Tendon and ligament: basic science, injury and repair

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Abstract

Tendons and ligaments share many similar features in structure and function. They are load-bearing structures, with tendons transmitting forces from muscle to bone and ligaments transmitting forces from bone to bone. They have specialized zones (at the myotendinous junction for tendons and at the insertion to bone for both), which manage stress loading at these specific areas. They both have a hierarchical physical structure, mainly composed of type I collagen, and both elongate with a typical stress–strain pattern. Injury to both tendons and ligaments is followed by the same pattern of healing phases and can take up to two years to remodel back to a normal structure. The major cell type is the tenocyte (specialised fibroblast) in both tendons and ligaments. They are found within an extracellular matrix. Tendinopathy causes pain and swelling within tendons. Inflammatory cells and myxoid degeneration are characteristic features, with angiogenesis and small fibre nerve growth also seen. The causes are multifactorial and brought together by several hypotheses.

Keywords anatomy; basic science; injury; ligament; repair; tendinopathy; tendon

Tendon and ligament anatomy

There are specialized areas of tendon and ligament at their attachments. The attachment of tendons and ligaments to bone is termed the enthesis, whilst the attachment of tendon to muscle is termed the myotendinous junction.

There are two types of enthesis; fibrous and fibrocartilaginous. In a fibrous enthesis the tendon or ligament attaches directly to bone (such as the deltoid tendon attachment to the humerus); in a fibrocartilaginous enthesis, there are transitional zones – uncalcified fibrocartilage, calcified fibrocartilage and bone (such as is seen in the Achilles tendon). The enthesis dissipates stress at the junction between the relatively soft tendon and the hard bone and thereby reduces peak stress. The myotendinous junction is a highly specialised region where collagen fibrils are inserted deep into recesses formed by myocytes. This arrangement allows transmission of tension forces across the tendon and muscle interface.[1]

Tendons are composed mainly of water and type 1 (85%) collagen, arranged in hierarchical levels of complexity (Figure 1).

Other types of collagen are present at the enthesis, as well around blood vessels. Around major tendon bundles, as well as around the whole tendon itself, there is a thin reticular connective tissue called the epitenon. This transmits lymphatic and blood vessels as well as nerve fibres. Tendon sheaths are found where tendons bend sharply around bone (such as the tibialis posterior around the medial malleolus). The sheath contains synovial fluid to aid movement and reduce friction. The Achilles and patellar tendons have a 'false sheaths' termed the paratenon, which is a condensation of surrounding connective tissue.[2] The functions of this are to allow vascularization of the epitenon, reduce friction and facilitate free movement.

Tendons come in various shapes and sizes. Some have shallow groves on their surface and others are divided into slips (e.g. the obturator internus). The largest tendon is the Achilles tendon. As a general rule, extensor tendons are flatter than flexor tendons, which tend to be round or oval. The extensor tendons, by being flat and having fibrous interconnections, reduce the risk of subluxation as they pass over convex structures such as the metacarpophalangeal and interphalangeal joints when flexing the fingers. The longest tendons are those of the hands and feet and, as well as having an effect on movement, have biomechanical properties related to their length and course that need to be taken into account. Strategic placement of tendons means they acts as effective pulleys - an example would the Achilles tendon using the superior tuberosity of the calcaneus as a pulley to maximize the change in the tendon moment arm as the foot moves from dorsiflexion and plantar flexion.[2]

The extracellular matrix (ECM) surrounds collagen and tendon cells. It is composed of a mixture of proteoglycans, glycoproteins, elastin and various other inorganic molecules (such as calcium, copper and manganese). The ECM binds together fibrils of the collagen fibres in a parallel alignment to allow gliding of the fibrils on movement and diffusion of water soluble molecules.[1]

The major cell type in tendons is the tenocyte. These are specialized fibroblasts, arranged longitudinally around collagen fibrils and are responsible for the secretion of the ECM. Tendons and tendon cells respond to mechanical load. The tenocytes upregulate collagen synthesis when subjected to tensional forces; this occurs through a complex communication system involving gap junctions and neighbouring cells.[2]

As a general rule, a tendon has a vascular supply which is quantitatively considerably less than that of muscle (which gives it its characteristic white appearance).[2] The blood supply is from three different sites: the myotendinous junction; the osteotendinous junction and the tendon sheath. The main supply comes from the tendon sheath, from where a rich vascular network penetrates deep into the tendon. The muscle supplies the tendon with vascular branches in its proximal portion. The osteotendinous junction contributes a limited blood supply, being restricted to the insertion site itself.[1] The vessels are small and thin walled; blood flow varies depending on exercise levels and can be captured on Doppler ultrasound at varying degrees of loading. Tendons can have areas of poor vascularization. These are particularly seen where tendons cross bone (e.g. in the peroneus longus and tibialis posterior tendons). Angiogenesis seems to be restrained at these sites due to inhibitory factors being secreted from cells (such as endostatin – an inhibitor of angiogenesis).[2]

The nerve supply to tendons is mainly sensory. Nerve branches originate from cutaneous, muscular and peritendinous nerves, mainly terminating in the paratenon/tendon sheath.

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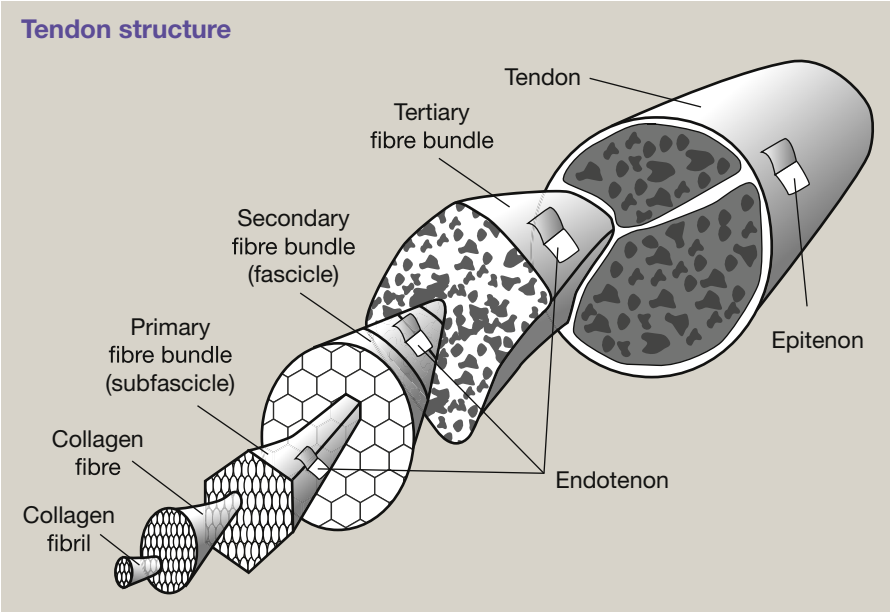

Figure 1 Schematic diagram of tendon in cross-section. Collagen fibrils are bundled into fascicles containing vessels, lymphatics and nerves. The fascicles are grouped together, surrounded by epitenon, and form the gross structure of the tendon, which is further enclosed by paratenon.[3]

Some nerve fibres enter the tendon itself and follow the vascular network into the body of the tendon. These nerves act as Golgi-type organs, mainly located at the myotendinous junction. They detect changes in pressure and pain (with associated neurotransmitters glutamate, acetylcholine and substance P).[1] Nerves can grow into damaged or ruptured tendons in association with blood vessels; this tends to correlate with areas of tendon pain. There is a degree of neuronal plasticity whereby tendon loading can cause involution of the initial ingrowth of nerves into a damaged tendon.[2]

Tendons can elastically recoil after a stretching force is removed. This is functionally related to 'crimps' within the tendon fibrils. When stretched, a tendon reduces the number of crimp zones; recoil of tendon fibrils then occurs on removing the stretch, generating force.[2]

There are various anatomically specialized zones in relation to tendons. Around joint capsules, tendons tend to attach beyond the joint and can blend to the joint capsule, resulting in a common attachment (e.g. as seen in the rotator cuff of the shoulder). Fascial connections of tendons are also seen, especially around bone. Stress dissipation occurs at the enthesis as a result (e.g. as seen at the insertion of the biceps brachii tendon to the bicipital aponeurosis and radial tuberosity). Bursae are closely related to tendons at insertion points e.g. the retrocalcaneal bursa. Fat pads are located close to tendons. Large fat pads are seen adjacent to the Achilles and patellar tendons. They are richly vascularized and innervated. The infrapatellar fat pad (Hoffa's fat pad) has finger-like extensions of fat projecting into the patellar tendon whilst Kager's fat pad moves in and out the of the retrocalcaneal bursa with ankle plantar and dorsiflexion.

Ligaments

Ligaments are short fibrous bands connecting bone or supporting soft tissue structures. They are hierarchically organized and composed mainly of type I collagen fibres (70% dry weight) (Figure 1). They also contain small amounts of elastin, though proportionally more than tendons, and also display a crimp pattern which allows elongation in relation to load. At the insertion into bone, the ligament becomes more flexible and can have either a direct or indirect insertion. Direct insertions are associated with long ligaments inserting into small areas of bone. They comprise of four distinct zones: ligament; unmineralized fibrocartilage; mineralized fibrocartilage and bone. An example is the femoral origin of the anterior cruciate ligament.

Indirect insertions are generally found on short ligaments that insert into a larger area. They connect to bone via Sharpey's fibres — collagen fibres continuous from ligament to bone forming a very strong attachment. An example would be the tibial attachment of the medial collateral ligament.

On application of load, the ligament fibres initially straighten their crimp pattern under relatively small forces (toe phase). As fibrils become uncrimped, the ligament stiffens and then absorbs considerably greater energy from applied force, elongating in a linear fashion until failure occurs (called the yield phase) (Figure 2).[4]

Blood supply to ligaments is via diffusion from synovium and from the extracellular space around the periphery of tendons; in the central part of tendon, there is a complex of vessels passing longitudinally through the ligament.[5] Its importance is for nutrition of the central part of the tendon. Knee ligaments have been found to have proprioceptive and nociceptive nerve endings. The cruciate ligaments accommodate morphologically different sensory nerve endings (Ruffini endings, Pacinian corpuscles, Golgi tendon organ-like endings, and free nerve endings) with different capabilities, providing the central nervous system with information not only about noxious and chemical events but also about characteristics of movements and position-related stretches of these ligaments.[6]

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