The Achilles Tendon
The Achilles Tendon

Treatment and Rehabilitation

Edited by

James A. Nunley, MD
Duke University Medical Center, Durham, NC, USA
To my wife, Elise,
for her love, support, and encouragement of so many years.

To my children, Ryan, Stephanie, and Jefferson,
for the excitement and joy that they have brought to my life.

To all of the residents and fellows at Duke University,
for their unwavering support and for providing me with intellectual stimulation for so many years.
Disorders of the Achilles tendon are universal, affecting people in a wide range of age groups. Because the Achilles tendon is one of the most powerful musculotendinous structures in the body, the impact of an injury to the Achilles tendon becomes magnified. There is a wide range of disorders or problems that can involve the insertional region, where pathology may rest with bone, tendon, or bursae. A completely different set of pathologic entities resides in the noninsertional region, one of which may include the frustrating degenerative tendinopathy. As our growing population ages but remains physically active longer into life, the incidence of these disorders will continue to increase.

I am proud to be given the opportunity to write the foreword to this text, which is intended for foot and ankle surgeons worldwide. Seldom does a book on a single entity become a current concepts review, as this work has. Too often, textbooks are not published for several years after the chapters have been written, making them obsolete upon publication. Not so with this book, which deals with timely topics on the Achilles tendon. Dr. James Nunley has compiled this work in slightly over a year, thus providing the reader with state-of-the-art material.

Dr. Nunley had the foresight to create a much needed techniques-oriented book dealing with the complexities of the Achilles tendon. His approach was to develop a comprehensive guide to managing Achilles tendon problems. You will learn not only the latest nonoperative approaches to specific Achilles problems, but also updated surgical techniques, with comparisons and references to traditional treatments. The chapters include a thorough description of indications and contraindications. Less invasive and minimally invasive technical advancements from the recent past are also included.

Dr. Nunley has met many experts in the field of foot and ankle surgery through his extensive travels and ongoing education in this subspecialty. He has enlisted these internationally renowned physicians to contribute chapters based on their vast experience. Introductory chapters provide essential background on basic anatomy, imaging, physiology, and pathomechanics, and subsequent sections cover the spectrum of Achilles tendon injuries. Acute and chronic conditions are addressed both in young adults and in elderly patients who are limited by Achilles symptoms. The book also takes a very practical approach to rehabilitation of the Achilles tendon postinjury and postsurgery. Athletic training, as it relates to the role of the Achilles complex, is highlighted with an emphasis on a faster return to play. Finally, case studies tie each chapter together and demonstrate the application of concepts to daily practice.
The text is further enhanced with high-definition photos and artwork, which include illustrated anatomy, MRIs, physical therapy tips, and surgical techniques and tools. Dr. Nunley has succeeded in compiling this information in a concise, understandable format.

I find this textbook to be extremely timely, given the complexities of the Achilles tendon and the large number of patients affected. This book will serve as a valuable reference—one that every orthopedic surgeon who manages such disorders will refer to often. I congratulate Dr. Nunley for the successful completion of this valuable endeavor.

February 5, 2008

Robert B. Anderson, MD
For many years, I participated in an instructional course lecture series for the American Academy of Orthopaedic Surgeons that addressed problems of the Achilles tendon. Through this lecture series it became apparent to me that there were numerous methods to treat the various pathologies associated with the Achilles tendon, but that there was no text available to guide surgeons in how to select the appropriate treatment. Thus, I felt that there was a need for a book to address not only historical issues associated with the Achilles tendon, but also the innovative ideas. A number of the authors of this text met at an international meeting where we discussed the possibility of a textbook. As we discussed a topic as simple as the weight-bearing status of a patient after an acute repair of the Achilles tendon, I saw that there was a wide and diverse group of opinions among the experts. This textbook consolidates these opinions to help guide students, patients, therapists, and surgeons in deciding on a course of treatment.

I have had many friends ask why a topic as simple as the Achilles tendon requires a textbook. I think the reader will agree that the amount of information available today concerning injury and repair of the Achilles justifies a textbook dedicated to the topic. The book addresses the anatomy and imaging characteristics of the Achilles tendon, as well as the assessment of acute and chronic injuries, which over the years has seen numerous refinements in surgical technique for repair and rehabilitation. The last section of the book addresses chronic tendinopathy, which is a vast area and incorporates many degenerative and athletic injuries.

The chapters in this text were written by experts who have been recognized worldwide for their contributions. The text presents the most common surgical procedure for any given condition, as well as any debate that might still exist. This text can help practitioners decide if they should treat the acute rupture of the Achilles tendon nonoperatively or with a percutaneous technique, with a mini-open procedure or with a formal open repair. The text also discusses the pros, cons, risks, and benefits of each of these surgical techniques. A case-based example in each chapter helps provide the reader with a greater understanding of the possible solutions available for any given problem.

My hope is that this text will provide a stimulus for the improved treatment of the many types of injuries to the Achilles, and guidance for those who are in the trenches treating the pathologies relating to Achilles tendon disorders.

February 7, 2008
James A. Nunley, MD
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Section I

Introduction
The Achilles tendon is the conjoined tendon of the two heads of the gastrocnemius and the soleus muscle. Together these structures are often referred to as the “gastroc-soleus complex.” It is the largest and strongest tendon in the human body and subject to tensile forces of up to 12.5 times body weight (9 kilonewton [kN]) during sprinting and six to eight times body weight during athletic activity such as jumping or cycling. Due to its size and functional demands, the Achilles tendon is susceptible to both acute and chronic injuries and is directly or indirectly implicated in many pathologic conditions of the foot and ankle. To diagnose and treat these disorders, a thorough knowledge of the anatomy of the Achilles tendon and its surrounding structures is crucial.

**Microstructure**

Tendons are complex, composite, roughly uniaxial structures consisting of collagen fibrils embedded in a matrix, rich in water and proteoglycans with a paucity of cells. Collagen (mainly type I collagen) accounts for 65% to 80%, and elastin for approximately 2%, of the dry mass of the tendon. The predominant cells are tenoblasts and tenocytes (elongated fibroblasts). Their spindle-shaped cell bodies are arranged in rows between the collagen fiber bundles and they produce the extracellular matrix proteins. Soluble tropocollagen molecules are cross-linked to create insoluble collagen molecules, which then aggregate into microfibrils. Further aggregation leads to the formation of collagen fibrils. The diameter of collagen fibrils in the Achilles tendon varies from 30 nm to 150 nm. The basic unit of a tendon, the collagen fiber, is created by the binding of multiple collagen fibrils (Fig. 1.1). Each collagen fiber is surrounded by a fine sheath of connective tissue, the endotenon, which allows the fiber groups to glide and provides access channels for blood vessels, nerves, and lymphatics to the deep portions of the tendon. Moreover, the endotenon binds fibers together to form primary fiber bundles (subfascicles), which then group to form secondary fiber bundles or fascicles. A group of secondary bundles then forms the tertiary bundle, with an average diameter of 1000 to 3000 µm through incorporation in a proteoglycan-rich extracellular matrix.
The tendon is made up of several tertiary bundles surrounded by the epitenon. On its outer surface, the epitenon is in contact with the paratenon, whereas the inner surface the epitenon is continuous with the endotenon.\(^1\)

**Gross Anatomy**

The leg consists of four compartments (anterior, lateral, superficial, and deep posterior) divided by strong fascial septa. The superficial posterior compartment contains the gastroc-soleus complex and the plantaris muscle, supplied by the tibial nerve and branches from the posterior tibial and peroneal arteries. It is separated from the deep posterior compartment by the deep leaf of the fascia cruris.

**Gastrocnemius**

The gastrocnemius muscle crosses the knee, ankle, and subtalar joint; hence, it is maximally stretched with the knee fully extended and the ankle dorsiflexed while the heel is inverted.\(^5\) Consisting mainly of fast twitch muscle fibers, the gastrocnemius muscle flexes the knee, plantar flexes the ankle, and inverts the subtalar joint. It is the most superficial muscle in the calf and is responsible for its contour. The two heads of the gastrocnemius muscle are firmly attached to the posterior aspect of the femur, just proximal to the femoral condyles, by strong, flat tendons that expand into a short aponeurosis on the posterior surface of the muscle bellies. Both heads also attach to the posterior aspect of the knee joint capsule onto the oblique popliteal ligament. The medial, larger head takes its origin slightly superior to the lateral head and extends more distal in the calf (Fig. 1.2). Deep to the medial head is usually a bursa that often communicates with the knee joint. In 10% to 30% of the population, there is a sesamoid bone (fabella) in the proximal tendon of the lateral head of the gastrocnemius that often directly articulates with the lateral femoral condyle.\(^6\)
When present, it is usually bilateral and serves as an attachment site for the fabellofibular ligament in the posterolateral corner of the knee joint capsule. The muscle fibers from each head run obliquely and attach at an angle in the middle of the calf into a midline raphe that further distal broadens into an aponeurosis on the anterior surface of the muscle. This aponeurosis gradually narrows and unites with the tendon of the soleus to form the Achilles tendon. The gastrocnemius is innervated by the first and second sacral roots through the tibial nerve.

**Soleus**

The soleus is a postural muscle consisting mainly of slow-twitch muscle fibers. It helps to keep the body upright in stance and prevents the body from falling forward during gait, as it contracts when the center of gravity passes in front of the knee joint. It is the strongest muscle in the lower leg and the prime plantar flexor of the ankle joint. The soleus has its origin on the posterior surface of the fibula head and the proximal 25% of the posterior surface of the fibula as well as the middle third of the posteromedial border of the tibia. Some fibers arise from the fibrous arch between the tibial and fibular origins of the muscle. The soleus is a pennate muscle. It is wider than the gastrocnemius and consists
of an anterior and a posterior aponeurosis with the bulk of the muscle fibers in between (Fig. 1.3). The muscle architecture is nonuniform with variable fiber lengths between 16 and 45 mm.\textsuperscript{8} The muscle fibers extend more distally than those of the gastrocnemius and insert into the posterior aponeurosis, which lies directly anterior to the aponeurosis of the gastrocnemius. The two aponeurotic leaves of the soleus lie parallel for a variable distance before they join in the distal lower leg prior to uniting with the tendon of the gastrocnemius to form the Achilles tendon. Usually the soleus tendon contributes more fibers to the Achilles tendon than the gastrocnemius.\textsuperscript{7} The gastrocnemius is innervated by the first and second sacral roots through the tibial nerve.

An accessory soleus muscle has been recognized since the 19th century. Originally thought to be a rare finding, it has been diagnosed more frequently since the introduction of magnetic resonance imaging (MRI) into clinical practice.\textsuperscript{9} The reported incidence ranges from 0.7\% to 6\%.\textsuperscript{10-12} Its presence may be accounted for by the splitting of the anlage of the soleus early in development and may be unilateral or bilateral.\textsuperscript{13} The proximal origin is typically on the distal posterior aspect of the tibia, and less commonly on the deep fascia of the normal soleus or other flexor tendons.\textsuperscript{10,12} The accessory soleus most commonly inserts via a separate tendon on the calcaneus, anteromedial to
the Achilles tendon insertion. Other insertions include those on the Achilles tendon, superior calcaneus, or lateral calcaneus. The anomalous muscle is usually enclosed in its own fascia and has its own blood supply via branches from the posterior tibial artery. The presence of an accessory soleus muscle is clinically relevant as it may be a source of posteromedial ankle pain, likely related to a localized, exertional compartment syndrome.

**Plantaris**

The plantaris has its origin on the lower part of the lateral prolongation of the linea aspera, and on the oblique popliteal ligament of the posterolateral knee joint capsule. It has a small fusiform, usually a 7- to 10-cm-long muscle belly. The thin plantaris tendon crosses obliquely between the gastrocnemius and soleus muscles and then runs parallel to the medial aspect of the Achilles tendon (Fig. 1.3). It inserts most commonly into the posteromedial part of the calcaneal tuberosity. Occasionally, the tendon is lost in the laciniate ligament or in the fascia of the leg. The plantaris is absent in 6% to 8% of individuals.

**Achilles Tendon**

The Achilles tendon originates in the middle of the lower leg as the confluence of the tendons of the gastrocnemius and soleus muscles at the gastroc-soleus junction (Figs. 1.3 and 1.4). The length of the conjoined tendon is approximately 10 to 15 cm, that of the gastrocnemius component ranges from 11 to 26 cm, and that of the soleus component ranges from 3 to 11 cm.

The thickness of the Achilles tendon was measured with ultrasonography and MRI in 267 healthy individuals of various ages. Children under 10 had a tendon thickness (mean ± standard deviation [SD]) of 4.6 ± 0.8 mm, 10 to 17 years of age 6.1 ± 0.8 mm, 18 to 30 years of age 6.3 ± 0.5 mm, and over 30 years of age 6.9 ± 1.0 mm. The distance from the most distal extent of the gastrocnemius muscle fibers to the gastroc-soleus junction varies from 2 to 8 cm.

Muscle fibers of the soleus may insert into the anterior surface of the tendon to almost its insertion. The contribution of fibers of the gastrocnemius and soleus to the Achilles tendon is variable. In most individuals, the soleus contributes more fibers than the gastrocnemius, as demonstrated by Cummins and coworkers in anatomic dissections of 100 specimens. At the gastroc-soleus junction, the Achilles tendon is broad and flat. As it travels distally in the leg, it becomes progressively ovoid in cross section, to a level 4 cm proximal to its insertion, where it can become relatively flatter again. During their descent, the fibers of the Achilles tendon internally rotate to a variable degree (approximately 90 degrees) in a spiral manner, so that the initially posterior fibers of the soleus insert mainly on the medial aspect of the Achilles tendon footprint, whereas those of the gastrocnemius (initially anterior) insert laterally. The extent of fiber rotation is determined by the position of fusion between the two muscles, with a more distal fusion resulting in more rotation. This rotation makes elongation and elastic recoil within the tendon possible and allows the release of stored energy during the appropriate phase of gait. This stored energy allows the generation of higher shortening velocities and greater instantaneous muscle power than could be achieved by contraction of the gastrocnemius and soleus muscles alone. Fiber rotation reaches a maximum 2 to 5 cm proximal to the tendon insertion and creates high stresses in this
area of the tendon, which may explain the poor vascularity and susceptibility to degeneration and injury in this region.

The Achilles tendon inserts on the middle third of the posterior surface of the calcaneal tuberosity, starting approximately 1 cm distal to the most superior border of the bone (Fig. 1.5). The average area of insertion is approximately 19.8 mm in length with a width of 24 mm proximally and 31 mm distally. Typically the distance of insertion is longer on the medial side. More distally the tendon fibers transition into the periosteum of the calcaneus. In neonates there is a continuous heavy layer of collagen fibers connecting the Achilles tendon and the plantar fascia; however, the number of these fibers decreases with age and they eventually disappear completely.

The attachment site of the Achilles tendon displays the typical structure of a fibrocartilaginous enthesis, and thus four zones of tissue are commonly present: pure dense fibrous connective tissue, uncalcified fibrocartilage, calcified fibrocartilage, and bone (Fig. 1.6). The zones of uncalcified and
calcified fibrocartilage at the osteotendinous junction are referred to as the enthesis fibrocartilage. It dissipates the bending of tendon fibers away from the hard tissue interface and thereby protects them.  

Directly anterior to the tendon insertion, between the posterior surface of the calcaneus and the Achilles tendon, is the retrocalcaneal bursa (Fig. 1.7). The bursa is a wedge-shaped sac that is horseshoe-shaped in cross section with arms extending on the medial and lateral edge of the tendon. It mainly consists of synovial projections that allow alteration in its shape with plantarflexion and dorsiflexion of the ankle to promote free movement between tendon and bone. The posterior wall of the bursa, however, is made up of sesamoid fibrocartilage on the anterior surface of the Achilles tendon. This sesamoid fibrocartilage enables the tendon to resist compressive loading where it “articulates” with a corresponding periosteal fibrocartilage on the posterosuperior calcaneus (the anterior wall of the bursa) during dorsiflexion of the foot. The enthesis and the periosteal fibrocartilage can be viewed as a series of pulleys that provide the Achilles tendon with an efficient moment arm and mechanical advantage in its action on the calcaneus (Fig. 1.8).
The space between the Achilles tendon and the posterior border of the tibia is known as Kager’s triangle. It is occupied by a mass of adipose tissue: Kager’s fat pad. This fat pad consists of three distinct regions: the superficial Achilles-associated part, the deep flexor hallucis longus (FHL)-associated part, and a calcaneal bursal wedge, which moves into the bursa during plantarflexion. The mechanical functions of the fat pad include reducing friction between the tendon and the bone, preventing the tendon from kinking under load, acting as a variable space filler to prevent buildup of negative pressure in the bursa during plantarflexion, and protecting blood vessels supplying the tendon. It may also play a role in proprioception, as it contains a variety of sensory nerve endings.

The Achilles tendon is an extrasynovial tendon without a true synovial tendon sheath. Throughout its length the tendon is surrounded by the paratenon, a thin gliding membrane of loose areolar tissue, that permits free movement of
the tendon within the surrounding tissues, and, although not as effectively as a true tendon sheath, significantly reduces the gliding resistance of the tendon (Fig. 1.9). Under the paratenon, the entire Achilles tendon is surrounded by a fine, smooth connective tissue sheath called the epitenon. On its outer surface, the epitenon is in contact with the paratenon. The inner surface of the epitenon...
Vascularity of the Achilles Tendon

The Achilles tendon receives its blood supply from three main sources: the intrinsic vascular systems at the myotendinous junction and the osteotendinous junction, and from the extrinsic segmental vascular system through the paratenon surrounding the tendon.\textsuperscript{1} At the myotendinous junction, blood vessels from the muscle bellies penetrate the endotenon and contribute to the blood supply of the proximal third of the tendon. This contribution, however, is thought to be less significant, as only the vessels in the perimysium continue on to the tendon.\textsuperscript{32-34} The majority of the Achilles tendon is vascularized throughout its length by branches of the posterior tibial artery in the paratenon on the anterior surface of the tendon. These vessels reach the tendon through a series of transverse vincula, enter the tendon substance along the endotenon, and then run parallel to the axis of the tendon. The proximal part of the tendon receives additional blood supply through a recurrent branch of the posterior tibial artery, whereas distally the rete arteriosum calcaneum formed by branches of the posterior tibial, peroneal, and lateral plantar arteries,
Table 1.1 Summary of studies reporting regions of human achilles tendon vascularization.

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contributes significantly to the vascularization of the tendon. The distribution of vascularity throughout the Achilles tendon is not homogeneous. Despite varying reports, the majority of authors on the subject believe that the blood supply to the midsection of the tendon is the poorest, with an area of lowest vascularity approximately 2 to 6 cm proximal to the tendon insertion (Table 1.1) As this area of relative hypovascularity correlates with the most common site of rupture of the Achilles tendon, it is believed that the lack of blood supply either directly decreases the tensile strength or indirectly weakens the tendon through degenerative changes.

**Innervation of the Achilles Tendon**

The Achilles tendon is supplied by nerves from the attaching muscles and by small fasciculi from cutaneous nerves, in particular the sural nerve. The sural nerve is a purely sensory nerve, formed by the confluence of the medial cutaneous branch of the tibial nerve and the peroneal communicating branch off the lateral sural cutaneous nerve emanating from the common peroneal nerve. It descends distally between the heads of the gastrocnemius and takes a highly variable course. At the level of the gastroc-soleus junction, the sural nerve lies approximately 46 mm (range, 27 to 69 mm) lateral to the medial border of the gastrocnemius tendon, or 12 mm (range, 7 to 17 mm)
medial to the lateral border. At this level it may be superficial or deep to the muscle fascia. When performing a gastrocnemius recession (Strayer procedure), the sural nerve is especially at risk, as it has been shown to be directly applied to the gastrocnemius tendon in approximately 10%. The sural nerve crosses the lateral border of the Achilles tendon an average of 9.83 cm (range, 6.5 to 16 cm) proximal to the tendon insertion and then courses anteriorly towards the lateral border of the foot (Fig. 1.9A). Small branches of the sural nerve form the longitudinal plexus and enter the tendon through the endotenon. Some also pass from the paratenon by way of the epitenon to reach the surface of the interior of the tendon (Fig. 1.9B). The number of nerves and nerve endings is relatively low in large tendons such as the Achilles, and many nerve fibers terminate on the tendon surface or in the paratenon. Nevertheless, the Achilles tendon contains numerous receptors relating to both pain and other neurotransmitter actions.

References
Chapter 1 Anatomy of the Achilles Tendon