TENDON: ANATOMY, PHYSIOLOGY, AND HEALING

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Introduction

Tendons are frequently encountered during surgery or laceration injury of the foot and leg since they are numerous, superficial, and at times quite large. For this reason knowledge of the anatomy and physiology of tendons is important to any physician involved in the diagnosis or surgical treatment of the foot and leg. A review of the anatomy, physiology, and healing of tendon in the leg and foot is presented.

Anatomic Considerations

Tendons are composed of specialized connective tissue and function to concentrate the pull of their respective muscle of origin across a joint(s) to the point of insertion. They are relatively inelastic and have a tensile strength similar to stainless steel. They are living structures possessing cells and neurovascular supply as well as collagenous protein fibers. All of these facts seem fundamental, however, failure to recognize the implications of these statements can result in the compromise of any patient suffering injury or surgery on these important structures.

Gross Anatomy

The most common anatomic configurations of the tendons crossing the ankle to the foot are presented.

Tibialis Anterior

The tibialis anterior tendon originates from its muscle of origin in the middle one-third of the anterior leg. It courses slightly medially as it descends and enters its sheath just proximal to the superior extensor retinaculum. It then traverses beneath the superior extensor retinaculum or in approximately 25% of the population tunnels through the retinaculum. It then continues across the ankle joint over the superficial component and then primarily beneath the deep component of the oblique superomedial band of the inferior extensor retinaculum. The tendon exits its sheath variably at a level near the talonavicular joint. The tendon finally inserts at the medial cuneiform and first metatarsal base (Fig. 1).

Extensor Digitorum Longus

The tendon begins as a single entity above the level of the superior extensor retinaculum. Once deep to that structure the tendon divides into two portions which then enter a common synovial sheath. The two tendons then course distally becoming themselves split into two portions after exiting beneath the common tunnel of the inferior extensor retinaculum. The tendon sheath expands to encompass the four tendons as well as the peroneus tertius tendon. The distal limit of the tendon sheath is near the cuneonavicular joint. Each tendon slip extends to its respective digit of insertion being joined on its lateral side by a tendinous slip from the extensor digitorum brevis with the exception of the fifth digit which has no brevis insertion. The insertion into each digit is via a complex aponeurosis at the metatarsophalangeal joint level and by direct bony insertion into the dorsum of the middle and distal phalanges (Fig. 1).

Extensor Hallucis Longus

In the lower one third of the leg the extensor hallucis longus tendon courses just deep and lateral to the tibialis anterior tendon. It passes deep to the superior extensor retinaculum and upon exiting enters its sheath just proximal to the oblique superomedial band of the inferior extensor retinaculum. It then passes beneath the oblique superomedial band of the inferior extensor retinaculum. The tendon then passes deep to the oblique inferomedial band of the inferior extensor retinaculum and enters a fibrous tunnel over the dorsum of the foot. It then exists its synovial sheath and inserts via extensor aponeurosis into the base of the proximal phalanx before ending at its attachment to the dorsum of the distal phalanx of the hallux (Fig. 1).

Peroneus Tertius

The peroneus tertius tendon lies lateral to the common tendon of the extensor digitorum longus in the leg. It passes either separately or more typically with the extensor digitorum longus tendon beneath the superior and inferior extensor retinaculum. The tendon shares the sheath of the extensor digitorum longus and finally exits just lateral to the extensor digitorum longus tendon slip to the fifth digit. It then fans out to insert into the base of the fifth metatarsal. The peroneus tertius is estimated to be absent in about 8.5% of the population (Fig. 1).

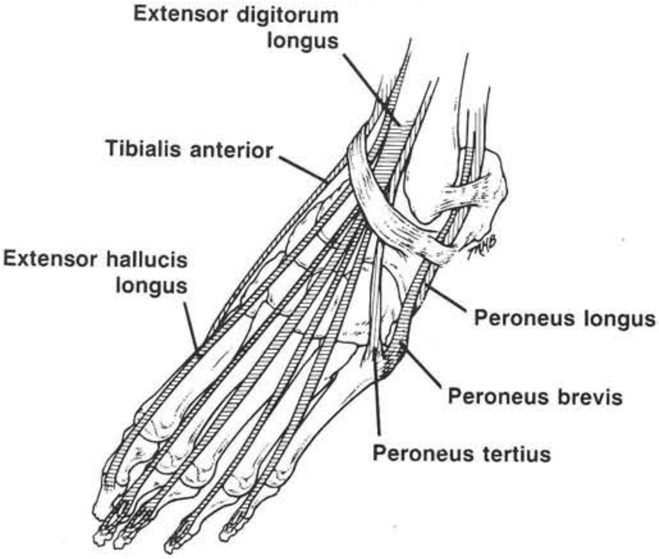

Fig. 1. Anterior and lateral muscle groups are pictured.

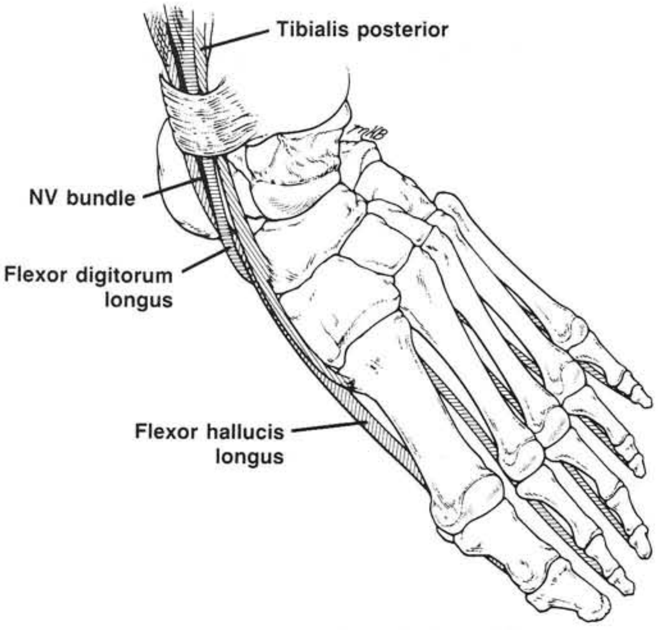

Fig. 2. Tendons of deep posterior muscle group are depicted as they enter tarsal canal at posteromedial ankle. **A.** tibialis posterior, **B.** neurovascular bundle, **C.** flexor digitorum longus, **D.** flexor hallucis longus.

Preoneus Longus

The peroneus longus tendon lies superficial to the peroneus brevis in the middle one-third of the leg. The peroneus longus gradually rotates to a position posterior to the peroneus brevis at the level of the ankle. It enters its synovial sheath which is separate from that of the brevis at a point 2 to 3 centimeters proximal to the superior peroneal retinaculum. Beneath the retinaculum the sheaths become common and then again split to follow each respective tendon as they exit beneath the inferior peroneal retinaculum. The sheath often communicates with the ankle joint; a relationship which becomes important during tenography or arthrographic examination. After exiting its sheath the peroneus longus tendon traverses the lateral wall of the calcaneus and then turns plantarly at the level of the cuboid. The tendon enters a second sheath in the plantar aspect of the foot before finally inserting into the medial cuneiform and first metarsal base (Fig. 1).

Peroneus Brevis

The peroneus brevis tendon continues to receive muscular insertion to a significant degree to the level of the lateral malleolus. Therefore, severing the tendon in the proximal leg for use during lateral ankle stabilization yields approximately one-half of the total tendon as the severed end is drawn distally. In the middle one-third of the leg the tendon lies deep to the that of the peroneus longus. Proximal to the superior peroneal retinaculum the tendon enters its arm of the common sheath. At the level of the malleolus the tendon is anterior to the peroneus longus and then courses superior to the peroneus longus tendon along the lateral wall of the calcaneus. There it exits its sheath shortly before inserting into the tuberosity of the fifth metatarsal base (Fig. 1).

Tibialis Posterior

The tendons of the posteromedial ankle all enter the tarsal tunnel within separate canals. Proximal to the tarsal tunnel the tibialis posterior tendon lies just anterior and slightly medial to the neurovascular bundle. For this reason care must be taken to avoid mistaking the posterior tibial nerve for the tendon. The tendon enters the first compartment of the tarsal tunnel just posterior to the medial malleolus. The synovial sheath is entered just proximal to the tunnel and is exited just distal to it. No mesotenon accompanies the tibialis posterior tendon, instead vincula slips from the sheath supply vascularity to the tendon within the sheath. These vincula are at times responsible for causing retrograding of the tendon for transfer difficult.

After exiting the synovial sheath the tendon courses at a level just superior to the sustentaculum tali. It then rides just inferior to the calcaneonavicular (spring) ligament. A fibrocartilaginous or bony sesamoid may be present at this level on the superior aspect of the tendon. At the level of the navicular tuberosity the tendon divided into three insertional components. The first component lies in direct line with the tendon and inserts mainly on the navicular tuberosity. This insertion fans out to extend to the medial cuneiform and cups the tuberosity of the navicular. The second component lies deep to the first and extends to the plantar surface of the cuneiforms and cuboid. Distal extensions of this component traverse deep to the peroneus longus tendon to insert on all lesser metatarsal bases.

The third component of the tibialis posterior tendon insertion is recurrently oriented and inserts into the sustentaculum tali of the calcaneus (Fig. 2).

Flexor Digitorum Longus

The common tendon of the flexor digitorum longus enters its synovial sheath approximately 5 centimeters proximal to the tip of the medial malleolus. The tendon enters the third compartment of the tarsal tunnel and courses distally at the level of the sustentaculum tali. As it enters the plantar aspect of the foot it exits its sheath and crosses plantar to the tendon of the flexor hallucis longus. The flexor digitorum longus tendon then divides into four digital branches which insert into the middle and distal phalanges of each toe (Fig. 2).

Flexor Hallucis Longus

The flexor hallucis longus tendon courses as the most lateral of the tendons passing posterior to the medial malleolus. The tendon enters a fibro-osseus tunnel at the posterior aspect of the talus, coursing between the posteromedial and posterolateral tubercles of the talus. This anatomic relationship can be helpful in diagnosing fractures of these tubercles since motion of the flexor hallucis tendon often produces pain as it induces motion at the fracture site.

The flexor hallucis longus tendon enters the fourth compartment of the tarsal tunnel and then courses plantarly beneath the sustentaculum tali. It then turns distally, deep to the flexor digitorum longus tendon sending a vincula slip to that tendon after crossing. The tendon then passes beneath the first ray between the sesamoid bones and inserts into the plantar aspect of the base of the distal phalanx (Fig. 2).

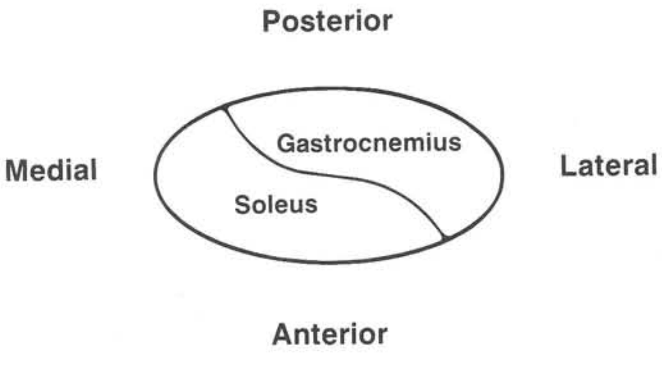

Fig. 3. Orientation of gastrocnemius and soleus tendinous contributions at level of insertion into calcaneus is shown.

Tendo Achillis

This tendon originates from the gastrocnemius and soleus muscles. The tendon has a relatively straight course which obviates the need for a tendon sheath. Instead the tendon is invested in paratenon from origin to insertion. The tendon inserts onto the middle to distal one-third of the posterior aspect of the calcaneus. Some fibers of the tendon actually continue plantarly to insert into the plantar aponeurosis. The fibers of this conjoined tendon rotate as they descend. The majority of the gastrocnemius' contribution attains a posterolateral insertion and the soleal fibers rotate to an anteromedial position distally (Fig. 3).

Tendon Physiology

The physiology of tendon function was defined extensively by Leo Mayer in 1916. Very little additional information on basic tendon function has been added since that time. The ability of the tendon to glide is a basic concept and must be understood if the surgeon is to achieve predictable results when repairing or performing other procedures on these structures.

Peritendinous Structure and Function

Tendons are living structures which must be supplied with nutrients in order to survive. This creates a dilemma since tethering of the tendon with blood vessels along its length would not allow the excursion necessary for the tendon to function. Blood supply from the insertion and origin only would force the central zone of tendon to rely precariously on this morphologic configuration. Therefore, a means of maintaining the tendons cellular structures is based on an elastic system of supporting structures. These structures involved in the protection and nutritional support of tendons are the peritendinous coatings and synovial sheaths.

Tendons which have a relatively straight course do not have a true sheath. Instead they are surrounded by a loose highly vascular areolar tissue known as paratenon. Tendons which turn around a surface are protected by a synovial sheath. This sheath is a relatively complex sac-like structure which provides lubrication and nutrients to the tendon via synovial fluid. Within the sheath a mesotenon or in some cases a vascular vinculus imparts nutrients to the surrounding epitenon and tendon. When conditions permit these sheaths can be used to prevent adhesion and allow gliding function of tendons transferred through them on their course to a new site of insertion (Fig. 4).

Factors Influencing Muscle-Tendon Function

The muscle-tendon unit can actually perform only one active function and that is to contract. However, this contraction can be harnessed and influenced to produce smooth and graceful motion. Some of the ways in which the muscle-tendon unit is influenced are discussed.

If strength of contracture is required of the muscle, the tendon is positioned approximately at right angles to the axis of the joint being moved. The greater the distance between the tendon and the joint axis the greater the lever arm, and therefore, the greater the mechanical advantage (Fig. 5). Surgeons may make use of this mechanical property by placing a transferred tendon a point more distal to the original insertion of a paralyzed muscle. Transferring a tibialis posterior tendon subcutaneously to the dorsum of the foot will result in bow stringing of the tendon, increasing the distance between the axis of the ankle and the line of pull. An increase in mechanical advantage and, therefore, force of contracture is obtained.

As a tendon's line of pull approaches being parallel to a joint axis the force of contracture becomes a stabilizing rather than an accelerating influence. The tibialis anterior has this effect on the subtalar joint when the foot is held in a neutral position.

One of the most common tendon procedures involves transferring the point of tendinous insertion to balance a point of weakness or remove an over-powering deforming force. Silver and associates would discard the term "muscle balance" and suggest that a tendon with "task appropriateness" dictate the choice of transfer since true muscle balance is not actually ever present. The sum total of the posterior muscle group's strength was estimated to be six times that of the anterior muscle group. This appears reasonable since the posterior group is for the most part involved in the propulsive phase of gait, while the anterior group simply works to clear and position the foot during swing phase.

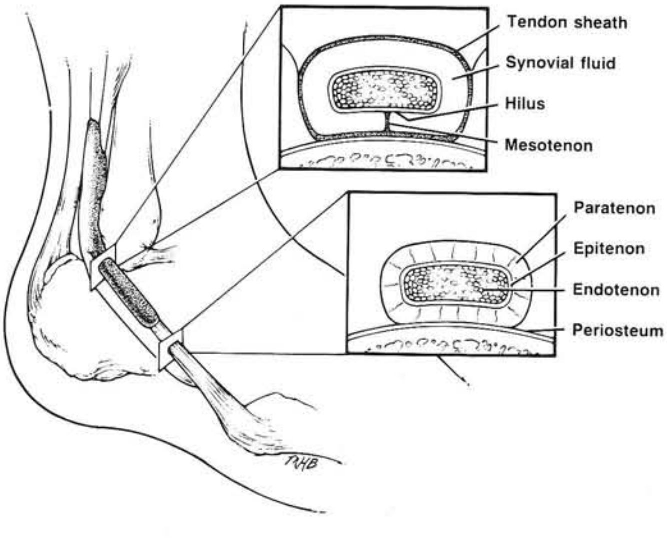

Fig. 4. Peritendinous sheath and vascular epitenon are depicted. Mesotenon shown here may be replaced in some instances by vincula.

Since the posterior group musculature is more powerful than the anterior, transfers from posterior to anterior are more likely to cause overcorrection than when the reverse procedure is performed. Transferring a tendon to assist in plantarflexion (propulsion) requires much more strength of the transferred muscle than does a posterior to anterior transfer to assist in dorsiflexion of the foot. Tendencies for overcorrection or creating imbalance are more common when transferring an entire tendon than if a split transfer is performed spreading the force of contracture between the two points of insertion.

Spastic muscles provide additional difficulty in transfer planning. Muscle strength may be normal, however, muscle fiber length is usually decreased resulting shorter tendon excursion. Lengthening a spastic muscle's tendon may release static contracture, however, no increase in active range of motion is gained. Therefore, a flail extremity may result.

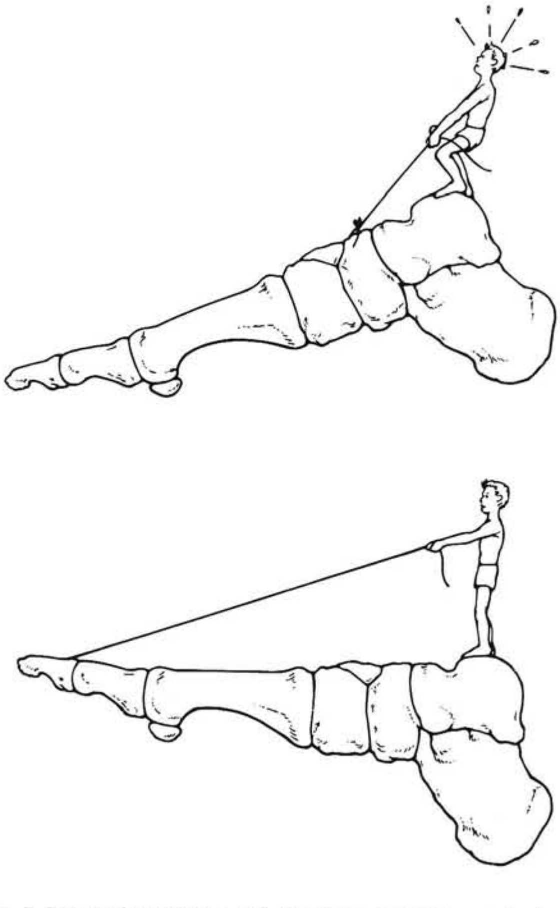

Fig. 5. Point of insertion, orientation, and distance between tendon and axis of motion all effect strength and action of muscular contraction.

Tendon Healing

Tendon healing has been extensively studied in the hand surgery literature. Restriction of motion by adhesions has been the main impetuous for the investigation by most authors. In contrast, tendon surgery about the foot and leg has not received the same amount of attention in regards to healing problems. It is doubtful that adhesions occur less frequently in the lower extremity, therefore one must assume their presence is more easily tolerated by the patient or by the physician. The patient suffering from a painful hallux limitus secondary to binding of the long flexor tendon may not be of the same opinion, however.

Fine control of the foot is not as necessary as in the hand. One rarely considers arthrodesing an interphalangeal joint in the hand, while this is an accepted procedure in podiatric surgery. However, this does not imply that tendon repair or surgery in the lower extremity does not require skill and careful attention to detail. The basic concepts in tendon handling combined with appropriate postoperative management are still based on knowledge of the physiology and healing of these structures.

The epitenon surrounding the tendon contributes most of the cellular elements active in the repair process. Some authors have suggested that the tenocytes within the tendon also participate in the reparative process. This would be the ideal situation since the tendon might be sequestered within its sheath structure and the tendinous scar kept separate from that of the surrounding wound. However, this appears to rarely occur in most clinical situations. Peacock championed the theory of "one-wound one-scar" healing in complex wounds (Fig. 6). However, his pessimistic discussion of impending adhesion formation in tendon healing has since been brightened and a scientific method of tissue handling has been shown to allow restoration of tendon strength and gliding function.

A severed or partially lacerated tendon heals most proficiently in paratenon. The tendon sheath contributes little to the healing process. Tendon ends which retract within the sheath become atrophic and rounded. Return of gliding function is rare in this situation if the tendon ends are not reapproximated. Repair and return to function in this situation are dependent on atraumatic technique with preservation of vascular supply and relaxation of tension at the repair site Restrictive adhesion formation appears to be the result of vascular embarrassment, hematoma, and sheath excision all combined with prolonged immobilization.

A rational approach to the post-operative care of patients undergoing procedures which require tendon healing is essential if a return to function is to be expected.

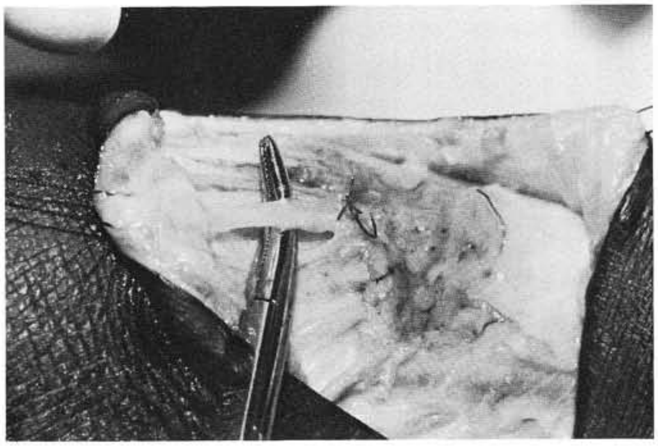

Fig. 6. This young black female suffered complex laceration to dorsum of right foot. Pain and limitation of motion of hallux prompted surgical exploration of wound three months after original primary repair of the laceration. Failure to recognize and repair lacerated extensor hallucis longus tendon resulted in fibrosis and massive adhesion formation.

Initially the healing process is dictated by the formation of a fibroblastic splint. This "splint" is actually an inflammatory infiltrate of granulation tissue which permeates the entire wound. By the second day this fibroblastic proliferation organizes. However, there is little tensile strength to this tissue and the tendon ends soften in response to the inflammatory process. Therefore, tension at the coapted tendon ends can easily result in suture pull-out and failure of the primary repair.

The second week is a period of scar organization. Passive tension on the tendon ends appears to influence the organization of the repair. The strength of the repair is still totally dependent on the suture material, however, and active motion and tension on the repair site will actually result in hypertrophy of the tendon, gap formation, and adhesions. Continued definition and strengthening of the cicatrix occurs during the third week. The fibrovascular cuff of granulation surrounding the tendon begins to separate and gentle motion should be permitted at this point to encourage strengthening of the union and prevent restrictive adhesion formation. Protected function is still necessary as the fourth week ends at which time the repair matures. Rapid strengthening of the repair will ensue in the fifth and sixth week under the influence of gradually increasing tensile forces.

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