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Opinion Article

Structure, Functions and Mechanics of Tendons

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ABOUT THE STUDY

Tendon, a type of connective tissue that connects muscles to bones and other bodily parts. Tendons, which are securely attached to muscle fibers at one end and to bone-related components at the other, are the connective tissues that convey the mechanical force of muscle contraction to the bones. One of the highest tensile strengths discovered in soft tissues, tendon strength is remarkable. The hierarchical structure, parallel alignment, and tissue composition of tendon fibers are responsible for their exceptional strength, which is required for withstanding the stresses caused by muscular contraction.

A tendon is made up mostly of collagenous fibers and is a thick, fibrous connective tissue. The fundamental components of a tendon are primary collagen fibers, which are made up of clusters of collagen fibrils. Primary fibers are gathered into primary fiber bundles (subfasicles), and collections of these bundles make secondary fiber bundles (fascicles). Tertiary fiber bundles are formed by a number of secondary fiber bundles, and these bundles in turn form the tendon unit. The endotenon, a connective tissue sheath that surrounds the primary, secondary, and tertiary bundles, makes it easier for the bundles to glide against one another when the tendon moves.

Structure

Tendons are composed of regular, thick connective tissue histologically. Specialized fibroblasts known as tendon cells make up the majority of tendons (tenocytes). The extracellular matrix of tendons, which is rich in tightly packed collagen fibers, is created by tenocytes. Collagen fibers are arranged into tendon fascicles in a parallel pattern. The endotendineum, a fragile loose connective tissue made up of tiny collagen fibrils and elastic fibers, binds individual fascicles. The epitenon, a sheath of densely uneven connective tissue, surrounds groups of fascicles. The fascia surrounds the tendon as a whole. The paratenon, a fatty areolar tissue, fills the area between the fascia and the tendon tissue. Sharpey's fibers serve as the anchor for normal, healthy tendons to the bone.

Ultrastructure and collagen synthesis

When collagen fibers combine, they form macroaggregates. The tropocollagen molecules spontaneously aggregate into insoluble fibrils upon secretion from the cell and cleavage by procollagen N- and C-proteases. The diameter of the collagen fibrils that are generated can be anywhere from 50 nm and 500 nm, while the collagen molecule itself is roughly 300 nm long and 1-2 nm wide. The fibrils in tendons then come together to form fascicles, which are around 10 mm long and range in diameter from 50 m to 300 m, and ultimately a tendon fiber, which has a diameter of 100 m to 500 m.

The proteoglycan (a compound made up of a protein bound to glycosaminoglycan groups, found particularly in connective tissue) elements decorin and, in compressed regions of the tendon, aggrecan, which are capable of binding to the collagen fibrils at specific locations, hold the collagen in tendons together.

Tenocytes

Collagen molecules are created by tenocytes, which then group together end-to-end and side-to-side to form collagen fibrils. Elongated tenocytes are arranged in fibril bundles to create fibers, which are tightly packed with one another. The collagen in the tendon is part of a three-dimensional network of cell processes. Gap junctions allow cells to communicate with one another, and this signaling enables the cells to recognize and react to mechanical pressure. Essentially, these communications are carried out by two proteins: connexin 32, which is only present in cell bodies where processes meet connexin 43, which is present where processes meet. Within the endotendon, blood vessels can be seen running parallel to the collagen fibers with sporadic branching transverse anastomoses.

Functions

Tendons have historically been thought of as a means of force transmission between muscles and bone, as well as between muscles themselves. Through this relationship, tendons can passively adjust forces while moving, adding stability without exerting any effort. But during the past 20 years, a lot of study has concentrated on the elastic characteristics of particular tendons and their capacity to act as springs. Not all tendons must have the same functional purpose; certain tendons are primarily used to position limbs, such as the fingers when writing (positional tendons), while others work as springs to improve mobility (energy storing tendons). Tendons that can store energy are highly effective at both storing and recovering it.

For instance, the Achilles tendon extends as the ankle joint dorsiflexes during a human stride. The elastic energy is released at the end of the stride as the foot plantar-flexes (points the toes downward). Additionally, because the tendon stretches, the muscle can work with little to no length change, increasing its ability to produce force. The collagen fiber's diameter and orientation affect the tendon's mechanical characteristics. Although the collagen fibers are parallel to one another and closely packed, planar undulations, or crimps, on a scale of several micrometers give them a wave-like look. Due to the absence of hydroxyproline and proline residues at specific points in the amino acid sequence, the collagen fibers in tendons have some flexibility.

Mechanics

Tendons are viscoelastic structures, meaning they have properties of both viscous and elastic behavior. Tendons behave like other "soft tissue" when

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stretched. As the collagen fibers align and the crimp structure straightens, the force-extension or stress-strain curve begins with a very low stiffness area, indicating a negative Poisson's ratio in the tendon fibers. More recent studies have revealed that healthy tendons are highly anisotropic and exhibit a negative Poisson's ratio (auxetic) in some planes when stretched up to 2% along their length, i.e. within their normal range of motion. These studies were conducted *in vivo* (through MRI) and *ex vivo* (through mechanical testing of various cadaveric tendon tissue). The structure gets much stiffer after this "toe" area and exhibits a linear stress-strain curve until failure. The mechanical characteristics of tendons vary greatly because they are tailored to the tendon's specific functional needs. The stiffer positional tendons tend to be a little more viscoelastic and less elastic, allowing for finer movement control, whereas the energy-storing tendons tend to be more elastic or less stiff, making it easier for them to store energy.