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Tendon Structure and Classification

Murat Kaya, Nazım Karahan and Barış Yılmaz

Abstract

Tendons play an important role in the movement by transmitting the contraction force produced by the muscles to the bone they hold, and their contribution to stability to the joints is extremely important. Tendons generally have a very complex structure; they are actually heavily composed of connective tissue and have a small number of cells and rich extracellular matrix, similar to other connective tissue structures. The tendons are mainly composed of three parts: the tendon itself, the muscle-tendon junction, and the bone insertion. The simplest classification for the tendons classified according to their shapes, settlements, and anatomical structures is the classification made according to their shapes. Tendons can be classified in many ways according to their location, but the most logical one is the tendon classification in relation to the functions they see as intraarticular and extraarticular. According to their anatomy, the tendons can also be classified as sheathed or synovial-coated or unsealed or paratenon-coated. According to their functions, tendons can be classified as energy storage or positional tendons.

Keywords: tendon, tendon structure, tendon classification, fascicle, endotenon, epitenon, paratenon, collagen fibrils

1. Introduction

Tendons are dense fibrous tissues that bind the muscles to the bone. They play an important role in the movement by transmitting the contraction force produced by the muscles to the bone they hold. At the same time, their contribution to stability to the joints is extremely important. Although they differ in shape and size depending on the location, the common feature of all is that they can attach to a bone and transmit large loads without deforming them. Although they are structurally sound as they can withstand very high powers due to their function, degeneration and various damages caused by aging can result in loss of muscle strength [1–3].

Although tendons generally have a very complex structure, they are actually heavily composed of connective tissue and have a small number of cells and rich extracellular matrix, similar to other connective tissue structures. In terms of total tissue volume, while the cellular structure constitutes approximately 20% of total tissue volume, the remaining cells form 80% of the extracellular matrix. As a result of these factors, the cellular structure is mainly 60–85% collagen, 0.2% proteoglycans such as inorganic substances, 2% elastin, and 4.5% other proteins, while the matrix is composed of 55–70% water and the rest of the extracellular matrix consists of proteoglycans [4, 5].

2. Morphology, histology, microanatomy, and cell biology

When we look at the structure, tendons are composed of collagen fibrils; they consist of fiber bundles, fascicles, and finally the tendon structure, also known as a group of fascicles. In conclusion, tendons are composed of multiple bundles, fibroblast, and dense linear collagen fibrils, which form the macroscopic structure of tendons and give the appearance of fibrous. In general, connective tissue surrounding the tendons allows some friction. In this way, the ligament around many tendons has a mesotendon that sticks to the tissue and encircles it. This structure also allows the tendon to flush. The connective tissue of low density surrounds tendon fascicles, which is called the endotendon. The fact that tendon fascicles are surrounded by endotendon actually allows tendon bundles to make small slip motion. Endotendon tissue continues in the form of an epitendon covering the tendon surface. When the tendon joins with the muscle, it continues as epimysium in the epitendon muscle. At this point, the muscle-tendon junction must transmit the muscle contraction to the tendon exactly. The tendon adhesion of the muscle occurs when the fibrous tissue layers of the muscle enter the collagen fibers of the tendon into the collagen fibers. In a study conducted by electron microscopy, the position of the muscle cells and tendons is like the fingers of two hands that are locked together. Collagen fibers do not enter the muscle cells, but they bind tightly under the basal membrane. The movement of a normal tendon, the transfer of muscle power for the entire movement of the joints, and the feeding of tendons depend on peritendinous connective tissue. This structure is called the peritendon. These structures form the sheaths, which are very finely organized structures from the loose connective tissue [3, 6].

The cell and matrix compositions of tendons are similar to ligaments and capsules and contain only small differences. In fact, they all have the same cell type and similar vascular and innervation sources. Collagen, elastin, proteoglycan, and noncollagenous proteins combine to form the macromolecular framework of dense fibrous tissues. In all of them, the dominant cell type is fibroblasts. In particular, the cells within the tendons are specific fibroblasts called tenocytes. The main role of these cells is to control cell metabolism (production and degradation of extracellular matrix) and to react to mechanical stimuli applied to the tendon. Especially tensile loads act as a signal for collagen production, and this process is called mechanical transmission. These cells stretch along collagen fibrils in the form of longitudinal arrays where they have a tensile load [7, 8].

The extracellular matrix of tendons is largely composed of collagen fiber network and less proteoglycans, elastin, and other proteins. The main task of these components is to maintain the structure of the tendon and facilitate the biomechanical reaction of the tissue against mechanical loads. An important component of extracellular matrix, proteoglycans, forms less than 1% of the dry weight [9].

The main substance in tendons and ligaments is basically about 0.2% inorganic substances and about 4.5% other proteins. The most effective of inorganic substances are proteoglycans. In addition to prostaglandins with a small amount in the main substance, the most common biomechanical properties are the decorin and cartilage oligomeric matrix protein (COMP) [10].

The protein clusters in the structure are connected to a large portion of the extracellular matrix of tendons, making the matrix a structure similar to the gel. Thanks to this compound, collagen provides spaces and lubrication between microfibrils, while cement-like material also makes the collagen structure of tendons stable and contributes to the resistance of the tissue [3, 11, 12].

The collagen in the tendon structure is found as the main molecule of dense fibrous tissue and forms approximately 70% of dry weight. When examined as

collagen type, it is largely composed of Type I (60%) and other types, namely, Types III, IV, V, and VI. Collagen Type-I fibers are capable of withstanding large tensile loads and are found in abundance from the tendon structure, allowing a certain degree of stretch and mechanical deformations of the tendons [13].

According to today's information, synthesis of collagen in connective tissue begins in the cell membrane of fibroblasts. This synthesis process is similar to that of all connective tissue, although it may differ slightly depending on the type of complex collagen. Therefore, tendons, which contain Type-I collagen, have a process of synthesis and degradation similar to those in the ligaments and bones. From here, with a more detailed look, we can say that synthesizing for collagens in tendon structure begins in the cell membrane of the tenocytes. "Integrin" molecules have an important role in collagen production because they are sensitive to the transmission of mechanical charge from inside the cell to the outside or vice versa. In other words, the integrins are like force sensors and, in particular, detect cell withdrawal, allowing the cell to react to these mechanical stimuli. At the same time, various growth factors contribute to the regulation of this mechanical conversion process [14].

Cross-linkages form between collagen molecules, which are very important for clustering at the fibril level. The cross-links between the fibrils are more complex. And this cross-link structure of collagen fibrils provides the strength of the tissue and thus ensures that it performs the task of the tissue under mechanical loads. In the newly formed collagen, these cross bonds are less in number, soluble in salt or acid solution, and can easily break with heat. As collagen matures, the number of cross bonds that can dissolve and break down decreases and decreases to the minimum level. As a result, organized collagen molecules form microfibril, sub-fibrils, and fibrils. The fibrils are also clustered to form collagen fibers, collagen clusters or fascicles, and the tendon. Tenocytes are arranged between these fascicles and aligned in the direction of the mechanical load [10].

In the cellular structures of tendons, as mentioned above, there is much less amount of elastin than collagen, because the mechanical properties of the tendons depend not only on the architecture and properties of collagen fibers but also on the extent to which this structure contains elastin. However, in tendons, elastin proteins, which usually constitute about 2% of the dry weight, can be up to 70% in elastic bonds such as nuchal ligament and ligamentum flavum. Because the bond has a special function and the nerve roots of the spine, mechanical stresses, stresses, etc. provide stability to the spine [9, 15].

Blood circulation in tendons is very important, because the current circulation of blood directly affects metabolic activity especially during healing. However, blood circulation in tendons is not as rich as muscles and bones, and it accounts for only 1–2% of the extracellular matrix. Therefore, they have a white color when compared to the muscles with a much higher blood vessel density. However, there are a few factors such as the anatomical location, structure, previously damaged condition, and physical activity level of tendons that contribute to blood supply besides the small amount of vascular structure. There are studies that show that blood flow increases in tendons in the case of increasing physical activity in the literature. There are more vascular tendons due to their anatomical position or shape and function. The flushing of tendons is primarily derived from the synovium at the point of attachment to the bone or paratenon. However, some tendons feed on the tendon like the Achilles tendon and the paratenon structure, and some tendons are fed by a true synovial sheath they are surrounded. Bone and tendon adhesion is a layer of cartilage where blood flow cannot pass directly from the bone-tendon compound. Instead, they make anastomosis with the veins on the periosteum and make indirect connections [16].

In contrast, tendons have a very rich neural network and are often innervated from the muscles in which they are associated or from the local cuticle nerves. However, experimental studies on humans and animals have shown that tendons have different characteristics of nerve endings and mechanoreceptors. They play an important role especially for proprioception (position perception) and nociception (pain perception) in joints. In fact, studies have shown that there is internal growth in the nervous and vascular systems during the healing of tendon, which causes chronic pain. Internal growth of the vein is an indicator of the tendon trying to heal, but because of this growth, nerves may feel pain in areas without pain before. This means that the nerves play an important role not only in the proprioception but also in the nociception. Nerve endings are located below the muscle-tendon junction and typically in the bone-tendon junction in the form of Golgi organs, Pacini bodies, and Ruffini endings. Of these, the Golgi organs are only mechanically stimulated by pressure and compression, so that they receive information from the power produced by the muscle. Pacinian bodies are rapidly adaptive mechanoreceptors due to nerve endings with a highly sensitive capsular end to deformation, thus dynamically responding to deformation, but are insensitive to constant or stable changes. Ruffini termination results from multiple, thin capsule-tipped, and single axons and has slowly adapting mechanoreceptors and thus continues to receive information until a constant warning level is stimulated during deformation [17].

The tendons are surrounded by loose, porous connective tissue, which is called paratenon. A complex structure, paratenon, protects the tendon and allows shifting tendon cover format. Tendon sheaths consist of two continuous layers: parietal on the outside and visceral on the inside. The visceral layer is surrounded by synovial cells and produces synovial fluid. In some tendons, the tendon sheath extends along the tendon, while in others it is found only in the binding parts of the bone.

The parietal synovial layer is found only under the paratenon in the body regions where tendons are exposed to high friction. This is called the epitenon and surrounds the fascicles. In this case, epitenon's synovial cells produce lubricating liquid. In regions where friction is less, tendon is surrounded by paratenon only. At the tendon-bone junction, the collagen fibers of endotenon continue into the bone and become a peritendon.

The regions of the tendon bonding to the bone consist of a dense connective tissue, which is able to adhere to the hard bone from the dense connective tissue and is resistant to movement and damage. Although they occupy a small area in size, the areas of adhesion to the bone have a complex structure that is much different from that of the tendon itself. According to the size of the load they carry, they show a different proportion of collagen bundles [18].

The tendons cling to the bone is a complex event; collagen fibers mix into fibrocartilage, mineralize, and then merge with the bone. "Sharpey's penetrating fibers" continue with the external lamellar structure of the bone of tendon fibrosis along the period that is important for the entry of the tendon called enthesis. Sticking to the bone is done in two ways. In the first type, the adhesion of many collagen fibers is direct to the bone, while the second type indirectly adheres to the periosteum. In other words, the tendon is attached to the bone in the form of fibrous or indirect adhesion to the metaphysics and diaphysis of long bones or fibrocartilaginous or direct adhesion to the epiphyses of the bone. In fibrous adhesions, while the collagen fibers of the tendon are permanently adhered to the periosteum during bone development, fibrocartilaginous adhesions have a gradual transition from tendon to bone. This gradual transition in fibrocartilaginous adhesions includes the tendon, decalcified fibrocartilage, calcified fibrocartilage, and four zones of bone, so that the uniform distribution of the load at the adhesion site and the joint movement and

the coordination of the collagen fibers are ensured. However, changes in the fibrocartilaginous structure due to compressive loading vary depending on the adhesion sites of the tendons. This ensures better protection against compressive forces. The bones of the tendons are composed of four regions within the bone; at the end of the tendon (region 1), collagen fibers enter the fibrocartilage (fibrous cartilage—region 2). As the fibrocartilage progresses, it becomes mineral fibrocartilage (area 3) and then integrates with cortical bone (fourth region). This transformation, which is more bone structure than tendon structure, leads to gradual increase of mechanical properties of the tissue [3, 19–21].

3. Classification of tendons

The tendons are mainly composed of three parts: the tendon itself, the muscle-tendon junction, and the bone insertion. In general, they pass through the joints and adhere to their distal. In this way, they increase the effectiveness of the muscles on the joints. At the same time, similar to bones, mechanical properties vary depending on the load carrying place. For this reason, knowing where they are helps us understand the structure. In fact, not every muscle has a tendon. While some tendons are involved in some muscles that play an active role in joint movements, the presence of some tendons is to increase muscle movement distances rather than the movement of the joint. For example, Achilles tendon is a very special tendon for the body carrying the loads by centralizing the strength of a few muscles. In contrast, some tendons, such as the posterior tibial tendon, act by distributing the load to several bones. Although it is known that most tendons originate from the muscle and adhere to the bone, some tendons may be the starting point for muscles, or two muscles are connected to each other through a tendon [22, 23].

The simplest classification for the tendons classified according to their shapes, settlements, and anatomical structures is the classification made according to their shapes. They can be very small and very long, and they can be very large and very short. Tendons are very variable according to their shape, long, round, rope-shaped (such as Achilles tendon), or short; flat tissue adhesion (such as bicipital aponeurosis) can be seen. In other words, tendons may change from flat to cylinder, from fan shape to ribbon shape. However, round tendons (such as flexor digitorum profundus) or flat tendons (such as rotator cuff, bicipital aponeurosis) are more involved in the body. In this simple classification, tendons are divided into round and flat and are very different from each other as structural and functional. For example, while round tendons respond equally to tensile loads with parallel collagen patterns, flat tendons such as rotator cuffs can respond microanatomically in the form of compression and shear forces due to longitudinal, oblique, and transverse collagen sequences. However, in round tendons, the section area is proportional to the maximum isometric strength of the muscle. In other words, due to parallel collagen sequences, flat tendons are resistant to compression and shear forces due to flat, longitudinal, and oblique collagen sequences in comparison to round tendons that respond equally to the tensils [3, 24].

Tendons can be classified in many ways according to their location, but the most logical one is the tendon classification in relation to the functions they see as the intraarticular (biceps long head and popliteus tendon) and the extraarticular (Achilles tendon). Most tendons are non-articular, but the intra-articular ones lack the ability to repair after injury as in the same intra-articular ligaments (an example of anterior cruciate ligament tear). At the same time, although most tendons adhere to the bone, some tendons form the origo point for the muscles (lumbrical muscles originate from the flexor digitorum profundus) or connect two muscles (such as

	Energy storage tendons	Positional tendons
Function	-Storage and release of elastic stress energy	-Transport the forces created in muscles to the bones
Material specifications	-Bimodal with smaller fiber diameter -More glycosaminoglycan and water content, softer matrix -Increased interfascicular slip due to lower intrafascicular rigidity	-Unimodal with a wider diameter of a fiber -Lower glycosaminoglycan and water content, the harder matrix -Tightly packed fascicles with less interfascicular slip at low loads
Biomechanical features	-It can extend in physiological loads -Higher tensile strength -Lower tensile strength	-Cannot stretch in physiological loads -Lower tensile strength -Higher tensile strength
Injury	-More	-Less
Example	-Achilles tendon	-Anterior tibial tendon

Table 1.
Classification and properties of tendons according to their functions.

omohyoid and digastric muscle). In addition, the large part of the tendon may originate from the muscle itself (gastrocnemius and soleus). For example, in some muscles tendons move into the muscle joint and tendon sticks at an angle. This allows a high proportion of muscle fibers to adhere to the tendon, thereby increasing the strength of the muscle-tendon unit but reducing the range of motion.

According to their anatomy, the tendons can also be classified as sheathed or synovial-coated (such as the long flexor of the fingers) or unsealed or paratenon-coated (such as Achilles tendon). In other words, these tendons, which are separated by intrasynovial and extrasynovial, have a higher slippage resistance compared to the intrasynovial tendon structure, when examined more closely. At the same time, the soft tissue protection and vascularity of these two tendons are different [20].

According to its functions, tendons can be classified as energy storage or positional tendons (**Table 1**). In general, the muscles tend to tendon to shorten the stress load; the affected tendon is stretched and the muscle can relax again when relaxed. This makes the tendon a structure that stores elastic voltage energy. The best example of energy storage tendons is Achilles tendon. Tibialis anterior tendons in human are examples of positional tendons, and they can never extend relatively. Positional tendons are rarely injured because they extend less [25–27].

4. Conclusion

In conclusion, tendons are composed of multiple bundles, fibroblast, and dense linear collagen fibrils, which form the macroscopic structure of tendons and give the fibrous appearance. The cell and matrix compositions of tendons are similar to ligaments and capsules and contain only small differences. In fact, they all have the same cell type and similar vascular and innervation sources. The extracellular matrix of tendons is largely composed of collagen fiber network and less proteoglycans, elastin, and other proteins. The main task of these components is to maintain the structure of the tendon and facilitate the biomechanical reaction of the tissue against mechanical loads.

Knowing where tendons are helps us understand the structure. While some tendons are involved in some muscles that play an active role in joint movements, the presence of some tendons is to increase muscle movement distances rather than the movement of the joint.

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