral view of the left knee demonstrates well defined patellar (arrow) and quadriceps tendons (arrowhead) with uniform thickness and normal surrounding soft tissues.

A lateral view of the left ankle shows a similar normal appearing Achilles tendon stripe (arrows) and adjacent Kager’s fat pad.
On CT, tendons appear as moderately hyperattenuating compared to adjacent muscle and fat and are best appreciated on soft tissue windows. Outer margins of normal tendons are smooth and sharply demarcated.

In long axis, these tendons are contours, band-like and uniform in thickness. In cross-section, tendons are round or oval with, typically, normal adjacent soft tissues.

As with radiographs, indirect signs of tendon injury are nonspecific though slackening of the tendon, an adjacent osseous avulsion fragment, or regional hemorrhage are slightly more reliable signs that can be detected on CT.
Normal Imaging Appearance

Radiography • Computed Tomography • Ultrasound • Magnetic Resonance

Tendons on Ultrasound

Most tendons are easily apparent and well evaluated by US due to their relatively superficial location and their fibrillar microstructure. Clusters of tiny fiber bundles invested in endotendineum create a highly sono-reflective pattern and characteristic US appearance. Color Doppler flow is not detectable within the substance of normal tendons.

Tendon sheaths and contained fluid and synovium are also evident on grayscale US and color Doppler interrogation.

Dynamic evaluation can also be helpful in confirming the integrity of a tendon, assessing its overall mobility, and identifying abnormal patterns of motion that may not be evident on other static imaging modalities.
Healthy tendons demonstrate low signal intensity on all conventional sequences. Collagen and water molecules are aligned in normal tendon tissue. Secondary to this, the dipole interactions between the molecules substantially shorten the T2 of normal tendon.

In rare cases, intrasubstance striations can result from interdigitating strips of fatty and loose connective tissue.

As with other modalities smooth and well-defined outer contours, uniform thickness, and normal surrounding soft tissues increase confidence in the presence of a normal tendon.

Typically tendons are hypoenhancing compared to surrounding soft tissue.
Tendon Pathology

**Trauma/Microtrauma**
- Tendinosis
- Rupture/Avulsion
- Laceration
- Muscle Strain

**Tenosynovitis**
- Inflammatory
- Infectious

**Deposition Disease**
- Calcific Tendonitis
- Gout
- Tendon Xanthoma

**Neoplasia**
- Giant Cell Tumor
- Fibroma
- Hemangioma
- Sarcoma

**Misc. Disorders**
- Triggering
- Bowstringing (Pulley Injury)
- Dislocation/Subluxation
- Entrapment
- Lipotendinosis
Ultrasound: Thickening of the ligament with a more heterogeneous echogenicity. Will also see a loss of the fibril structural appearance.

MRI: Increased signal intensity within the tendon with/without associated tendon thickening.

Tendinosis

Trauma/Microtrauma • Tenosynovitis • Deposition • Neoplasia • Misc
Tendon Pathology

Trauma/Microtrauma • Tenosynovitis • Deposition • Neoplasia • Misc

**Tendon Tears**

Tears result from failure of an already diseased tendon. Typically this represents the accumulation of gradual attritional loses of tendon integrity that, when overloaded, suddenly tears in a more discrete and profound manner.

These tears may be complete or partial and longitudinal split and entirely intra-substance varieties are commonly seen.

MRI and US are useful in identifying tendon tears, evaluating the underlying condition and quality of the tendon, localizing retracted ends, and characterizing the extent of tears. Often there are obvious reactive changes in the surrounding soft tissues.
Additional Tendon Tear Variations

**Longitudinal Split Tear Long Head of Biceps (arrow) -** The linear fluid cleft identifies the site of a longitudinal defect in the long head of biceps tendon that is otherwise normally situated within the bicipital groove.

**Partial Rupture of the Distal Biceps Tendon -** The arrows identify the distal portion of the biceps tendon as it inserts on the proximal radius. The proximal long head portion of the attachment is intact (arrow) while the more distal short head component is torn just proximal to the osseous site of attachment (arrowhead).

**Fluid signal surrounding the biceps tendon represents bicipitoradial bursitis.**

**Achilles Tendon Complete Tear -** The tear lies at the level of the critical zone (arrows) 5-7 cm proximal to the calcaneal insertion. Note the marked fraying and thickening of the underlying tendon suggesting pre-existing tendinopathy. Fluid and hematoma fill the tendinous gap.
**Tendon Avulsion**

An avulsion of the tendon from its bony attachments is a frequently encountered injury at the apophyses of adolescents nearing skeletal maturity as well as in adults with underlying tendinopathy, poorly mineralized bone, or sudden harsh eccentric loading injuries.

On imaging identification of a tendinous avulsion injury and qualitative assessment of the condition of the underlying tendon are keys to evaluation.

Avulsion injuries commonly include an osseous component and are, therefore, directly visible on radiographs and CT.

Right Hamstrings Tendon Avulsion – There is complete avulsion of the right conjoined tendon from its proximal attachment on the ischial tuberosity (arrow). The torn tendon is retracted and slackened indicated by the wavy and meandering course. Fluid and hematoma surround the avulsed tendon.
Laceration

Tendon lacerations are the result of direct penetrating trauma most commonly with primary injury to the fibers of a previously normal tendon. As a result, laceration appear similar to tears in that the tendon is separated and possibly retracted. Unlike tears, the lacerated tendon is usually normal in thickness and texture with a sharply demarcated linear defect.

Dynamic assessment on ultrasound is helpful in establishing whether laceration is complete or partial.

Deep Flexor Tendon Laceration - There is complete transection of the deep flexor tendon. The distal stump sharply and abruptly ends (arrow) and fluid is evident in the tendon gap (asterisk). The cine shows passive manipulation of the DIP and motion of the distal stump as well as its lack of connection to the proximal tendon elements.

Extensor Pollicis Brevis Laceration - There is complete transection of the EPB at the level of a known laceration (skin marker). Note the transection and retraction of the tendon (arrows) as well as the otherwise normal appearance of the tendon. This is in sharp contrast to the attritional tears on the prior slides.
Muscle Strain

When subjected to an overwhelming eccentric load, the myotendinous unit most commonly fails at the site where the muscle fascicles joint the tendon. This injury, also known as a muscle strain, may result in a stretch injury (without tearing) or varying degrees of tearing of muscle fibers from tendon.

Secondary signs include edema and contusion in the surrounding muscle in addition to fascial edema, fluid, and focal hematoma within and surrounding the stretched or torn fibers.

MRI and ultrasound are effective in demonstrating pertinent findings in these patients.
Tendon Pathology

Aseptic Tenosynovitis

Aseptic tenosynovitis results from mechanical irritation of a tendon or tendon sheath, as a reactive phenomenon secondary to adjacent tendon disease, or as a result of an underlying inflammatory condition.

Tenosynovitis includes fluid accumulation within the tendon sheath as well as varying degrees of synovial hypertrophy and hyperemia. Adjacent osseous or soft tissue inflammation may result.

Aseptic and septic tenosynovitis may be indistinguishable on imaging. Thus, the patient’s clinical history and objective data must be carefully considered.
Tendon Pathology

Septic Tenosynovitis

Septic tenosynovitis can result from direct seeding of the tendon sheath from penetrating trauma or hematogenous seeding of the synovium in patients with bloodborne pathogens.

Pyogenic tenosynovitis results in the most exuberant inflammation, usually with abundant tendon sheath fluid and varying amounts of associated synovitis. Atypical infections such as mycobacterial and fungal species may result in a preponderance of inflamed synovium or soft tissue debris.

Ultrasound or MRI without and with contrast are critical to verify the presence of drainable fluid prior to attempted aspiration.

Staph Aureus Flexor Tenosynovitis – Enhancement and edema surround the flexor tendon sheath. The sheath is distended with enhancing hypertrophic synovium (asterisk). A small amount of nonenhancement within the tendon sheath likely represents purulent material (arrowhead) and an erosion is evident in the base of the proximal phalanx (arrow).

Mycobacterial Tenosynovitis – Enhancing soft tissue fills the common flexor tendon sheath just proximal to the carpal tunnel (arrow). The tenosynovitis here predominantly consists of proliferative soft tissue with only minimal fluid (arrowhead) as is typical with mycobacterial infections.
Deposition Diseases

Systemic inflammatory and metabolic disease may result in deposition of crystals or soft tissue within the substance of tendons or within the synovium of surrounding tendon sheaths. These deposition disease typically result in patterns of tendinosis that are unusual in their marked severity, presence of adjacent soft tissue or osseous inflammation, or in macroscopic deposits within the tendon that are readily apparent on imaging.

Xanthomatous Tendinosis of the Achilles Tendon – Note the marked thickening of the Achilles tendon with punctate flecks of high signal (arrows) representing sites of deposition.

Gouty Tendinopathy – Thickening and increased signal within the substance of the Achilles tendon (arrows) results from urate deposition and associated tophaceous inflammation. Also note the erosion in the calcaneal tuberosity (arrowhead).
Calcific tendonitis results from hydroxyapatite (HA) deposition within the substance of tendons. Rupture of this HA aggregation results in an exuberant inflammatory response and associated pain symptoms. These deposits are readily apparent on imaging. Imaging is also helpful for guidance during percutaneous lavage of HA deposits.

Calcific Tendonitis of the Rotator Cuff – Radiopaque hydroxyapatite deposition (arrows) is noted in the region of the infraspinatus, on this AP internal rotation radiograph of the left shoulder.

Calcific Tendonitis of the Rotator Cuff – In this different patient, HA deposition appears as a low signal amorphous mass in the rotator cuff tendon on all sequences (arrows). Note surrounding reactive fluid in the subacromial subdeltoid bursal (arrowhead).

Calcific Tendonitis of the Rotator Cuff – Echogenic shadowing material (arrow) within the rotator cuff tendon is apparent in this patient who subsequently underwent percutaneous lavage under US guidance (cine).
Neoplasms

Several tumors are commonly found within the tendon or tendon sheath. The vast majority of these are benign though the imaging appearance can be somewhat nonspecific.

Imaging is helpful in demonstrating the relationship of the mass to the tendon and tendon sheath. Ultrasound is particularly useful in assessing for mobility restriction of the associated tendon. Alternatively, contrast enhanced MRI is more likely to identify evidence of periosteal, osseous, or surrounding soft tissue infiltration which would suggest a more ominous tumor histology.

Giant Cell Tumor of the Tendon Sheath – Echogenic mass (arrow) within the flexor tendon sheath of the long finger. The mass shows color Doppler flow and is clearly within the tendon sheath (arrow).

Giant Cell Tumor of the Tendon Sheath of the Fifth Toe on MRI – location within the tendon sheaths can be difficult to document on MRI when lesions occur in small parts.

Plantar Fibroma – Anechoic mass adjacent to the plantar fascia show color Doppler Flow. Its location, echotexture and fusiform appearance are typical for fibromas.
Tendon Pathology

Trauma/Microtrauma • Tenosynovitis • Deposition • Neoplasia • Misc

- Tenosynovitis
- Deposition
- Neoplasia
- Misc

Tendon Sheath Venous Malformation (Hemangioma) – Demonstrates a phlebolith on the lateral radiograph (arrow). MRI shows a heterogeneously enhancing mass that splays the flexor tendons and results in a palpable lump along the volar aspect of the wrist.

Myxoinflammatory Fibroblastic Sarcoma – Malignant lesions, though rare, do occur in association with tendons. This lesion completely encases the extensor apparatus (arrow) and causes reactive marrow edema in the underlying middle phalangeal shaft.
The study above demonstrates rupture of the A2 and A3 pulleys with resulting bowstringing of the flexor tendons (arrow). A2 is the most commonly injured pulley.

Trigger Finger – Triggering is noted on the dynamic cine image (top) as the patient attempts to extend a flexed digit. The thickened tendon (bracket) is hung up as it passes from proximal to distal through thickened A2 pulley (arrow).
Tendon Pathology

Subluxation

Tendons can sublux or dislocate from their sheath or normal location when there is disruption of adjacent anchors or retinacula. In addition, when two tendons occupy a single sheath abnormal rotation or shifting of the tendons can occur resulting in so-called intra-sheath subluxation. Often, these abnormalities are only apparent during provocative maneuvers during a dynamic ultrasound examination.

Lipotendinosis and Tendon Entrapment

Tendon assessment is an important part of the CT evaluation of traumatized extremities. Soft tissue windows with a smooth reconstruction algorithm are useful for this purpose. Layering fat within a tendon sheath effusion – so-called lipotendinosis – is an indirect sign of an adjacent fracture. In addition, tendons may become entrapped between fracture fragments. If undetected, these incarcerated tendons may lead to inadequate reduction, loss of function, or persistent pain symptoms.
Anisotropy is an ultrasound artifact that occurs when the beam is focused on a structure composed of and organized linearly striated microstructure such as tendons and ligaments. There is maximum return of sound waves when the beam is perpendicular to tendon. When the incident beam strikes the target at a non-perpendicular angle, there is reflection of some or all of the returning sound beam away from the transducer. This causes normal tendon to appear artifactually hypoechoic or anechoic and can lead to false diagnoses including tears or tendinosis.

Anisotropy is corrected by rocking or tilting the probe relative to the tendon of interest, thereby changing the angle of insonation.
Magic Angle Phenomenon

Magic angle phenomenon is an MRI artifact that commonly occurs on sequences with a short TE. This artifact, seen in areas of tightly bound collagen oriented at ~55 degrees from the main magnetic field ($B_0$), results in artfictually increased intra-substance signal and can easily be mistaken for tendinosis.

Clues to the presence of this artifact are the orientation of tendon fibers relative to $B_0$, decrease in signal on longer TE sequences, and lack of associated findings of tendinosis including normal outer contours and thickness of the tendon of interest.
T2 Mapping

This technique utilizes ultrashort echo times and allows visualization of T2 relaxation times mapped to anatomic regions of interest. Using this method, areas with relatively small amounts of water protons and organized parallel orientation of collagen fibers will result in shorter T2 relaxation times.

Foci within diseased and inflamed tendons will generally accumulate water. The underlying disease process often will disrupt the parallel and organized arrangement of collagen fibers. Both of these factors will result in T2 prolongation.

Has shown promise in evaluation of tendon healing after injury as well as determining the extent of partial tendon tears.
Shearwave soloelastography

Ultrasound technique in which a focused acoustic shear wave is imparted into the soft tissues of interest. The propagation of this wave is then measured generating a map of the shear wave transmission speed (shear modulus) of the tissues.

Softer less elastic soft tissues result in a smaller shear modulus while more rigid tissues propagate the shear waves more quickly. The normal parallel fibrillar longitudinal organization of tendons results in a relatively high shear modulus. Fiber disruption, edema, and disorganized fibrinous material within diseased tendons results in a decrease in the shear modulus.

This method has been shown to accurately assess the functional integrity of tendons.
References