ACUTE ACHILLES TENDON RUPTURE

Outcome, Prediction and Optimized Treatment

Nicklas Olsson

Department of Orthopaedics, Institute of Clinical Sciences
Sahlgrenska Academy at University of Gothenburg

UNIVERSITY OF GOTHENBURG

Gothenburg , Sweden 2013

"If you can't explain it simply, you don't understand it well enough"

Albert Einstein

ACUTE ACHILLES TENDON RUPTURE

Outcome, Prediction and Optimized Treatment

Nicklas Olsson

Department of Orthopaedics, Institute of Clinical Sciences
Sahlgrenska Academy at University of Gothenburg

ABSTRACT

The optimal treatment for Achilles tendon rupture is the subject of debate and could be either surgical or non-surgical with various alternatives in terms of immobilization and rehabilitation. The purpose of this thesis was to evaluate the short- and long-term outcome of a new surgical treatment protocol, including early tendon loading and ROM training, in comparison with non-surgical treatment using a functional brace. Patients in this randomized, controlled trial were evaluated with regard to symptoms, function and complications at 3, 6 and 12 months. Predictors of outcome were assessed in a multiple linear regression model. The outcome two years after injury was also evaluated in a previous randomized study of Achilles tendon rupture. The studies showed no significant differences between surgical and non-surgical treatment in terms of symptoms, physical activity level or quality of life. There was a trend towards a greater improvement in function in surgically treated patients. No re-ruptures occurred in the group treated with the new surgical technique. The heel-rise test showed that half the patients were unable to perform a single heel rise three months after injury and this ability appears to be an important early achievement, which influences patient-reported outcome and physical activity. Future treatment protocols focusing on regaining strength early after injury appear to be of great importance. Regardless of surgical or non-surgical treatment, there were significant functional deficits on the injured side compared with the contralateral side two years after the tendon rupture and the patients appear to adjust to these changes. Treatment was a moderate predictor, in contrast to age and BMI, which were relatively strong predictors of function and symptoms respectively. This thesis found that an Achilles tendon rupture impacts heavily on a person's general health and quality of life and has a significant effect on lower leg function but with large inter-individual differences, indicating that the choice of treatment should be based on the best available evidence in combination with individual patient factors.

Keywords: Achilles tendon rupture, Outcome, Functional evaluation, Achilles tendon Total Rupture Score (ATRS), Predictors, Heel-rise, Rehabilitation
ISBN: 978-91-628-8633-2

Akillessenan är kroppens största sena och har relativt hög risk att skadas. En akut hälseneruptur drabbar vanligen medelålders manliga motionsidrottare. Allt fler skadas bland befolkningen och 1996 redovisades en incidens på 37 per 100 000 invånare och år. Det finns flera olika behandlingsalternativ såsom kirurgisk och icke-kirurgisk behandling, men även olika typer av rehabilitering och immobilisering (avlastning av fotleden i gips eller i s.k. ortos). Konsensus saknas om optimal behandling både på gruppnivå och för den enskilde patienten. Vid val av behandling har man i litteraturen huvudsakligen väglets utifrån risken för komplikationer framför allt reruptur. Valet står då mellan kirurgiska komplikationer såsom sårinfektion, ärrproblem och nervskada och risken för reruptur som har visats vara vanligare vid icke-kirurgisk behandling. I tidigare studier har relativt lite fokus lagts vid alla de patienter som inte drabbas av en komplikation vid rekommendation om behandling.

Syftet med avhandlingen var att vid en akut hälseneruptur utvärdera symtom och funktion tidigt och sent i läkningsprocessen, identifiera vilka faktorer som kan prediktera utfallet samt att bedöma möjligheten att optimera behandlingen med en stabil kirurgisk teknik och accelererad rehabilitering.

En randomiserad studie genomfördes där stabil kirurgisk teknik med accelererat rehabiliteringsprotokoll jämfördes mot behandling utan kirurgi i en belastningsbar ortos. Patienterna följdes i ett år och testades med avseende på patient-rapporterade symtom, funktionsmätningar (hopp-, styrke-, och uthållighetstester och förmågan att utföra en enbent tåhävning) samt komplikationer. Statistisk analys med en multipel linjär regressionsmodell utfördes för att identifiera vilka faktorer som kunde prediktera utfallet efter en hälseneruptur. Efteruppföljning av patienter från en tidigare studie avseende symtom och funktion utvärderades två år efter skada.

Den randomiserade studien visade inga skillnader mellan behandlingsgrupperna avseende symtom, fysisk aktivitetsnivå och livskvalitet. Det fanns en trend mot att den kirurgiska gruppen visade bättre resultat avseende funktion, även om det endast var statistiskt säkerställt i två typer av hopptester. Ingen reruptur uppkom i den kirurgiskt behandlade gruppen, däremot uppstod reruptur hos fem patienter i den icke-kirurgiskt behandlade gruppen. Tre månader efter den initiala skadan kunde cirka hälften av patienterna utföra en enbent tåhävning och de som klarade detta funktionsmått var oftare yngre, män och hade lägre grad av symtom. Oavsett behandling uppvisar många patienter betydande nedsättning av funktion två år efter skada, även om många uppger låg grad av symtom. Val av behandlingsprotokoll (kirurgisk eller icke-kirurgisk) är en variabel som måttligt prediktterar grad av symtom och i mindre utsträckning funktion. Ökande ålder är däremot en relativt stark prediktor för sämre funktion samt att högre BMI prediktterar också relativt starkt för högre grad av symtom.

Resultaten visar att behandlingen med en stabil kirurgisk teknik och accelererat rehabiliteringsprotokoll är en säker behandlingsmetod som i studien inte gav någon reruptur. Inga statistiska skillnader mellan behandlingsgrupperna avseende på symtom, fysisk aktivitet, livskvalitet kunde påvisas. Patienter uppvisar däremot betydande funktionsnedsättningar två år efter skadan oavsett behandling och patienterna förefaller ha anpassat sig till detta. Tåhävningstestet verkar vara ett viktigt mått i den tidiga rehabiliteringsfasen som påverkar utfallet. Val av behandling tycks inverka relativt lite i förhållande till andra faktorer såsom ålder och BMI, därför kan denna studie vara ett tidigt steg mot ett mer vetenskapligt underbyggt val av individualiserad behandling.

PREFACE

PERSONAL REFLECTION

As a middle-aged man, I can easily identify with all the patients suffering an Achilles tendon rupture. We are in a period of life where I, along with others, have high expectations of our ability to take part in physical activity. I want to go on cycling, running and skiing without my body failing and I find it very difficult to accept impairments in bodily functions.

This thesis shows scientifically the deficits in function after an Achilles tendon rupture and, unfortunately, I have close personal experience of the impact of an Achilles tendon rupture.

To summarize: "That's one small slip for a man, one giant leap for quality of mankind". Personal fear of not having the ability to move about is a strong argument and motivation for future research.

LIST OF PAPERS

This thesis is based on the following studies, referred to in the text by their Roman numerals.

I. **Major functional deficits persist 2 years after acute Achilles tendon rupture**

    Olsson N, Nilsson-Helander K, Karlsson J, Eriksson B. I, Thomeé R, Faxén E, Silbernagel K. G

    Knee Surg Sports Traumatol Arthrosc 2011; 19: 1385-93

II. **Ability to perform a single heel-rise is significantly related to patient-reported outcome after Achilles tendon rupture**

    Olsson N, Karlsson J, Eriksson B. I, Brorsson A, Lundberg M, Silbernagel K. G

    Scand J Med Sci Sports; E-published, DOI-10.1111/j.1600-0838.2012.01497.x

III. **A randomized, controlled study comparing stable surgical repair, including accelerated rehabilitation, with non-surgical treatment for acute Achilles tendon rupture**

    Olsson N, Silbernagel K. G, Eriksson B. I, Sansone M, Brorsson A, Nilsson-Helander K, Karlsson J

    Manuscript provisionally accepted for publication in Am J Sports Med.

IV. **Predictors of clinical outcome after an acute Achilles tendon rupture**

    Olsson N, Petzold M, Brorsson A, Karlsson J, Eriksson B. I, Silbernagel K. G

    Manuscript

Contents

ABBREVIATIONS

ADL   Activities of Daily Life

ATRS   Achilles tendon Total Rupture Score

BMI   Body Mass Index

CI   Confidence Interval

Drop CMJ   Drop Counter Movement Jump

EQ-5D™   EuroQol, a generic health-related quality of life score

FAOS   Foot and Ankle Outcome Score

LSI   Limb Symmetry Index

MRI   Magnetic Resonance Imaging

PAS   Physical Activity Scale

QoL   Quality of Life

RCT   Randomized Controlled Trial

ROM   Range of Motion

RR   Relative Risk or Risk Ratio

RSA   Radiostereometric Analysis

SD   Standard Deviation

SMFA   Short Musculoskeletal Function Assessment

SSC   Stretch Shortening Cycle

TSK-SV   Tampa Scale for Kinesiophobia Swedish Version

US   Ultrasonography

VAS   Visual Analogue Scale

DEFINITIONS

Concentric muscle contraction   When a muscle shortens while producing a force

Drop CMJ   Drop jump followed by a vertical jump on one leg

Eccentric muscle contraction   When a muscle lengthens while producing a force

Heel rise   The exercise in which the subject performs a plantar flexion when standing and back down

Hopping   A continuous rhythmical jump, similar to jumping rope

Hopping quotient   Same as plyometric quotient. Flight time divided by contact time

Incidence   The number of new cases of a condition or injury that develop during a specific period of time, such as a year

Kinesiophobia   A specific fear of movement and physical activity that is (wrongfully) assumed to cause re-injury

LSI   Limb symmetry index. The LSI is defined as the ratio of the involved limb score and the uninvolved limb score expressed in percent (involved/uninvolved x x100 = LSI)

Non-parametric statistics   A statistical method where the data is not required to fit a normal distribution

Parametric statistics   A statistical method that relies on assumptions of a normal distribution

Power   **1.** In statistics: the probability that a test will not commit a type II error (Power = 1 - probability of type II error) **2.** The rate at which work is performed. The product of force and velocity. The SI unit is watts (W)

Predictor   The independent variable used to predict or explain the outcome (dependent) variables

Relative risk   The ratio of the probability of the event occurring in the exposed group versus a non-exposed group

Risk factor   A variable associated with an increased risk of injury or disease

Work   The product of a constant force and the distance the object is moved in the direction of the force. The SI unit is joules (J)

The Achilles tendon:

"This tendon, if bruised or cut, causes the most acute fevers, induces choking, deranges the mind, and at length brings death" – Hippocrates

Achilles is the heroic Greek warrior of Homer's *Iliad*, son of Peleus and the nymph Thetis. In the classical version, his mother Thetis made Achilles immortal by immersing him in the river Styx. As she was holding him by the heel, this part of his body remained vulnerable. Another, less famous story tells that Thetis anointed him in ambrosia and put him into the fire to burn all the mortal parts of his body. Peleus interrupted Thetis before she had completed the mission of burning all the mortal parts, leaving the heel vulnerable. In the Trojan War, Achilles killed Hector, the prince of Troy. Hector's brother Paris killed Achilles, with assistance from Apollo, in revenge, by shooting a poisoned arrow into Achilles' unprotected heel.

FIGURE 1 *The Greek warrior Achilles hit by a poisoned arrow*

In 1693, Philip Verheyen (1648-1711), a Dutch surgeon, was the first actually to name the Achilles tendon after the Greek hero Achilles. It had previously been known known as "tendo magnus of Hippocrates".[156] The use of the expression "Achilles heel" to describe an area of general weakness dates from the 19th century.

The Achilles tendon is, however, not weak. It is instead the thickest and strongest tendon in the human body. It is the conjoined tendon of the gastrocnemius and soleus muscles and transfers the force to the calcaneus. Despite its strength, it is susceptible to both overuse injury and acute injury, such as a complete rupture.

The incidence of Achilles tendon rupture appears to be rising and approximately 75% of all ruptures occur during sporting activities.[35] Today, an Achilles tendon rupture is treated surgically, using either the standard open technique or the mini-invasive (percutaneous) technique, or non-surgically, with different mobilization alternatives. There is a wide variation of immobilization methods after both surgical and non-surgical treatment, including a cast and functional brace with or without weight-bearing and range-of-motion training. The main focus in the literature has been to compare the outcome of different treatment options in terms of re-rupture and surgical complications. A large number of medical reports and meta-analyses have been published in the field of Achilles tendon rupture, but there is still a lack of consensus on the best management.

Ambroise Paré (1510-1590) described the first closed rupture as follows:

 "...It oftimes is rent or torn by a small occasion without any sign of injury or solution of continuity on the outside as by a little jump, the slipping aside of the foot, the too nimble getting on horseback, or the slipping of the foot out of the stirrup in mounting into the saddle. When this chance happens, it will give a crack like a coachman's whip: above the head where the tendon is broken the depressed cavity may be felt with your finger; there is great pain in the part and the party is unable to go. This mischance may be amended by long lying and resting in bed and repelling medicines applied to the part....neither must we promise to ourselves or to the patient certain or absolute health. But on the contrary at the beginning of the disease we must foretell that it will never be so cured, and that some relics may remain...".[62]

1.1 ANATOMY

The superficial group of muscles in the posterior crural compartment consists of the gastrocnemius, soleus and plantaris muscles. The most superficial muscle, the gastrocnemius, has two heads of origin. The medial head that arises from the medial condyle of the femur is slightly larger and extends a little more distally than the lateral head. The lateral head arises from the lateral surface of the lateral condyle of the femur. The origin of the soleus muscle is entirely below the knee at the posterior aspect of the head and superior fourth of the fibula, the soleal line and the middle third of the medial border of the tibia. The gastrocnemius and soleus muscles are sometimes together called the triceps surae muscle.[109] The plantaris muscle is very small and absent in approximately 10% of the population and its tendon lies in close proximity to the Achilles tendon.[87] The plantaris tendon can

be used as a graft for reinforcement during Achilles tendon surgery. The Achilles tendon is formed by three flat and broad aponeuroses from each muscle in the triceps surae. The Achilles tendon becomes progressively rounder in shape until it reaches four centimeters from the insertion site at the superior calcaneal tuberosity where it becomes flatter again. Kager's fat pad is located in Kager's triangle between the anterior aspect of the Achilles tendon, the posterior aspect of the tibia and the superior aspect of the calcaneus. It has been hypothesized that this fat pad lubricates the anterior part of the Achilles tendon and also reduces pressure from the tendon.[30] There is a retrocalcaneal bursa that is located between the tendon and the calcaneus. Between the skin and the tendon, there is a subcutaneous bursa, which reduces the friction between the tendon and the surrounding tissues. The fibers of the Achilles tendon rotate 90° during its descent, such that the fibers that lie medially in the proximal portion become more posterior further distally (Figure 2). This spiraling of the tendon contributes to the elongation and elastic recoiling within the tendon.[87] The gastrocnemius muscle acts on both the knee and ankle joint by flexion of the knee and plantar flexion of the ankle but also via supination of the foot. The soleus muscle only acts over the ankle joint and therefore produces a plantar flexion and, to the same extent, a supination of the foot. The gastrocnemius muscle contains a larger number of white, type II fibers producing fast action that is important during activities like running. The soleus muscle contains more of the slow, red type I fibers and is important for maintaining posture.[88] The triceps surae muscles are innervated by the tibial nerve.[109]
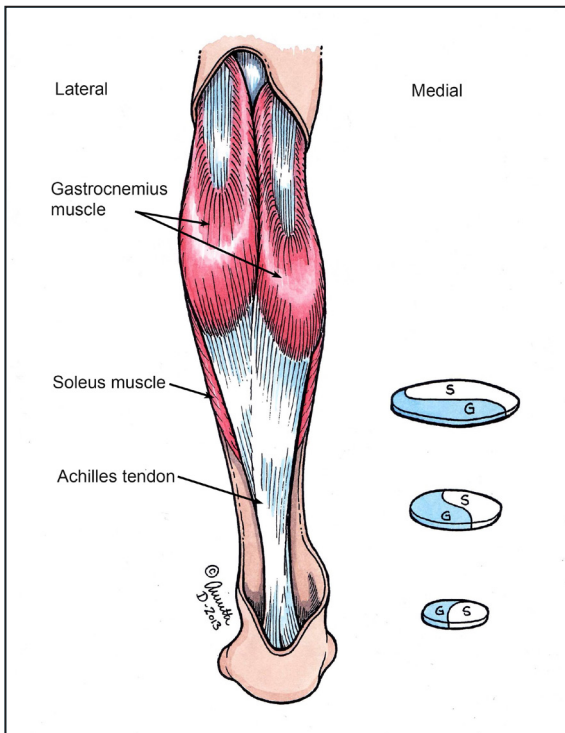

FIGURE 2

The Achilles tendon anatomy and rotation

1.2 STRUCTURE OF THE TENDON

The Achilles tendon is the strongest tendon in the body and needs to resist forces of up to 2.6 kN (approximately 3-4 times the weight of the body) during walking and 9 kN (approximately 12 times the weight of the body) during running.[66] The estimated length of the Achilles tendon is approximately 15 cm from the musculo-tendinous junction and calcaneal insertion.[18] It has been stated that the mean (SD) thickness is 6.5 mm (0.8), with a normal variation between individuals of 25%, and the width is about 2.5 times the thickness.[64] Magnusson et al.[94] reported a larger cross-sectional area of the Achilles tendon in active runners compared with non-runners.

Like all tendons, the Achilles tendon is dominated by type I collagen, which explains its considerable strength. The collagen accounts for 65-80% of the dry weight and elastin approximately 1-2%. The collagen is embedded in a proteoglycan-water matrix. Collagen is produced by fibroblasts and fibrocytes that lie between the collagen fibers in a complex structure.[48] Tendon stem cells have recently been found in human tendons.[170] The synthesis of collagen fibrils follows first as an intracellular step assembling and secreting procollagen. The extracellular step converts the procollagen into tropocollagen. Five tropocollagen molecules (or microfibrils) are cross-linked and aggregated into collagen fibrils.[121] The stability and quality of the collagen is largely based on the cross-links.[59] Multiple collagen fibrils are embedded in the extracellular matrix and form collagen fibers. This is the basic unit of a tendon and the smallest visible (light microscopy) tendon unit.[48]

The tendon is organized in *primary, secondary and tertiary* bundles, even though the nomenclature may vary in the literature (Figure 3).[48, 49] The length of the collagen fibers varies, but it could be as long as the tendon. Tendons in the hand and foot are covered by a synovial sheet. The Achilles tendon does not have a true synovial sheet, but instead it has a peritendinous sheet often called the paratenon. The paratenon functions as a sleeve that allows free movement of the tendon. A fine connective tissue sheath called the epitenon surrounds the tendon and the outer surface is contiguous with the paratenon. Inside the Achilles tendon, the endotenon surrounds the different bundles of the tendon (Figure 3).[48] Blood vessels and nerves run inside the endotenon.[121]
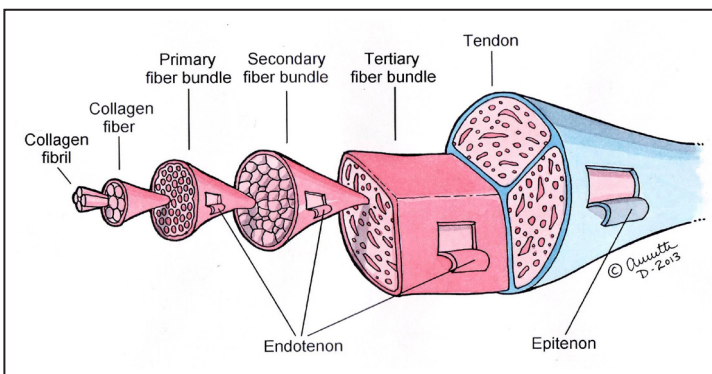

FIGURE 3

The organization of the tendon structure from collagen fibrils to the entire tendon

1.3 CIRCULATION

The Achilles tendon is vascularized by two arteries, the posterior tibial and the peroneal arteries, even though the exact vascularization is not well known.[150] The Achilles tendon is thought to be primarily vascularized by the paratenon, which is known to be a highly vascularized tissue.[150] Three vascular territories have been identified, where the mid-section (4-7 cm from insertion site) is supplied via the peroneal artery and the proximal and distal parts via the posterior tibial artery. The mid-section has less good vascularization than the proximal and distal tendon ends, according to some studies[18] and this section is also the most common rupture site. In a relatively recent review article by Theobald et al.,[150] it was found that the distribution of blood supply along the tendon varies considerably between studies and both the insertion and origin have been reported to be the most hypovascularized areas.

1.4 INNERVATION

The Achilles tendon is supplied by sensory nerves from the contributing muscles, from the nervus suralis and also from nearby cutaneous nerves. There is more innervation in the paratenon than the actual tendon. The paratenon also contains Pacinian corpuscles, which are probably important for proprioception.[88]

1.5 METABOLISM

Tendon tissue was historically thought to be metabolically inert, but today it is well known that tendon cells have an active metabolism.[155] The oxygen consumption of tendons and ligaments is 7.5 times lower than that of skeletal muscle, but it is adequate for the needs of tendon tissue.[45, 121, 155] In healthy tendons, there is a balance between collagen synthesis and degradation.[121] The synthetic activity is high during growth and lessens with age.[45] The important clinical aspect of the metabolic rate of the tendon is its relatively slow healing response. On the other hand, the low metabolism allows the tendon to carry loads and maintain tension for a long period of time.

1.6 BIOMECHANICS

The function of the Achilles tendon is to transmit the forces from the triceps surae muscle to the calcaneus. The tendon possesses substantial elastic potential and, together with the muscular components, this gives the muscle-tendon complex efficiency of force production during various activities.[66] This muscle-tendon complex is active when walking, jumping and running but also during standing for postural control. For optimal function, the tendon must be capable of resisting high tensile forces with limited elongation.[98] When the Achilles tendon is stretched, the stretch shortening cycle (SSC) is activated and the tendon stores elastic energy that is released during the shortening phase.[28, 66] The SSC is a combination of actions that begins with a lengthening of muscle and tendon during an eccentric movement.

This is followed by a concentric muscle contraction and the tendon releases the elastic force.[65] The force is higher during this eccentric-concentric action compared with just a concentric action, due to the utilization of the passive components in both the muscle and tendon.[65, 66, 92]

Komi et al.[66] have studied the in-vivo forces at the Achilles tendon during activities like walking, cycling and running. During a normal gait cycle, they found that the force is built up before the heel contacts the ground and is then released shortly after. There is a second force peak in the Achilles tendon at the end of the push-off phase.

The mechanical properties of tendons can be described in a force-deformation (elongation) curve. Force and deformation are commonly measured when testing tendon structures and these variables together provide a quantitative description of the mechanical behavior of tendons.[92] The more common description in the literature is the stress-strain curve that describes the material property of the tendon.[98] The tendon stress is measured as the force divided by the cross-sectional area of the tendon and strain is measured as the change in the percentage of tendon length during loading. This means that a tendon with a larger cross-sectional area is able to resist higher forces than a thinner tendon and a longer tendon can be stretched further than a shorter tendon before permanent damage occurs.

Young's modulus is the slope of the linear region of the stress-strain curve and it describes the stiffness of the tendon. The Achilles tendon fibers are at rest in a curly configuration but become fully stretched at a strain of 1-3%. At this stage, the tendon is able to return to its initial length when the force is released. When the tendon is stressed and elongated more than approximately 4%, some fibers start to break. Further stress on the tendon will cause the failure of the rest of the fibers in an unpredictable manner and this will result in a complete tendon rupture.[92] There is a variation between studies of tendon strain at failure of 4-16%[92, 166] and 8%[160] is often used as the strain level at which macroscopic failure occurs (Figure 4).
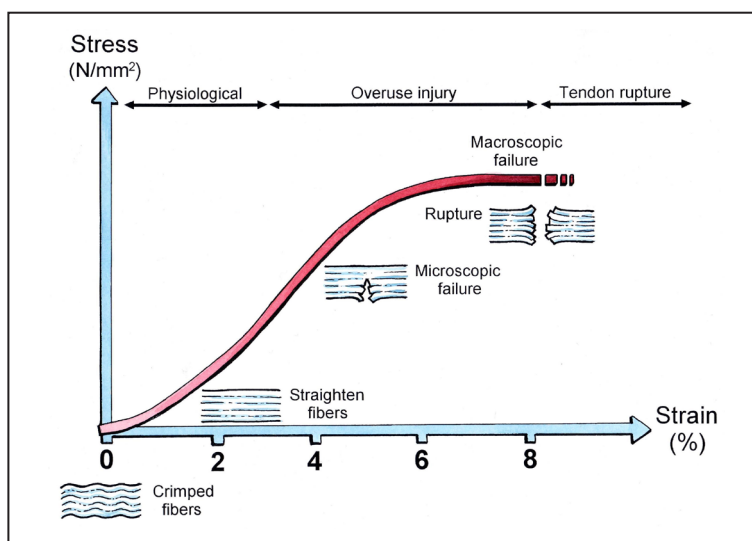

FIGURE 4

Tendon stress–strain curve

1.7 EPIDEMIOLOGY

Jozsa et al.[44] reported that, of all the tendons requiring surgery, the Achilles tendon is the most frequently ruptured. The incidence of Achilles tendon ruptures in the population is increasing.[35,74] Leppilahti et al.[74] reported an annual incidence rising from 2/100,000 in 1979-1986 to 12/100,000 in 1987-1994 and, in a more recent study, Houshian et al.[35] reported an annual incidence rising from 18/100,000 in 1984 to 37/100,000 in 1996. The incidence was highest in the 30-39 year age group. Houshian et al.[35] showed that 73% of the injuries were sports related and the peak of sports-related injuries occurred in the 30-49 age group. There is a second non-sports-related peak in incidence occurring at a mean age of 53 years.[74] There is an almost 200-fold increase in the risk of a contralateral tendon rupture in patients who have previously suffered an Achilles tendon rupture.[7] Most Achilles tendon ruptures occur in men and the ratio between men and women is between 3:1 and 18:1, in general approximately 10:1.[24,35]

1.8 ETIOLOGY

The etiology of Achilles tendon ruptures is regarded as multifactorial,[161] but there is little agreement in the literature. There is some evidence of degenerative changes in the ruptured tendon.[6,90,161] Jozsa et al.[43] showed hypoxic degenerative (necrotic) changes in the ruptured tendon. Aging reduces the collagen fiber diameter [132] and this change, combined with a high activity level, may partly explain the sports-related peak in incidence in the middle-aged group. Mechanical wear and overuse (microtrauma) might lead to permanent tendon weakening and incomplete tendon regeneration.[45] There is limited evidence that both systemic and locally injected corticosteroids are risk factors for Achilles tendon ruptures.[95,114] There are case reports of fluoroquinolone-associated tendon ruptures and also laboratory evidence of a negative effect by fluoroquinolone on tenocytes, but there is no clear conclusion about its role in humans. However, the administration of fluoroquinolones should be carefully considered, especially in patients undergoing corticosteroid treatment.[100] Achilles tendon rupture can also be associated with systemic diseases such as gout, lupus erythematosus and rheumatoid arthritis.

A mechanical theory has been discussed for especially young and healthy patients.[88] In this theory, even a healthy tendon may rupture under violent muscular strain (macrotrauma) in the presence of certain anatomical and functional conditions.[88] A malfunction of the normal inhibitory mechanism of the musculotendinous unit is also suggested as an important part of the mechanical theory.[38]

1.9 MECHANISM OF RUPTURE

The most common injury mechanisms for Achilles tendon ruptures have been classified into three main categories, all with a very distinct patient history [5] In the first mechanism, the patient pushes off with the weight-bearing forefoot while the knee is

extended. This mechanism is described by the majority of patients and is seen in sprint starts, jumping and racket sports. The second mechanism is a sudden, unexpected dorsiflexion of the ankle, which occurs when the patient slips into a hole or falls down stairs. The third mechanism is a violent dorsiflexion of a plantar-flexed foot, which may occur after a fall from height.

1.10 PRESENTATION AND DIAGNOSIS

Patients who sustain an Achilles tendon rupture have a characteristic history of a sudden pain in the Achilles tendon without any previous symptoms. It is often reported by patients that it felt as though they had been struck by something/someone from behind, often accompanied by an audible snap. In the typical case, the diagnosis is clear. The diagnosis is clinical and there is a palpable gap at the site of the rupture during the first week. The ability to plantar-flex the ankle is absent or very weak. In the literature, numerous different clinical diagnostic tests are described.[86]

Sensitivity and specificity have been evaluated for these various clinical tests.[86] The calf-squeeze test and Matles test had the highest sensitivity (0.96 and 0.88 respectively) and specificity (0.93 and 0.85 respectively) and these tests are also non-invasive, simple and inexpensive.[86]

The calf-squeeze test is also known as Simmond's or Thompson's test [152] The patient lies in a prone position and the examiner squeezes the affected calf muscle and, if the tendon is intact, the foot will plantar-flex, but, if the tendon is ruptured, there will be minimal or no reaction in the foot and the test is said to be positive. In the Matles test, the patient actively flexes both knees and a change in foot position is observed. The test is positive if the foot on the injured side moves into neutral or dorsiflexion. Imaging examinations by either ultrasonography (US) and/or magnetic resonance imaging (MRI) are not recommended for routine use to establish the diagnosis in acute ruptures.[19]

1.11 TENDON HEALING

At the moment of injury or directly thereafter, the body initiates a process of healing. Tendon healing is a highly complex process with interaction between blood and tissue-derived cells, inflammatory mediators and matrix molecules. The goal of the healing and repair process is to achieve hemostasis, tissue integrity and load-bearing capacity. The healing process can be divided into three overlapping stages of healing.[45,70]

Inflammation is the first phase which also includes hemostasis and lasts for a few days.[45] This phase starts immediately after injury and the formation of a blood clot, which activates platelets and vasodilatation. For temporary stiffness, a fibrin clot is formed. There is a cascade of pro-inflammatory mediators that leads to angiogenesis and the recruitment of the inflammatory cells to the injury site and these cells start to disintegrate the blood clot and debris.[77]

The second phase, known as the proliferation or repair stage, begins two days after injury and lasts for up to 6 to 8 weeks.[70] This phase is characterized by profuse synthetic activity directed by macrophages and fibroblasts. The macrophages change from being phagocytic to reparative a few days after injury and they direct the cell recruitment and release the growth factors. The fibroblasts produce mostly collagen III for temporary stability at this stage.[158]

The third phase, known as the remodeling or maturation phase, begins one to two months after injury and can last for more than a year. During this phase, collagen I synthesis starts to dominate and the structures become more aligned. At the end of this phase, a mature scar is formed, but the tendon will display a slow yet possibly incomplete recovery of initial properties.[70 158]

1.12 STIMULATION OF HEALING BY MECHANICAL LOAD

Mechanical load and tension over the rupture site is reported to be an important factor in the healing process.[8, 157] Tension over the repair enhances the realignment of collagen fibers. Physical activity and early motion speed up tendon healing by nerve ingrowth and thereby possibly promote the mechanisms of repair in an animal model.[12] Loss of mechanical stimulation has been shown to be very negative for the healing process.[61] In an animal study using botulinum toxin to paralyze the muscle-tendon complex to eliminate the mechanical stimulation, drastic negative effects on callus strength were found.[157] In humans, lack of mechanical stimulation has also been shown to be detrimental.[45, 61] There appears to be a difference in how the healing tendon tolerates various types of mechanical stimulation.[113] The capability to tolerate dynamic movement also appears to improve more rapidly than the ability to withstand static stress.[113]

Tendon is a mechanosensitive tissue and the ability of the cells to respond to mechanical loading is an important component in tendon healing and has been described in a number of studies.[27, 57, 160] Other studies at cellular level indicate that tendon stem cell proliferation with mechanical loading is magnitude dependent, which means that low mechanical stretching may be beneficial to tendons by differentiating tendon stem cells, while high mechanical loading can be detrimental.[170] In human models, mechanical load shows an increase in collagen synthesis and tendon size.[60]

The treatment of Achilles tendon ruptures can be broadly classified as either surgical (open or mini-invasive) and non-surgical (cast or functional brace).
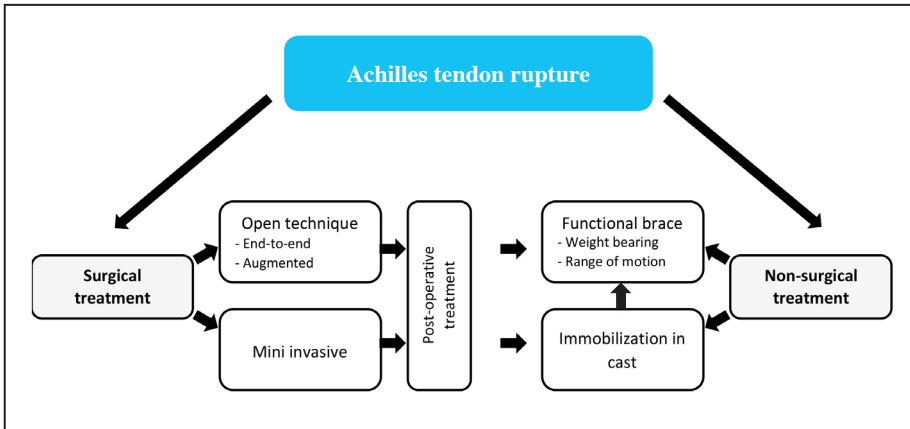
FIGURE 5 *Different methods of treatment for Achilles tendon rupture*

This review of the literature focuses on the main purposes of the thesis.

2.1 SYSTEMATIC REVIEW COMPARING SURGICAL WITH NON-SURGICAL TREATMENT

"Rupture of the achilles tendon should be operated on without delay" Quenu and Stoianovitch 1929[127]

"Operative repair of Achilles tendon rupture is unnecessary" Lea and Smith 1972[69]

This is an overview of reviews and meta-analyses and only includes randomized, controlled studies to avoid bias. The original articles included in the systematic reviews are shown in Table 1. The reviews are presented in order of publication date.

Studies included in the systematic reviews for open surgical versus non-surgical treatment							
	Bhandari et al. 2002	Khan et al. 2005	Cochrane collaboration 2010	Jiang et al. 2012	Jones et al. 2012	Wilkins et al. 2012	Soroceanu et al. 2012
Search date	1969-2001	*	1950-2009	1980-2011	1966-2009	*	*
Nistor et al. 1981	X	X	X	X	X	X	X
Coombs et al. 1981	X						
Cetti et al. 1993	X	X	X	X	X	X	X
Thermann et al. 1995	X						X
Schroeder et al. 1997		X	X	X	X		X
Majewski et al. 2000	X						X
Möller et al. 2001	X	X	X	X	X	X	X
Costa et al. 2006				X			
Twaddle et al. 2007			X	X	X	X	X
Metz et al. 2008			X	X	X	X	X
Willits et al. 2010				X	X	X	X
Nilsson-Helander et al. 2010				X	X	X	X
Keating et al. 2011				X			
Re-rupture rate Surgical vs non-surgical	3.1% vs 13%	3.5% 12.6%	5% vs 12%	4.3% vs 9.7%	4.4% vs 10.6%	3.6% vs 8.8%	5.5% increased risk in non-surgical
Infection rate Surgical vs non-surgical	4.7% vs 0%	4% vs 0%	3.6% vs 0%	3.2%.** vs 0%	3.9% vs 0%	2.4% vs 0%	*
Total complication rate (other than re-rupture)	*	34.1% vs 2.7%	29.2% vs 8.0%	26.6% vs 7.2%	27% vs 6%	*	15.8% increased risk in surgical
* Not defined in the article ** Only superficial infections							

TABLE 1 *Table of systematic reviews*

Treatment of acute Achilles tendon ruptures: a systematic overview and meta-analysis; Bhandari et al. 2002[10]

This is the first systematic review and meta-analysis including only randomized (and quasi-randomized) trials.[10] The purpose was to determine the effect of surgical vs non-surgical treatment of acute Achilles tendon ruptures on the rate of re-rupture. Six studies were included for analysis.[16, 21, 96, 108, 119, 151] The studies varied in terms of surgical technique, rehabilitation and methodological quality. Pooled (n=448 patients) statistical analyses showed that surgical treatment significantly reduced the risk of re-rupture compared with non-surgical (3.1% versus 13%). Five studies (n=421 patients) were analyzed for infection and found that it occurred in 4.7% of the surgically treated patients, with a large variation between studies (from 4% to more than 20%). Pooled analyses for a

return to normal function and risk of spontaneous complaints were also made and they found no significant differences between surgical and non-surgical treatment. The studies did not report any clear definition of these outcomes and this absence of definition can be regarded as a major limitation. The authors postulated that strong recommendations require a large, randomized trial comparing surgical and non-surgical treatment.

Treatment of acute Achilles tendon ruptures. A meta-analysis of randomized, controlled trials; Khan et al. 2005[56]

The aim of this study was to identify and summarize the evidence from randomized, controlled trials on the effectiveness of the various surgical and non-surgical interventions for acute Achilles tendon rupture.[56] This was done by dividing the surgical treatments into open versus percutaneous. The postoperative and non-surgical treatments were divided into cast versus functional bracing. The outcomes were re-rupture and other complications of treatment (adhesions, disturbed sensibility, deep or superficial infection and delayed wound healing). The other outcomes (sport activity, patient satisfaction and length of hospital stay) were not analyzed due to the heterogeneity between the included studies. Pooled (n= 356 patients) statistical analyses from four studies[16, 108, 119, 136] of open surgical treatment versus non-surgical treatment showed a re-rupture rate of 3.5% in the surgically treated group and 12.6% in the non-surgically-treated group (relative risk 0.27, 95% confidence interval, 0.11 to 0.64). The pooled rate of complications other than re-rupture showed 34.1% in the surgically treated group versus 2.7% in the non-surgical group. The authors summarize their results such that non-surgical treatment carries a more than three times higher risk of re-rupture, but there is a minimal risk of other complications related to treatment. One-third of surgically treated patients suffered a complication. Compared with the other systematic reviews, this study found the incidence of surgically related complications to be high. Percutaneous repair was associated with a lower complication rate compared with open repair (relative risk, 2.84, 95% confidence interval, 1.06 to 7.62) and the patients who used a functional brace postoperatively had a lower complication rate compared with the group in a cast (relative risk, 1.88, confidence interval, 1.27 to 2.76).

Surgical interventions for treating acute Achilles tendon ruptures; the Cochrane collaboration – Khan et al. 2010[55]

In a recent Cochrane review, a meta-analysis was performed with the objectives of comparing surgical with non-surgical treatment, open repair with percutaneous surgical repair and different surgical repair techniques.[55] Six studies (n=536 patients)[16, 102, 108, 119, 136, 153] were included in an analysis of surgical versus non-surgical treatment and pooled data found a significantly (p=0.006) lower re-rupture rate in surgical treatment (5%) compared with non-surgical treatment (12%), with a risk ratio of (RR) 0.41 (95% CI 0.21 to 0.77). Other complications related to treatment were also analyzed and pooled data showed that there were significantly more adhesions, infections, other skin-related problems and sural nerve injuries in the surgically treated group. On the other hand,

there is heterogeneity in the way these results have been reported and this should be considered when interpreting the results. The authors conclude that open repair significantly reduces the risk of re-rupture, but it has the limitation of a significantly higher risk of other complications including infection.

Return to pre-injury sports activity level was analyzed and data pooled from four studies[16, 102, 119, 136] showed no statistically significant differences (p=0.86) between surgical versus non-surgical treatment in the included studies. Cetti et al.[16] was the only study that has shown a significant difference in favor of surgical treatment.

For the other outcomes, including patient-reported outcomes, activity and functional evaluation, pooling of the data was not possible due to differences in scoring tools and incomplete data recording.

Operative versus non-operative treatment for acute Achilles tendon rupture: a meta-analysis based on current evidence; Jiang et al. 2012[41]

This study was a meta-analysis of ten randomized, controlled studies[16, 23, 52, 102, 108, 116, 119, 136, 153, 164] (n=894 patients) to determine the advantages and disadvantages of surgical and non-surgical treatment.[41] This study shows that the re-rupture rate in the surgical group was 4.3%, while it was 9.7% in the non-surgical treatment group (relative risk 0.44, 95% confidence interval, 0.26 to 0.74, p=0.002). Due to the different assessment systems for functional evaluation, the authors found it impossible to perform a pooled analysis for this outcome. The authors concluded that surgical treatment is able effectively to reduce the risk of re-ruptures but leads to more complications than non-surgical treatment and there is a need for a larger RCT. The authors conclude that major technical improvements in surgical and non-surgical treatment may change the advantages and disadvantages of each treatment.

Surgical interventions for treating acute Achilles tendon rupture: key findings from a recent Cochrane review; Jones et al. 2012[42]

This study[42] is one of the largest meta-analyses and comes from the same group that made the Cochrane review, but in this study another two recent studies (Willits et al. and Nilsson-Helander et al.)[116, 164] were included. When pooling data from eight studies[16, 102, 108, 116, 119, 136, 153, 164] (n=730 patients), the prevalence of re-rupture associated with open surgical and non-surgical treatment was significantly (p=0.002) lower for surgical treatment (4.4%) compared with non-surgical treatment (10.6%), with a risk ratio (RR) of 0.41 (95% CI 0.24 to 0.72). Möller et al.[108] is, however, the only study in which the difference between the two treatments was statistically significant. This meta-analysis supports the results of the previous studies concerning other complications (infection, adhesions and sural nerve injury/sensory disturbances), with a significantly (p<0.001) higher prevalence in the surgically treated group. Pooling data for function and activity level was not possible in this study due to differences in definitions and variability in scoring tools.

Operative versus non-operative management of acute Achilles tendon ruptures: a quantitative systematic review of randomized, controlled trials; Wilkins et al. 2012[163]

Wilkins et al.[163] published a systematic review of seven randomized, controlled studies (n=677 patients)[16, 102, 108, 116, 119, 153, 164] with the aim of comparing surgical with non-surgical treatment after an acute Achilles tendon rupture.[163] Their primary outcome was re-rupture. Open surgical treatment was related to a significantly lower rate of re-rupture compared with non-surgical treatment (3.6% vs 8.8%), but there was a significantly higher rate of complication (deep infections, non-cosmetic scar complaints and sural nerve dysfunction). Calf muscle strength as a measurement of function was a secondary outcome, but the authors were unable to analyze this variable due to non-standardized evaluations between studies.

Surgical versus non-surgical treatment of acute Achilles tendon rupture: a meta-analysis of randomized trials; Soroceanu et al. 2012[143]

The most recently published meta-analysis of acute Achilles tendon ruptures is from Soroceanu et al.[143] The aim was to compare surgical with non-surgical treatment and also to explore the effect of early range of motion on the re-rupture rate. A pooled analysis of ten randomized, controlled trials (n=826 patients)[16, 96, 102, 108, 116, 119, 136, 151, 153, 164] showed a risk ratio of 0.4 in favor of surgical treatment in terms of re-rupture rate. This meta-analysis defined two groups of studies in which the first group included early range-of-motion training, while the second group did not start this training until 6-8 weeks after the injury. When comparing these two groups, there was no significant difference between surgical and non-surgical treatment in terms of the re-rupture rate (absolute risk difference 1.7%, p=0.45).

This is an important analysis, but it is possible to accuse it of selection bias, since the meta-analysis results are highly dependent on the way the researchers defined early range of motion, which was also the basis for grouping the studies.

Mixture of studies

Five other reviews (Lo et al., Wong et al., Kocher et al., Leppilahti et Orava and Lynch et al.)[63, 73, 79, 83, 165] have compared surgical and non-surgical treatment. These reviews include not only randomized, controlled studies but also a mixture of retrospective and prospective comparative studies. Only reviews and meta-analysis with a high level of evidence are selected in this overview and, for this reason, these studies including a mixture of level of evidence are not discussed further.

2.2 RECENT RANDOMIZED, CONTROLLED STUDIES COMPARING SURGICAL WITH NON-SURGICAL TREATMENT

All the individual randomized, controlled studies that are included in the reviews are not further discussed here, except for the three recently published, high-quality randomized trials. The studies are presented in order of publication date. Möller et al.[108] and Nistor et al.[119], among others, have made an important contribution to current knowledge of acute Achilles tendon ruptures, but these studies are not discussed in detail, since these results are included in the systematic reviews.

Acute Achilles tendon rupture: a randomized, controlled study comparing surgical and non-surgical treatments using validated outcome measures; Nilsson-Helander et al. 2010[116]

Nilsson-Helander et al.[116] studied 97 patients in a randomized, controlled study using validated outcome measurements, comparing open surgical treatment with non-surgical treatment after an acute Achilles tendon rupture. Exactly the same rehabilitation protocol including early range of motion was used in both groups and surgical intervention was the only parameter that differed. The primary outcome was re-rupture and the follow-up was one year. There were two (4%) re-ruptures in the surgically treated group and six (12%) in the non-surgically treated group, but no statistical difference (p=0.377) was found between the groups. In some of the muscle function tests, there were minor advantages in favor of surgical treatment, especially at 6 months. This study concluded that there was no statistically significant difference between surgical and non-surgical treatment. The results suggest that early mobilization is beneficial for patients with acute Achilles tendon rupture, irrespective of surgical or non-surgical treatment.

Operative versus non-operative treatment of acute Achilles tendon ruptures: a multicenter, randomized trial using accelerated functional rehabilitation; Willits et al. 2010[164]

Willits et al.[164] performed a randomized, controlled study comprising 144 patients. The patients were treated with open surgical repair or non-surgical treatment and they all underwent an identical accelerated rehabilitation protocol and were followed for two years. The primary outcome was re-rupture. Two patients (2.8%) in the surgically treated group and three patients (4.2%) in the non-surgically treated group sustained a re-rupture. The p-value is not stated. The authors found no clinically important differences between the groups for the secondary outcomes (strength, the Leppilahti score, range of motion and calf circumference). There were thirteen complications in the surgically treated group and six in the non-surgically treated group, with the main difference being the larger number of soft-tissue-related complications in the operative group. They concluded that this study supports accelerated functional rehabilitation and non-surgical treatment for acute Achilles tendon rupture, since serious complications related to surgery can be avoided.

Operative versus non-operative treatment of acute rupture of tendo Achillis: a prospective, randomised evaluation of functional outcome; Keating et al. 2011[52]

The most recent high-quality, randomized, controlled study is by Keating et al.[52] They randomized a cohort of 80 patients to either open surgical treatment or non-surgical treatment and both groups were immobilized in a cast. The primary outcome measurement was muscle dynamometry and the follow-up was one year. Two (5%) re-ruptures occurred in the surgical group and four (10%) in the non-surgical group (p=0.68). There were no statistically significant differences between the two treatment groups in terms of peak torque or work. They concluded that, based on the complication rates, recommending surgical treatment as a routine for acute Achilles tendon rupture was not supported by their study. Non-surgical treatment remains a valid alternative to surgery.

SUMMARY

These reviews and meta-analyses included high-quality, randomized, controlled studies and they all concluded that surgical treatment involves an approximately 2-4 times lower risk of re-rupture, but that it is related to increased risks of complications, such as scar problems, sural nerve dysfunction and infection. The functional outcome data are inconclusive and no treatment can therefore be recommended over the other according to the data in the reviews and larger studies are needed. The last three individual studies were also inconclusive in terms of recommendations. The re-rupture rate is relatively low regardless of treatment and might therefore not be the most appropriate outcome measurement when comparing treatments.

QUESTION NUMBER 1

What treatment should we use? On what criteria should we base the decision?

2.3 SUMMARY OF SCORING SYSTEMS AND FUNCTIONAL OUTCOME MEASUREMENTS

Achilles tendon rupture-related scores

A variety of different scoring systems are used in the literature, where some include only subjective measurements and others combine both subjective and objective parameters. The Leppilahti score[72] is injury specific and commonly used in Achilles tendon rupture studies.[47, 102, 164] This score has, however, not been evaluated for reliability, validity and responsiveness. The score is a combination of both subjective and objective data, including patient-reported symptoms, range-of-motion measurements and isokinetic muscle strength. In recent studies, there is a trend towards using scores that have been shown to be reliable and valid. The Achilles tendon Total Rupture Score (ATRS) has good reliability, validity and responsiveness[50, 117] and is an injury-specific questionnaire including only subjective parameters. This score was originally developed and evaluated in Swedish, but it has been cross-culturally adapted to English.[15] The English version has also been shown to have good reliability, validity and responsiveness.[15] The Foot and Ankle Outcome Score (FAOS) is also a patient-reported questionnaire for foot- and ankle-related disorders. This score consists of five different subscales (pain, other symptoms, function in daily living, function in sport and recreation and foot- and ankle-related quality of life). It has been shown to have high reliability and validity in patients with ankle ligament injuries, but it has not been evaluated for Achilles tendon ruptures. The Short Musculoskeletal Function Assessment questionnaire (SFMA) has been validated and can be used for clinical assessments of patients with musculoskeletal disease or injury[148] and it has been used as an outcome measurement after Achilles tendon ruptures[52], but this questionnaire is not injury specific.

Functional evaluation

Lower leg function can be affected by various aspects, such as muscle strength and endurance, joint range of motion and symptoms, and the use of several reliable, valid and objective measurements is therefore recommended to describe function. Measurements such as calf circumference, ankle range of motion, calf muscle strength and endurance, jumping ability and gait analysis have been used to evaluate outcome after an Achilles tendon rupture.

Calf circumference is often used as a clinical measurement of muscle hypotrophy, but it cannot be used to determine muscle quality and there is only a weak correlation to calf muscle strength and endurance after treatment for Achilles tendon rupture.[105] Isokinetic testing to evaluate strength is often used and has shown high reliability.[23, 52, 106, 164] Muscular endurance is another type of muscle function measurement; the heel-rise test for endurance has been shown to be reliable and valid for the endurance of the calf muscle.[107, 147] Evaluating both the total amount of work performed and the maximum height of the heel rise is recommended when using this test to evaluate outcome in patients with Achilles tendon rupture.[139] Nilsson-Helander et al.[116] used a test battery

that evaluated not only muscular strength but also jumping ability in order better to understand how overall function is affected by an Achilles tendon rupture. This test battery has been shown to be reliable and valid and has been used in several studies to evaluate outcome after Achilles tendon injury.[115, 116, 138, 139]

SUMMARY

There is a trend towards using more reliable and valid outcome measurements, which reflect both the patient's perspective and objective measurements of function to obtain a wider perspective of patient outcome after an Achilles tendon rupture.

2.4 SHORT- AND LONG-TERM RESULTS AFTER AN ACUTE ACHILLES TENDON RUPTURE

There are several studies that show a deficiency in function after an acute Achilles tendon rupture in both the short and long term.[34, 52, 75, 106, 108, 112, 116, 164]

In the randomized, controlled study by Möller et al.,[106, 108] there were deficits in strength of at least 10% two years after injury in both surgical and non-surgical treatment groups. Endurance testing two years after an Achilles tendon rupture showed that 82% (surgical) and 68% (non-surgical group) were unable to perform more than five single heel rises (non-significant difference). Independent of treatment, 54% of the patients resumed their previous level of sport one year after an Achilles tendon rupture.

Nilsson-Helander et al.[116] reported significantly lower values in terms of jump, endurance and strength tests in the injured leg compared with the uninjured leg both at 6 months (10-46% deficits) and at 12 months (12%-32% deficits). The patient-reported outcome, measured as ATRS, was 88 points in the surgically treated group and 86 points in the non-surgically treated group 12 months after the injury. The physical activity was significantly reduced 12 months post-injury compared with the pre-injury activity level in the same study.

Keating et al.[52] showed deficits in plantar flexion strength compared with the uninjured side of 26% vs. 30% (surgical vs. non-surgical) at 6 months and 20% vs. 25% at 12 months after an Achilles tendon rupture. Similar deficits were found by Willits et al.[164] In the study by Willits et al., the Leppilahti score was 82 points in the surgically treated group and 83 points in the non-surgically treated group two years after an acute Achilles tendon rupture and these values are considered to be good but not excellent in the definition of the score protocol.

In non-randomized cohort studies, there are reports of similar impairments on the injured side compared with the uninjured side. Leppilahti et al.[75] studied a surgically

treated cohort of 101 patients and found a 3-17% impairment in muscle strength after an Achilles tendon rupture and these deficits were even greater in females. Horstmann et al.[34] studied the long-term result (10 years) in a cohort (n=63 patients) after surgically treated Achilles tendon ruptures. A significant difference in plantar flexion work of approximately 15% and a difference in heel-rise height of 0.5 cm were found between the injured side and the uninjured contralateral side. In a study by Mullaney et al.,[112] a significant plantar flexion strength deficit of 20-34% (p<0.001) was reported approximately two years after surgical treatment and 14 of 17 patients were unable to perform a heel rise standing on a decline. These differences could not be seen in a heel rise standing on an incline and no strength weakness was found in dorsiflexion. They hypothesized that this difference was due to increased tendon length because the muscle is already in the shortened position when the ankle is in the plantar flexion position and below the angle of optimal force production. They concluded that weakness in end-range plantar flexion might be an unrecognized problem after Achilles tendon repair.

<div style="border:1px solid">

SUMMARY

There are important deficits in function in both the short and long term, but there is no clear evidence in favor of one specific treatment over the other. The reasons for these deficits are unclear and the factors that can predict the functional outcome are unknown.

</div>

<div style="border:1px solid">

QUESTION NUMBER 2

What factors are responsible for deficits in function and patient-reported outcome?

</div>

2.5 WEIGHT-BEARING AND FUNCTIONAL BRACING AFTER AN ACUTE ACHILLES TENDON RUPTURE

The rate of re-ruptures has decreased in recent studies[37, 56, 153, 159, 164] and this is interpreted as a result of a more active functional rehabilitation protocol. The first study to describe immediate weight-bearing and a functional bracing protocol was published by Speck and Klaue.[144] There is wide heterogeneity in terms of early rehabilitation protocols, with various methods of early weight-bearing and functional bracing, and this complexity results in increased difficulty when comparing different studies.[56] In a systematic review, Kearney et al.[51] found (n=424 patients) that the efficacy of different immediate weight-bearing rehabilitation protocols following an acute Achilles tendon rupture remains unclear.

In a study by Maffulli et al.[91] in patients treated with open surgical repair, early weight-bearing and ankle mobilization were compared with a less active rehabilitation protocol. They found more satisfied patients and a shorter time for rehabilitation in the early weight-bearing group, but no significant differences were found in terms of strength and muscle hypotrophy. Kangas et al.[46] performed a similar randomized, controlled study and also concluded that early functional postoperative treatment after Achilles tendon rupture repair can be recommended.

Khan et al.[56] performed a meta-analysis of five studies[17,47,53,91,110] (n=273 patients) comparing different kinds of postoperative immobilization (cast vs. cast and functional bracing) and found a re-rupture rate of 5.0% in the cast group compared with 2.3% in the group with functional bracing. When they pooled data from two studies[126,131] (n=90 patients) of non-surgical treatment, they found a re-rupture rate of 2.4% in the non-surgically treated group with a functional brace and 12.2% in the group treated with a cast alone.

Costa et al.[23] performed two independent, randomized, controlled studies in order to assess the potential benefits of immediate weight-bearing in the rehabilitation protocol after an acute Achilles tendon rupture. The first study (n=48 patients) was performed on surgically treated patients and the second study (n=48 patients) on non-surgically treated patients. Patients were randomized to either immediate weight-bearing in a functional brace or non-weight-bearing in a cast. The primary outcome was the time of a return to normal activities as reported by the patient and the follow-up was one year. The first trial showed an improved functional outcome for patients mobilized to full weight-bearing after surgical repair, e.g. an earlier return to walking and stair climbing. This beneficial effect of immediate weight-bearing was, however, not shown in the non-surgically treated study. They concluded that the practical advantages of immediate weight-bearing did not predispose to a higher rate of complications, thereby supporting the use of an immediate weight-bearing protocol in rehabilitation after an acute Achilles tendon rupture.

In a meta-analysis involving six trials (n=315 patients), Suchak et al.[146] aimed to determine whether an early functional rehabilitation protocol improved patient satisfaction without any increase in re-rupture rates. Variables, such as infection, range of motion, strength and minor complications, were also analyzed. They found that early functional treatment protocols improved patient satisfaction with a reduction in minor complications and no increase in re-rupture or infection rate. This was, however, based on trials with small sample sizes and they concluded that larger randomized trials are required to confirm these results.

Suchak et al.[145] compared early weight-bearing with non-weight-bearing after surgical repair in a randomized, controlled study of 110 patients. At six weeks, they found that the weight-bearing group had significantly higher scores for health-related quality of life, but, at six months, no difference was found in any of the outcomes (health-related quality of life, activity level, calf muscle strength, ankle range of motion, return to sports and work and complications). They concluded that early weight-bearing after the surgical repair of an acute Achilles tendon rupture improves health-related quality of life in the early postoperative period and has no detrimental effect on recovery.

SUMMARY

Early weight-bearing and accelerated rehabilitation are well tolerated by patients and there is no evidence of a higher rate of complications, even though there is a fine balance between load on the tendon and the risk of complication.

2.6 DIFFERENT SURGICAL TECHNIQUES

The goal of the specific surgical technique is to obtain sufficient strength during the healing process and optimal tendon length without any increased risk of complications.

2.6.1 Surgical suture technique

In vitro

In a recent systematic review of eleven papers (n=196 repairs) by Sadoghi et al.,[130] the initial strength of different surgical techniques was analyzed from human cadaver trials. The techniques reported for open repair were the Kessler, Bunnell, triple-bundle, Krackow and Giftbox (modified Krackow) techniques and, for mini-invasive repair, the Ma-Griffith technique and the Achillon® device.[20, 26, 29, 32, 36, 40, 68, 71, 99, 137, 169] The mean initial strength of the different techniques showed a variation from 150N to 453N, with the triple-bundle technique performing best. The Kessler, Krackow and "Giftbox" techniques showed similar results of approximately 170N, while the Bunnell technique obtained a slightly higher value (217N). The mini-invasive techniques showed a low value for Ma-Griffith (150N) and a high value for the Achillon® device (342N). Cadaveric animal models by Yildirim et al.[167] produced similar results, where the Kessler technique was less resistant to tensile forces, the Krackow locking loop was most resistant and the Bunnell technique came in between. In a cadaveric study by Lee et al.,[71] epitendinous suture augmentation with the criss-cross technique has been shown to withstand higher forces than non-augmentation.

Shepard et al.[137] showed in a cadaveric study that repairs augmented with epitenon sutures had greater resistance to gap formation and increased the average load to failure by 119%. A biomechanical study of porcine tendons by Hirpara et al.[33] showed a significant increase in the strength of repair with multiple strands without any increased bulking of the tendon and the same study showed that the Silfverskiöld technique[141, 142] (peripheral criss-cross stich) greatly increases the strength of the core repair. Kim et al.[58] showed in canine tendons that an epitenon cross-stich increased the tensile strength by 245%.

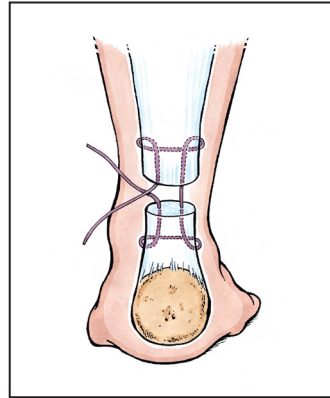**FIGURE 6** *Open surgical suture techniques illustrated:*
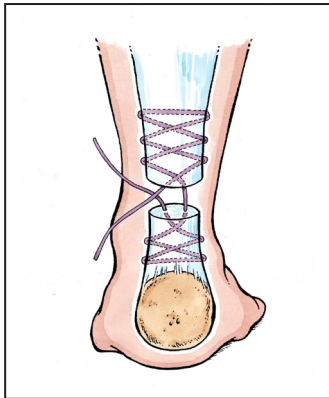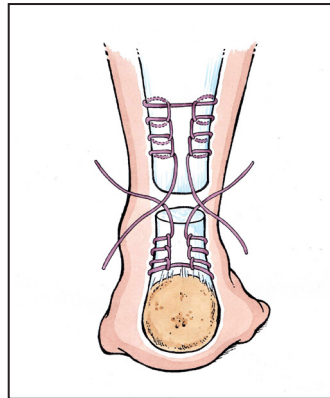

FIGURE 6A *Kessler*

FIGURE 6B *Bunnell*
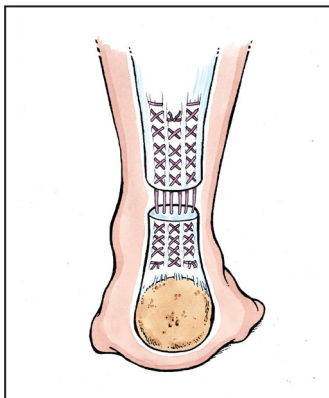

FIGURE 6C *Krackow*
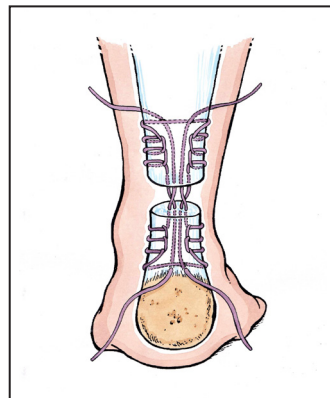

FIGURE 6D *triple-bundle*

FIGURE 6E *"giftbox"*

In vivo

Mortensen et al.[111] performed a randomized trial comparing a two-strand (Mason suture technique) and six-strand technique (reinforced continuous six strand). The patients had metal markers inserted during surgery in the tendon that were detectable by radiology for the measurement of tendon-end separation. There were no differences between the two techniques in terms of separation or complications.

Uchiyama et al.[154] performed a case series of 100 patients with a modified surgical repair. The length of the tendon was adjusted by a Tsuge suture and the tendon ends were separated into two or three bundles, where each of them was sutured with a Bunnell-like technique. Initial cast immobilization, followed by a brace, was used. Full weight-bearing was allowed at week two and immobilization ended at week 5. Single heel rises were achieved at a mean of 12 weeks and jogging started at a mean of 15 weeks. Two (2%) re-ruptures occurred.

Yotsumoto et al.[168] performed a new approach to surgical repair and rehabilitation in a case series of 20 patients. They used their own design of a side-locking loop technique and peripheral criss-cross stiches and no immobilization was used. Partial weight-bearing walking started after the first week and full weight-bearing walking began from the fourth week. They found no complications and 20 continuous single heel rises were possible at an average of 10 weeks. The patients were able to resume sports activities or heavy labor at an average of 14 weeks.

Aoki et al.[3] performed a case series of open surgical repair with a single Kirschmayer core suture (similar to Kessler) and cross-stitch epitenon suture of 22 patients. The patients were immobilized in a splint for 2 to 5 days and full weight-bearing was allowed at 2 weeks postoperatively. Patients were allowed to return to sports when they were able to perform a pain-free single heel rise. The patients returned to full sports activity at an average of 13 weeks, but two partial re-ruptures occurred.

2.6.2 Augmented repair

Pajala et al.[125] randomized sixty patients to either end-to-end repair with the use of Krackow locking-loop technique or augmented repair using a down-turned gastrocnemius fascia and the same immobilization and rehabilitation of both groups. No significant differences were found between the two groups according to symptom and functional evaluation. This study concluded that augmented repair had no advantage over end-to-end repair in an acute Achilles tendon rupture. Another randomized study of thirty patients comparing end-to-end sutures (Krackow locking-loop technique) with augmented repair with the plantaris tendon was performed by Aktas et al.[1] This study was unable to find any significant differences in favor of augmented surgery and recommended end-to-end repair in acute cases of Achilles tendon rupture.

2.6.3 Mini-invasive repair

The first mini-invasive or percutaneous technique for the surgical repair of the Achilles tendon was described in 1977 by Ma and Griffith.[84] No re-ruptures occurred in their study of 18 patients. Several modifications of this technique have been made and a randomized, controlled study was performed by Lim et al.[76] In this study, 66 patients were randomized to either percutaneous repair or open surgical repair. Due to the significantly lower infection rate in the percutaneous group and the enhanced cosmetic result, they concluded that this technique was superior.

FIGURE 7

Percutaneous surgical suture techniques illustrated:
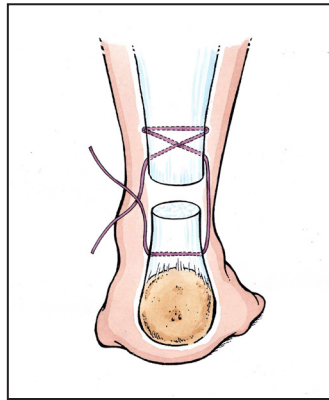
FIGURE 7A *Ma–Griffth*
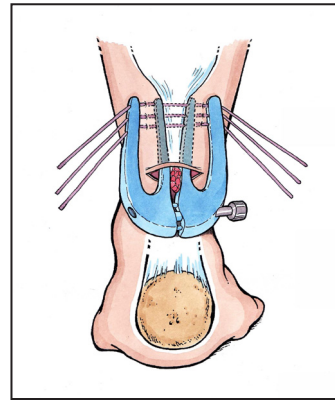
FIGURE 7B *Achillon® device*

Khan et al.[56] compared open surgical treatment with percutaneous surgical treatment in a systematic review and included two studies[76, 136] (94 patients). They found that the pooled rate of re-rupture was 4.3% in open surgical treatment and 2.1% in the percutaneously treated group. Complications other than re-rupture were 26.1% in the open surgical group and 8.3% in the percutaneous group.

In the meta-analysis from the Cochrane collaboration by Khan et al.[55] of four small studies (n=174) comparing open versus percutaneous repair, no significant reduction in re-rupture rate in percutaneous repair compared with open surgical repair could be shown. There was a significantly higher infection rate in the open surgical group compared with the percutaneous group. Only one patient in all four studies reported a sural nerve injury in the percutaneously treated group. This low rate of sural nerve injury in percutaneous treatment contrasts with the case-control study by Majewski et al.,[97] which reported an incidence of 18% of sural nerve-related complications. In a study by Cretnik et al., the incidence of sural nerve damage was 4.8%.[25] To summarize, the Cochrane review found that the percutaneously treated group showed a tendency towards a lower complication rate.

Metz et al.[101] published a retrospective case series of 340 patients treated with the mini-invasive repair of acute Achilles tendon rupture and 211 patients were re-evaluated and returned a completed questionnaire. The mean follow-up was 6 years and, at that point, a mean ATRS of 84, a re-rupture incidence of 8% and sural nerve injury of 19% were found. One patient suffered a severe wound infection and 6% experienced a minor wound-healing complication. In spite of this, they concluded that the long-term outcome was excellent.

SUMMARY

Limited conclusions can be drawn with regard to different suture techniques for the open repair of an acute Achilles tendon rupture. Tendon augmentation has not shown any superior results over end-to-end sutures. Studies of mini-invasive techniques indicate a decreased incidence of wound complications, especially infection, but this technique might increase the risk of sural nerve injury.

QUESTION NUMBER 3

Can a stable surgical repair, which tolerates immediate tendon load, improve measurements of patient reported-symptoms, overall quality of life and functional outcome?

2.7 ACHILLES TENDON LENGTH

In their studies, Mortensen et al.[111] and Nyström and Holmlund[120] showed a biphasic separation of tendon ends after surgically treated Achilles tendon ruptures, which was initiated the first week, followed by a second separation after another couple of weeks. Kangas et al.[46] randomized fifty patients to receive either a cast or a movable brace for six weeks after open surgical repair. Radiographic markers were inserted into the tendon to measure the separation of the tendon ends. The elongation was less in the early motion group (2 mm vs 5 mm; p= 0.054) and elongation correlated significantly to clinical outcome measured by the Leppilahti score. Schepull et al.[135] used radiostereometry (RSA) and showed a tendon elongation between the 3rd and 7th weeks of (median) 3.1 mm and between the 7th and 19th weeks of (median) 4.7 mm. In this study, there were no differences between surgical and non-surgical treatment with regard to tendon elongation. In an expert opinion article, Maquirrian[98] discussed how to avoid tendon lengthening and recommended secure tendon fixation repair, but without any clear conclusions on how to reach that goal.

Since there is an indication that tendon elongation has a negative effect on patient clinical outcome, it is of interest to include these measurements in treatment studies. However, the use of radiographic markers as a measurement of tendon length is not practical for large-scale clinical trials. Using other simpler methods would be beneficial. Costa et al. [22] have shown in a cadaveric study that the Achilles tendon is the anatomical structure limiting ankle dorsiflexion and an increase of one centimeter in length will result in an increase in dorsiflexion of 12 degrees. Ankle dorsiflexion is therefore a useful indicator of tendon length. Silbernagel et al.[140] measured tendon length non-invasively with ultrasound imaging and compared it with heel-rise height in a case series of both patients with healed Achilles tendon ruptures and healthy subjects. They found that the deficit in maximum heel-rise height correlated significantly with tendon lengthening and they therefore recommended this test as an indirect measurement of tendon elongation. The physiological Achilles tendon length has recently been described as correlating significantly with both tibia length and body height.[129] This might be useful knowledge when optimizing the Achilles length during surgery.

SUMMARY

Tendon lengthening is probably an important factor relating to the deficits in function following an Achilles tendon rupture.

QUESTION NUMBER 4

How can tendon elongation be avoided? Can tendon length be optimized during surgery and will this minimize tendon elongation in the long term? Is there a difference between surgical and non-surgical treatment in this respect?

2.8 PREDICTOR STUDIES

Bostick et al.[11] studied the possible predictive factors for the recovery of calf muscle endurance one year after the surgical repair of acute Achilles tendon rupture. This was an exploratory analysis of data from a randomized, controlled study evaluating the effects of weight-bearing.[145] Calf muscle endurance was measured as the maximum number of repetitions of single-legged heel rises. This study analyzed the factors in a multivariate linear regression model and found that male gender and Achilles pain at rest at three months were negative predictors of calf endurance at one year. They also found that lower physical functioning and calf endurance at six months were associated with reduced levels of calf endurance at one year. The finding relating to gender is in contrast

to the findings of Leppilahti et al.,[75] where the strength was reduced in females. In a pilot study of ten patients, Schepull et al.[134] showed a correlation between mechanical tendon properties (modulus) and functional outcome.

SUMMARY

There is limited knowledge about the predictive factors for outcome after an acute Achilles tendon rupture. The identification of important predictive factors would be beneficial for both an understanding of how to individualize treatments and when designing future treatment protocols.

QUESTION NUMBER 5

Which are the most important factors predicting outcome?

CONCLUSION

A new large-scale, randomized, controlled study is needed to answer the five questions.

Study I

To evaluate the long-term results 24 months after Achilles tendon rupture, using standardized, validated assessment methods for symptoms and function in patients treated surgically or non-surgically. A specific question of interest was to evaluate whether any improvement could be demonstrated after the first year.

Study II

To evaluate the recovery of function 12 weeks after injury and to study how function relates to patient-reported outcomes, with regard to lower limb function, as well as general health and quality of life. The secondary aim was to evaluate the degree of patients' fear of movement and how this fear relates to function and patient-reported symptoms.

Study III

To evaluate whether early loading of the tendon with stable surgical repair and early-accelerated tendon loading and range-of-motion training could improve patient-reported outcome and function after a total acute Achilles tendon rupture.

Study IV

The aim of this study was to investigate predictors of both symptomatic and functional outcome after an acute Achilles tendon rupture.

4.1 TREATMENT STUDY I

Surgical group

Forty-two patients in Study I were treated with open surgical repair. Surgery was performed with the patient in the prone position under local, spinal, or general anesthesia. A posteromedial skin incision including the paratenon was made over the rupture site. An end-to-end suture was placed using a modified Kessler suture technique[54] with 1-0 polydioxanone (PDS) sutures (PDS II, Ethicon, Somerville, New Jersey). Some variation in surgical technique occurred due to different preferences of the surgeon. The paratenon was carefully repaired and the skin closed with interrupted nylon sutures. Surgery was performed by 28 orthopedic surgeons familiar with the technique. Postoperatively, the patients were placed in a below-the-knee cast with the foot in a 30° equinus position for 2 weeks.

Non-surgical group

Thirty-nine of the patients in Study I were treated non-surgically. The patients were treated immediately after randomization with a below-the-knee cast with the foot in the equinus position for 2 weeks.

Immobilization

Both the surgical and non-surgical treatment groups used the same immobilization and rehabilitation program.

After the first two weeks in a cast, the immobilization shifted to an adjustable brace (DonJoy ROM Walker, DJO Nordic AB, Malmö, Sweden) for the next 6 weeks. The brace was set at free plantar flexion motion with dorsiflexion limited to -30° for the first 2 weeks, -10° for the next 2 weeks and +10° for the last 2 weeks. Weight-bearing as tolerated was allowed after 6 to 8 weeks. A physical therapist adjusted the brace and the patients were not allowed to remove the brace themselves.

Rehabilitation

All the patients followed a standardized rehabilitation protocol, previously published by Nilsson-Helander et al.[116], under the supervision of 2 experienced physical therapists.

4.2 TREATMENT STUDIES II, III, IV

Surgical group

Forty-nine patients were treated surgically by one of ten experienced orthopedic surgeons using the same standardized technique. Surgery was performed in all patients under local anesthesia. Prophylactic antibiotics (cloxacillin) and prophylaxis against deep-vein thrombosis (dalteparin natrium) were given, due to the high risk of deep venous thrombosis.[118] Patients were operated on in the prone position, without a tourniquet. A posteromedial skin incision was made over the rupture site and the paratenon was then carefully identified before further incision. The tendon was repaired end to end using core suturing with two strong, semi-absorbable sutures (No.-2 Orthocord™, Depuy Mitek, Norwood, MA) using a modified Kessler technique.[54] The double Kessler locking loop was carefully placed away from the rupture site and sutured in healthy tendon to achieve the greatest stability. The foot was placed in plantar flexion to close the gap in the tendon. Care was taken not to overtension the tendon with maximum plantar flexion of approximately 20° to suit the brace. A running circumferential suture was used with absorbable sutures (No.-0 Polysorb™, Tyco, Norwalk, CT), using an epitendinal criss-cross technique described by Silfverskiöld et al.[141] to reinforce the core sutures (Figure 8-10). The paratenon was then carefully repaired with absorbable No.3-0 Polysorb™ and continuous No.2-0 Polysorb™ subcutaneous sutures. Interrupted nylon sutures were used in the skin layer to ensure meticulous wound closure. No cast was used and the ankle was postoperatively immobilized in a pneumatic walker brace (Aircast XP Diabetic Walker, DJO, Vista, CA), including three heel pads that produce a plantar flexion angle of approximately 22° (Figure 11). A soft 5 mm inner sole was used to compensate for the somewhat stiff heel pads. Patients were allowed full weight-bearing, which was encouraged from the first postoperative day.

FIGURE 8

Illustration of the surgical technique
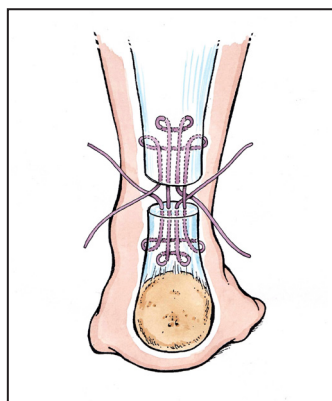
FIGURE 8A *Core suture*
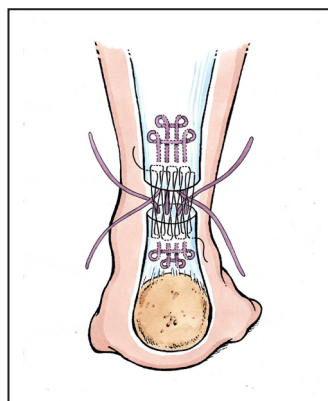
FIGURE 8B *Criss–cross suture*
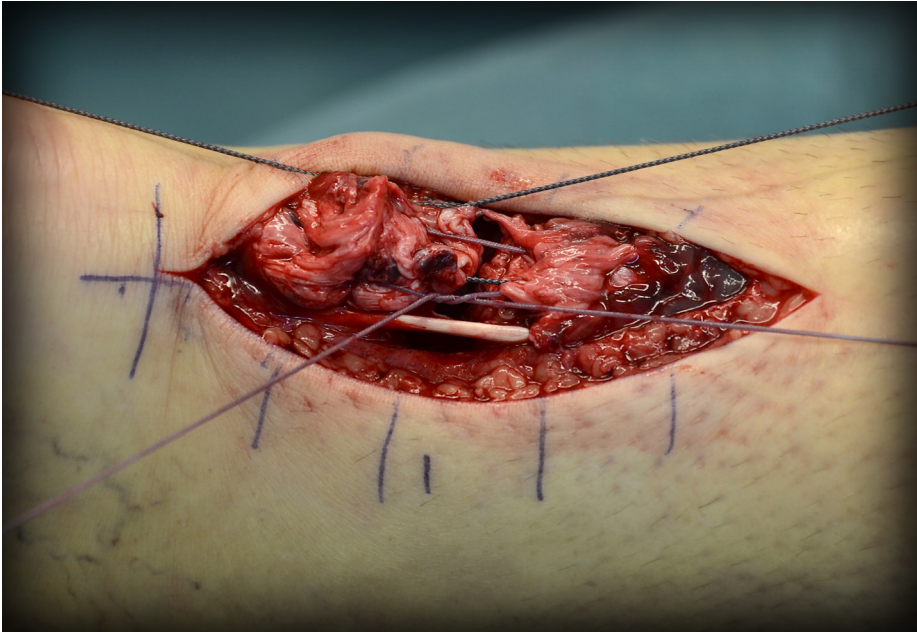
FIGURE 9   *Picture showing the double Kessler locking-loop technique*
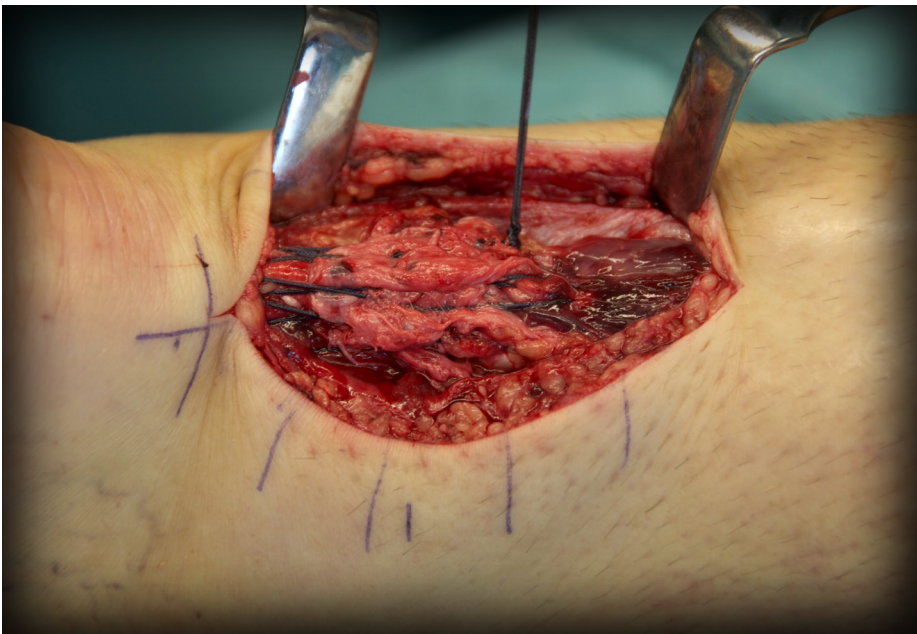
FIGURE 10   *Picture showing the epitendinal criss-cross technique*

Three experienced physical therapists supervised the postoperative care and the rehabilitation of all the patients and early active rehabilitation started postoperatively following a standardized protocol (Appendix 1).

At two weeks, training without the brace involved range-of-motion training up to 15° of plantar flexion, plantar flexion strength training within the same range using a rubber band as resistance and sitting heel rises. Exercise with the brace included cycling, gait and balance training. Two heel pads were used in the brace at this point.

At four weeks, the progression of the exercises included range-of-motion training without the brace at up to 10° of plantar flexion, increased resistance during the plantar flexion strengthening exercise and sitting heel rises with a light weight. Training of the lower limb continued with the brace on and the brace was used with one heel pad.

At five weeks, the progression involved performing the same exercises but with greater resistance and allowing motion at up to 0° of plantar flexion. The brace was used without heel pads.

At six weeks, the period of mobilization with a brace ended and shoes with heel lifts were used for another four weeks. Gait and strength training with heel rises up to 50% of body weight was initiated.

After eight weeks, the training gradually increased to single heel rises with full body weight.

At 12 weeks, gentle jogging and two-legged jumps were introduced.

FIGURE 11

Picture of the Aircast walker brace

Non-surgical group

Fifty-one patients were included in the non-surgical group. Treatment started immediately after randomization, using the same brace as in the surgical group, including the three heel pads. Full weight-bearing was allowed and encouraged from the beginning in the same manner as for the surgical group. This treatment group used another standardized protocol (Appendix 2). The patients were mobilized in the same walker brace (Figure 11) for eight weeks and no strength or range of motion training was permitted during the first eight weeks. The plantar flexion angle was gradually reduced in the brace and the heel pads were removed at two, four and six weeks. After the removal of the brace at eight weeks, shoes with heel lifts were used for another six weeks. This group had training similar to that of the surgically treated group but with a shift towards a delayed start of approximately four weeks. Gentle jogging and two-legged jumps were introduced at week sixteen.

Similar non-operative treatment has previously been described by Ingvar et al.[9,39]

4.3 PRIMARY OUTCOME IN THE RANDOMIZED, CONTROLLED STUDIES

Study I is a two-year follow-up from the previously reported randomized, controlled trial by Nilsson-Helander et al.[116] in which the primary outcome was re-rupture. In the randomized, controlled trial, Study III, the primary outcome was the Achilles tendon Total Rupture Score (ATRS).

4.4 EVALUATION

The patients were evaluated using patient-reported outcomes and functional evaluation tests by the same physical therapist at our testing laboratory. The evaluating physical therapist was not involved in the treatment of the patients. All patient-reported outcome data in this study were collected using a web-based protocol. This minimized the risk of missing values and lost data.

	Study I	Study II	Study III	Study IV
3-month evaluation weeks		12 (0.9)	12 (0.7)	12 (0.7)
6-month evaluation weeks			28 (2.1)	28 (2.1)
12-month evaluation weeks	Approx. 12 months*		56 (4.3)	56 (4.3)
24-month evaluation	Approx. 24 months*			
The data are reported as the mean (SD) *No exact data available				

TABLE 2 *Time of evaluation in the studies*

4.5 PATIENT-REPORTED OUTCOME AND PHYSICAL ACTIVITY

Prior to the functional testing, the patients answered five different questionnaires. They have been used in previous studies of the outcome after an Achilles tendon rupture and have been shown to be reliable and valid.[31, 117, 128]

To evaluate injury-specific, patient-reported outcome, we used the Achilles tendon Total Rupture Score (ATRS).[15, 50, 117] The ATRS ranges from 0 to 100; a lower score indicates greater limitations to physical activity and more symptoms. For a foot and ankle perspective, three subscales of the Foot and Ankle Outcome Score (FAOS)[128] were used: Function in daily living (ADL), Function in sport and recreation (Sport&Rec) and Foot- and ankle-related Quality of Life (QOL). All the subscales of FAOS scores range from 0 to 100. A score of 0 indicates a high degree of foot- and ankle-related symptoms, whereas 100 indicates no symptoms. The Physical Activity Scale (PAS) questionnaire[31] was used to evaluate the activity level. A score of 1 is equal to no physical activity, whereas a score of 6 equals heavy physical exercise several times a week. General health-related quality of life was measured by the EQ-5D (EuroQol Group).[13, 149] An EQ-5D score of 0 is considered to be the worst imaginable health state and a score of 1.00 the best imaginable health state. The quality of life scores, the FAOS QOL and EQ-5D, differ from one another in terms of different perspectives, such as quality of life from a foot and ankle perspective (FAOS) or a total health state (EQ-5D). Fear of physical activity and movement was measured with the Tampa Scale for Kinesiophobia Swedish Version (TSK-SV)[81] The TSK values varied between 17 and 68. A high TSK value indicates a high degree of kinesiophobia. Kinesiophobia is defined when the value is higher than 37.

	Study I	Study II	Study III	Study IV
ATRS	X	X	X	X
FAOS		X	X	
PAS	X	X	X	X
EQ-5D		X	X	X
TSK-SV		X		X

TABLE 3 *Patient-reported scores in the studies*

4.6 FUNCTIONAL EVALUATION

Function is an overall term that includes various abilities such as walking, jumping and running, all of which are dependent on aspects of muscular strength and endurance. To evaluate function after an injury, it is recommended to use a battery of tests in order better to describe a patient's overall function. In the studies included in this thesis, we

used a test battery that was designed to evaluate lower leg function in patients with Achilles tendon injury. The functional evaluation protocol consisted of two different jump tests, two different muscle strength tests and one muscular endurance test and all the tests were performed exactly as previously described in the literature.[116, 138, 139] The tests have been shown to be reliable and valid, have the ability to detect changes over time[107, 138, 139] and have been used in evaluating outcome after Achilles tendon rupture.[115, 117, 139] All the evaluations were performed by the same experienced physical therapist. The tests were always performed in the same order and all the patients were given standardized instructions. The subjects also performed 3-5 practice trials prior to testing. Verbal encouragement was used and athletic footwear was standardized. Prior to testing, the patients warmed up on a stationary bicycle for five minutes, followed by 3 sets of 10 two-legged heel rises.

A MuscleLab® (Ergotest Technology, Oslo, Norway) measurement system was used for the evaluations. MuscleLab® is a data collection unit with sensors of different kinds. For the jump tests, a "light mat", consisting of a field of infrared light beams, approximately 4 mm above the floor, connected to a timer that was triggered when the light beams were interrupted, was used. The response time is better than or equal to 2 ms. With this set-up, ground contact time and air flight times were recorded and jump height in centimeters was calculated by the system. A so-called linear encoder was used for the strength and endurance tests. Inside the linear encoder unit, a spring-loaded string is connected to a sensor. When the string is pulled, the sensor outputs a series of digital pulses that are proportional to the distance traveled. The resolution is approximately one pulse every 0.07 mm. Velocity, force and power (force times velocity) are calculated by counting the number of pulses/time and the total weight (body weight + external load). The spring-loaded string of the linear encoder was attached to the heel of the subject's shoe.

Jump test

The jump tests were a drop counter-movement jump (drop CMJ) and hopping. For the drop CMJ, the subjects started by standing on one leg, on a 20-cm-high box, then jumped down onto the floor and directly afterwards performed a maximum vertical jump. For data analysis, the maximum jumping height in cm was used. Hopping is a continuously rhythmical jump similar to skipping performed on one leg at a time. The patients performed 25 jumps, the average air flight and floor contact times were documented and the plyometric quotient (flight time/contact time) was used for data analysis. For data analysis the mean hopping height in cm was used. To calculate the plyometric quotient, the mean flight time/contact time was used.
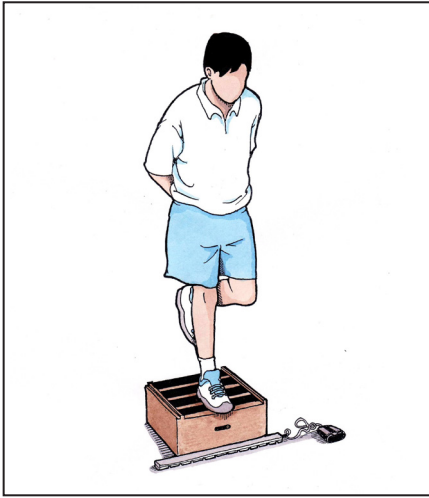
FIGURE 12 *The drop counter–movement jump test*
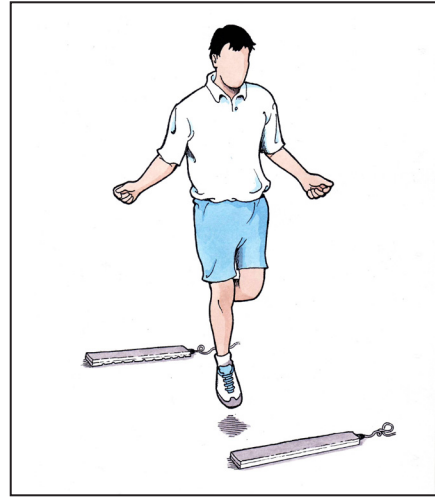
FIGURE 13 *The hopping test*

Strength test

The strength tests were a concentric heel rise and an eccentric-concentric heel rise performed standing on one leg in a weight machine. The patients performed three trials on each weight. The subjects started with 13 kg and increased by 10 kg until a decrease in power output was seen or the heel rise was less than two cm or the patient was unable to perform the test due to discomfort. The starting position was standing in the machine on both legs. The shoes had a mark to indicate where the foot should be placed and the shoulder positions were also standardized. During the heel rise, the subjects were not allowed to bend their knee more than 20 degrees. The starting position was the end range of dorsiflexion for the concentric heel rise and full plantar flexion for the eccentric-concentric heel rise. The best trial, i.e. the trial with the highest power in watts, for each weight was used for data analysis.
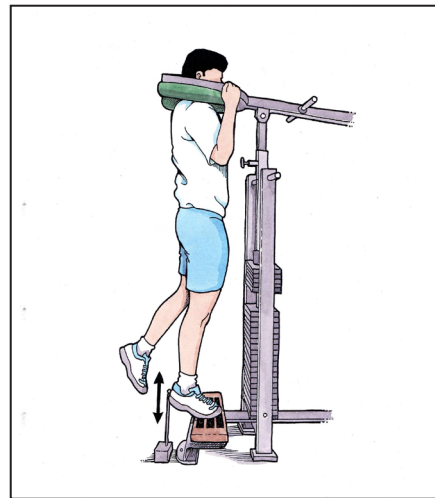
FIGURE 14 *The strength test*

Endurance test

Muscular endurance was tested using a standing heel-rise test. The heel-rise test for endurance was performed on one leg at a time with the participant standing on a box with an incline of 10°. For balance, the participants were allowed to place two fingertips per hand, at shoulder height, against the wall. A metronome was used to maintain the frequency of 30 heel rises a minute. The participant was instructed to go as high as possible on each heel rise and was asked to perform as many heel rises as possible. The test was terminated when the patient stopped, was unable to maintain the frequency, or did not perform a proper heel rise (minimum height of two cm). The number of heel rises, as well as the height of each heel rise and the total work (the body weight x total distance) in joules, was used for data analysis. To document the maximum heel-rise height, the maximum height obtained during the test was used for data analysis.

FIGURE 15 *The endurance test*

	Study I	Study II	Study III	Study IV
Hopping	X		X	
Drop CMJ	X		X	
Concentric power	X		X	
Eccentric power	X		X	
Heel-rise repetitions	X	X*	X	
Heel-rise height	X		X	X
Heel-rise work	X		X	
*Ability to perform a single heel rise (yes/no)				

TABLE 4 *Functional tests used in the studies*

05 SUBJECTS

Study	Patients included	Male/female	Age Mean (SD); Range	BMI	Smokers
I	81	67/14	42.0 (9.1); 27-64	26.4 (2.9); 21.5-37.1	*
II	81#	69/12	40.0 (9.6); 20-63	26.2 (3.0); 20.4-34.3	8 (10%)
III	100	86/14	39.7 (9.2); 20-63	26.4 (3.2); 20.1-39.4	9 (9%)
IV	93#	79/14	39.7 (9.3); 20-63	26.1 (2.9); 20.1-34.3	8 (9%)
*No available data, # Patients from Study III					

TABLE 5 *Demographics for the patients included in the studies*

Study I

Eighty-one patients with acute Achilles tendon rupture were included in this two-year follow-up (Table 5). The patients came from a cohort of 97 patients with acute Achilles tendon rupture included in a prospective, randomized controlled trial (RCT) during the period 2004-2007.[116] In all patients, the diagnosis was established based on medical history and clinical examination (tendon palpation and Thompson test[152]).

Patients between 16 and 65 years of age with a unilateral Achilles tendon rupture were included in the original study if they were randomized and treated within 72 hours of the injury. Patients were excluded if they had diabetes mellitus, previous Achilles tendon rupture, other lower leg injuries, immunosuppressive therapy and neurovascular diseases. In the original study, the patients were randomized to receive either surgical or non-surgical treatment. The results of the RCT, including a one-year follow-up, have been previously published.[116]

Eight patients sustained a re-rupture during the initial study and were excluded from this two-year follow-up. One patient in the surgically treated group sustained an Achilles tendon contracture and was therefore not available for evaluation. Six patients did not attend their scheduled appointment and one patient declined to attend. As a result, 81 patients (67 men and 14 women) were available for the two-year follow-up evaluation.

Study II

In this short-term follow-up, we included the first eighty-one patients from Study III. The demographics of all included patients independent of treatment are presented in Table 5.

Study III

One-hundred-and-one patients with an acute Achilles tendon rupture were included in this randomized, controlled study between April 2009 and October 2010 (Table 5). This study was conducted at one center, the Department of Orthopedics, Sahlgrenska University Hospital, Gothenburg, Sweden.

All patients (18-65 years old) with a closed mid-substance rupture, who attended this center, were included in the study. The diagnosis was based on medical history and clinical examination (a palpable gap and a positive Thompson test[152]). Patients were excluded if the rupture was older than four days and if they had had a prior Achilles tendon rupture (either side) or other injuries that affected their lower limb function. Neuromuscular disease, diabetes, peripheral vascular disease, immunosuppressive treatment including systemic cortisone, skin infection or wound and inability to attend rehabilitation or evaluations were all exclusion criteria. All the patients were given verbal and written information about the study details prior to randomization. Of the 201 patients with an Achilles tendon rupture during this period, 101 patients met the inclusion/exclusion criteria and agreed to participate in the study (Figure 16). The patients were randomized directly after inclusion and computer-generated opaque and sealed envelopes were used in the randomization process. The patients and the treating physician were not blinded to the treatment group.

One patient was initially included in the study, despite having an ongoing skin infection, and was therefore excluded from the study directly after randomization. This patient was randomized to surgical treatment. One hundred patients were therefore included in Study III (Figure 16).

201 patients with achilles tendon rupture

Excluded based on study criteria (n=60)

Eligible for inclusion (n=141)

Declined to participate (n=40)
Wanted non-surgical treatment (n=23)
Wanted surgical treatment (n=10)
Non-specific reason (n=7)

Randomized (n=101)

Incorrect inclusion (n=1)

Surgical (n=49)

Partial rerupture (n=1)
Lost to follow-up (n=1)

Non-surgical (n=51)

Rerupture (n=4)

Follow-up 3 months (n=47)

Follow-up 3 months (n=47)

Rerupture (n=1)

Follow-up 6 months (n=47)

Follow-up 6 months (n=46)

Lost to follow-up (n=4)

Lost to follow-up (n=1)

Follow-up 12 months (n=43)
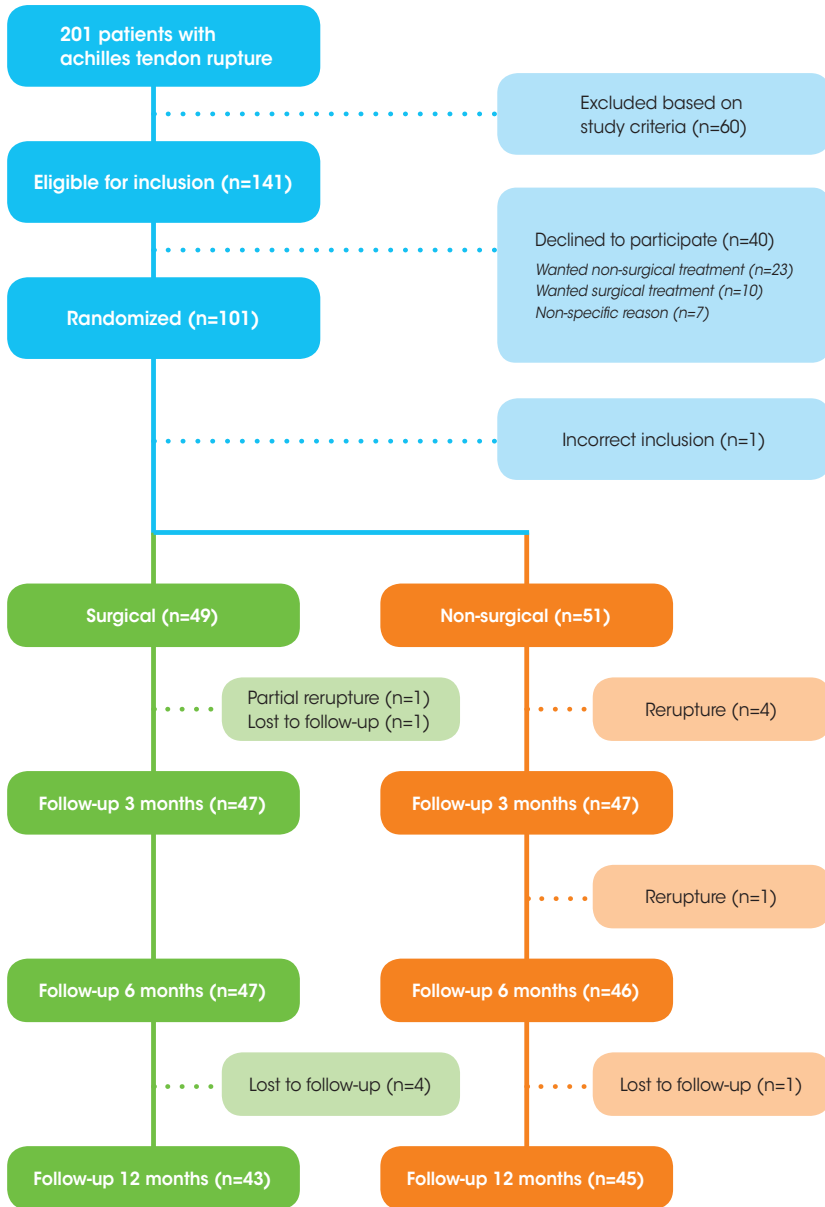
Follow-up 12 months (n=45)

FIGURE 16 *Flow chart for patients in Study III*

Patients sub-grouped for surgical and non-surgical treatment are presented in Table 6.

Variable	Surgical	Non-surgical	P value[a]
Number of patients	49 (49%)	51 (51%)	
Age (years)	39.8 (8.9) 40 (24-61)	39.5 (9.7) 39 (20-63)	0.740
Male Female	39 (80%) 10 (20%)	47 (92%) 4 (8%)	0.088
Height (cm)	179 (8.5) 180 (164-200)	179 (7.5) 179 (160-195)	0.425
Weight (kg)	87.2 (13.0) 89 (55-110)	82.0 (10.8) 81 (63-112)	**0.036**
BMI	27.1 (3.5) 26.2 (20-39)	25.7 (2.8) 25.7 (20-34)	**0.037**
Right side Left side	25 (51%) 24 (49%)	35 (69%) 16 (31%)	0.102
Smoker Non-smoker	4 (8%) 45 (92%)	5 (10%) 46 (90%)	1.000

For categorical variables, the data are reported as n and (%). For continuous variables, mean (SD)/median (min-max). BMI, body mass index.[a]**Boldface type indicates a significant difference.**

TABLE 6 *Patient baseline characteristics for the randomized, controlled trial*

Study IV

This study used the data from Study III for an exploratory secondary analysis.

Ninety-three patients were included in this study (Table 5). The patients came from a cohort of one hundred patients in the prospective randomized, controlled trial in Study III.

Five patients sustained a re-rupture and one patient had a partial re-rupture. One patient was lost to follow-up at the 6-month evaluation. As a result, ninety-three patients were available for analysis in this study. One patient had a knee injury and pain in the affected Achilles tendon and another patient had spinal disc herniation by the time of the 12-month evaluation and could therefore not be tested, but they completed the patient-reported outcomes.

Both the intervention group and control group from the original study were combined to create a single cohort for this secondary analysis.

5.1 ETHICS

All the patients gave their written informed consent to participate in the study. Ethical approval was obtained from the Regional Ethical Review Board in Gothenburg, Sweden.

Statistical analysis was performed using the Statistical Package for Social Sciences (SPSS). In Studies I and II, the data were analyzed using SPSS statistics, version 18.0 and, in Studies III and IV, SPSS Statistics, version 20.0, was used. The univariate analysis and the multiple linear regression analysis in Study IV used STATA version 11.

Descriptive data are reported as the mean, median, standard deviation (SD) and range (minimum-maximum). The level of significance was set at $p < 0.05$. The LSI was defined as the ratio between the involved limb score and the uninvolved limb score, expressed as a percentage (involved/uninvolved x 100=LSI). The limb symmetry index (LSI) was calculated in order to compare the two treatment groups.

Study I

The absolute values were used when measuring the recovery of function in each group and also the comparison over time. Wilcoxon's signed rank test was used to evaluate differences between the injured and uninjured side, as well as differences between the 12-month and 24-month evaluation. The Mann-Whitney U-test was used to compare the two groups of patients. An LSI equal to or greater than 85% was classified as an acceptable function for returning to sport and physical activity.

Study II

The Mann-Whitney U-test was used to compare the two groups of patients. For comparisons between groups, the chi-square test was used for dichotomous variables and Fisher's exact test was used when the sample sizes were small. The correlations were analyzed with Spearman's rank correlation.

Study III

Power calculations were based on data from a previous study in which the ATRS score at 12 months had an SD of 15 and this value was therefore used in this study. The effect size was set at 10, based on unpublished data of a minimal detectable change of 6.8. The power was set at 85% and the type-I error at 5%. Sample size calculation gave us a sample size of 41 in each group. The absolute values are used when measuring the recovery of function in each group and also the comparison over time. For this study, we used non-parametric statistics in all the questionnaires, as they contain ordinal data. The Mann-Whitney U-test was used to compare two groups of patients. The chi-square test was used for dichotomous variables and, when the sample size was small, Fisher's exact

test was used. The Wilcoxon signed rank sum was used to compare paired variables. An analysis of the functional data revealed normal distribution and parametric statistics were therefore used when evaluating these data. The independent t-test was used to compare the two groups and, to compare side-to-side differences, the paired t-test was used.

Study IV

For the descriptive statistics, we report the questionnaire results as median (range) values and the results of functional data and demographics as mean (SD) values. When comparing two groups, we used the Mann-Whitney U-test for ordinal data (ATRS) and the independent t-test for normally distributed ratio data (heel-rise height). A univariate analysis was performed using a simple linear regression model as a hypothesis-generating analysis model to identify variables associated with the two outcomes, ATRS and heel-rise height. Each variable was analyzed independently for each outcome. The criterion for including a variable in the multiple linear regression analysis was having a correlation coefficient of ≥ 0.25 in the univariate analysis. In the next step, multiple linear regression models were built up using the identified variables. The use of linear regression is a simplification, but an assessment of residuals showed no important deviations from the required conditions.

7.1 STUDY I

Major functional deficits persist two years after acute Achilles tendon rupture[123]

Purpose

The purpose of this prospective, randomized, controlled study was to evaluate the long-term results after an acute Achilles tendon rupture in patients treated surgically or non-surgically. The focus was to evaluate whether any improvements occurred between the one- and two-year evaluation.

Introduction

Until recently, the primary outcome in most studies has been re-rupture and not functional evaluation measurements. One and two years after an acute Achilles tendon rupture, indications of deficits in function are seen, independent of treatment.[106, 108, 112, 116] Until more is known about the short-term and long-term effects of an Achilles tendon rupture, it is difficult to make recommendations on how to optimize treatment to avoid long-term deficits. A tendon takes a long time to heal and, with the knowledge we have today, it is not possible to deduce whether the deficits seen after one year will become permanent or whether certain aspects of function and symptoms will continue to improve. In order to minimize permanent disability in this patient group, it is important to understand the areas of treatment and rehabilitation that require improvement.

Method

Eighty-one patients (67 men, 14 women) with a mean (SD) age of 42 (9.1) were included in this study. The patients came from a previously published randomized, controlled study with a one-year follow-up.[116] Forty-two patients were treated surgically and 39 treated non-surgically; otherwise, the treatment was identical for the two groups. All the patients were evaluated using the Achilles tendon Total Rupture Score (ATRS), the Physical Activity level (PAS) and validated functional tests including jumping, strength and endurance tests at one and two years after injury.

Results

There were significant functional deficits on the injured side compared with the contralateral side two years after Achilles tendon rupture, regardless of treatment.

The mean (median, range) ATRS was relatively high in both the surgical, 90 (94, 43-100), and non-surgical, 89 (96, 12-100), groups and no statistical differences were found between the two groups (p=0.540) at the two-year follow-up. There was only a significant improvement in the non-surgical group between the one- and two-year follow-up (p=0.017).

The PAS was significantly reduced at the 24-month evaluation compared with the pre-injury level in both treatment groups (p<0.001), but no significant changes were observed between the 12- and 24-month evaluations.

A comparison between the injured and uninjured side at the 24-month evaluation showed consistent and significantly (p<0.001-0.014) lower values on the injured side in all tests except for the hopping quotient and heel-rise repetitions in the surgically treated group. The limb symmetry index (LSI) showed for that approximately half the patients did not reach the level of 85% of function in the injured leg.

Only minor improvements, even though they were statistically significant, occurred between the 1- and 2-year evaluations.

There was a significant difference (p=0.017) in heel-rise work LSI between the non-surgical group (76%) and the surgical group (85%) at the 24-month evaluation. For all the other functional tests, there were no significant differences at the 24-month evaluation.

Conclusion

This long-term follow-up indicates that the majority of patients with an Achilles tendon rupture have not fully recovered (with regard to symptoms, physical activity level and function) two years after injury, regardless of surgical or non-surgical treatment. Furthermore, only minor improvements occur between the 1- and 2-year evaluations. This indicates that, to enhance the final outcome, the focus should be on improvements in treatment within the first year. The patients appear to have adjusted to their impairments, since the patient-reported outcome is relatively high in spite of functional deficits and lower activity levels compared with pre-injury.

7.2 STUDY II

The ability to perform a single heel rise is significantly related to patient-reported outcome 12 weeks after an Achilles tendon rupture[122]

Purpose

The purpose of this study was to evaluate the recovery of function at 12 weeks after injury and to study how function relates to the patient-reported outcomes, with regard to lower limb function, as well as general health and quality of life. The secondary purpose was to evaluate the degree of patients' fear of movement and how this fear relates to function and patient-reported symptoms.

Introduction

Very little is known about the initial short-term results after an acute Achilles tendon rupture. Costa et al.[23] and Suchak et al.[145] have evaluated general health in patients with an Achilles tendon rupture three months after injury. Only a few studies have reported the return of function at three months,[47, 52, 153] but, as far as we know, no study has evaluated function in connection with how it may affect the patients' general health and quality of life. To minimize the long-term deficits, it is important to understand the period during which a window of opportunity exists to prevent functional deficits from occurring and becoming permanent. Fear of physical activity and movement (kinesiophobia) is a known complicating factor for poor rehabilitation outcome in other conditions.[67, 82] Despite allowing early weight-bearing in patients with an Achilles tendon rupture, the actual load may be limited due to fear. To deepen our understanding of how the Achilles tendon recovers after injury in humans, it therefore appears to be important also to evaluate the short-term return of function and patient-reported symptoms and to compare them with the degree of kinesiophobia. This knowledge might help to implement a more optimal design in treatment protocols to address the early recovery of function and not just to prevent complications such as re-rupture, scarring and infections.

Method

This is a prospective cohort study and part of a larger randomized, controlled study (Study III). Eighty-one patients treated surgically or non-surgically with early active rehabilitation after Achilles tendon rupture were included in the study. The patients' ability to perform a single-legged heel rise (at least two centimeters), physical activity level (PAS), patient-reported symptoms (ATRS, FAOS) and general health (EQ-5D) and fear of movement (TSK-SV) were evaluated 12 weeks after injury.

Variable	Heel rise YES	Heel rise NO	P value[a]
Number of patients	41 (51%)	40 (49%)	
Age (years)	37 (8)	43 (10)	**0.005**
Male Female	39 2	30 10	**0.013**
Treatment: Surgical Non-surgical	 23 18	 17 24	0.269
For categorical variables, the data are reported as n and (%). For continuous variables, mean (SD). Fisher's exact test and the Mann-Whitney U-test were used. **[a]Boldface type indicates a significant difference.**			

TABLE 7 *Comparison of patients who were able to perform a heel rise and those that were not*

Results

At the 12-week evaluation, there was no statistical difference (p=0.269) between the surgical and non-surgical group in terms of heel-rise ability and demographics and other

parameters at baseline (p-values: 0.18-0.88) and we therefore present the results for the whole group, regardless of treatment.

There was a significant reduction (p<0.001) in the EQ-5D from the baseline value of 0.97 (0.08) to 0.75 (0.16) 12 weeks after injury. The mean (median, range) ATRS was 39 (37, 6-86) and the mean (median, range) FAOS-ADL was 78 (81, 13-100), FAOS-Sport&Rec 31 (30, 0-80) and FAOS-QoL 43 (44, 0-75) 12 weeks after injury.

The heel-rise test showed that 40 of 81 (49%) patients were unable to perform a single heel rise 12 weeks after injury.

Patients who were able to perform a heel rise were significantly younger, more often of male gender and had a higher score on the ATRS and all subscales of the FAOS, as well as a higher degree of physical activity at 12 weeks. There was no significant difference (p=0.270) between the degree of kinesiophobia between patients who were able to perform a heel rise and those that were not.

At the 12-week evaluation, we found a significant negative correlation between the TSK-SV score and all the patient-reported outcomes, ATRS, FAOS (ADL, Sport&Rec and QoL), PAS and EQ-5D (p= 0.001-0.032).

Conclusion

The heel-rise ability appears to be an important early achievement, which influences patient-reported outcome and physical activity. Future treatment protocols focusing on regaining strength early after injury therefore appear to be of great importance. The heel-rise test can be recommended as part of the evaluation protocol. Fear of physical activity and movement need to be addressed at an early stage during the rehabilitation process.

7.3 STUDY III

A randomized, controlled study comparing stable surgical repair, including accelerated rehabilitation, with non-surgical treatment for acute Achilles tendon rupture[124]

Purpose

The purpose of this study was to evaluate whether stable surgical repair allowing early loading of the tendon could improve the patient-reported outcome and function after an acute Achilles tendon rupture.

Introduction

The optimal treatment for acute Achilles tendon ruptures is still the subject of debate. The early loading of the tendon is a factor that has been shown to be beneficial to recovery and to minimize complications.[23, 46, 56, 91, 146] These favorable results related to

early mobilization have recently been shown to be independent of surgical or non-surgical treatment.[23, 116, 153, 159, 164] However, most study protocols do not initiate immediate weight-bearing or exercises of the ankle until after 4-8 weeks.[52, 116, 153, 164] Based on current pre-clinical studies, mechanical loading appears to be beneficial during the early stages of tendon healing.[2, 8, 57, 157, 160] The main outcome of previous studies has been complications such as re-ruptures and deep infections, without focusing on the patient-reported or functional outcomes relevant to the majority of patients who do not experience these complications. In this study, the symptoms measured as the patient-reported outcome, ATRS, was the primary outcome variable. When the suture technique in the present study was selected, we preferred a technique with high resistance to tensile strength, which was able to tolerate the accelerated rehabilitation protocol and could also be generally performed by orthopedic surgeons. We decided to use a technique including both a double core suture with modified Kessler and an epitendinal cross-stitch as described by Silfverskiold et al.[141]

Method

One hundred patients (86 men, 14 women; mean age 40 years) with an acute total Achilles tendon rupture were randomized to either surgical treatment, including an accelerated rehabilitation protocol, or non-surgical treatment, with a slightly modified rehabilitation protocol (Appendices 1 and 2). The primary outcome was the Achilles tendon Total Rupture Score (ATRS). The patients were evaluated at 3, 6 and 12 months for symptoms (ATRS and FAOS), physical activity level (PAS), general health (EQ-5D) and validated functional tests, including jumping, strength and endurance tests.

Results

At the 3-month evaluation, the surgical group had a median (range) ATRS of 44 (11-86) points, while the non-surgical group had a median (range) of 33 (6-73) points. There was no statistically significant difference (p=0.066) between the two treatment groups at 3 months as evaluated by the ATRS score. The results at 3, 6 and 12 months showed no significant differences between the treatment groups (Table 8). There were no significant differences in physical activity level between the groups' pre-injury level or at the 3-, 6- and 12- month evaluations (Table 8). Furthermore, no significant differences were found in physical activity level when comparing the pre-injury level with the level at 12 months, either in the surgical group (p=0.784) or in the non-surgical group (p=0.233). The FAOS-ADL and FAOS-Sport and Recreation subscores showed no significant differences between the groups (Table 8). The FAOS-ADL and FAOS-Sport and Recreation subscores improved significantly (p<0.01) over time in both the surgical and non-surgical groups at the 3-, 6- and 12-month evaluations, except for the FAOS-ADL in the surgical group between 6 and 12 months (p=0.098).

There were no significant differences between the groups in terms of quality of life and the FAOS-QOL scores at the 3-, 6- and 12-month evaluations are shown in Table 8.

The scores improved significantly over time between 3, 6 and 12 months (p<0.001). The median (range) pre-injury level on the EQ-5D was 1.00 (0.52-1.00) in the surgical group and 1.00 (0.26-1.00) in the non-surgical group (Table 8). At 12 months, the median (range) EQ-5D was 1.00 (0-1.00) in the surgical group and 1.00 (0.52-1.00) in the non-surgical group (Table 8). There were no significant differences (p=0.295) between the two treatment groups at the 12-month evaluation, but there was a significant decrease in the EQ-5D in both the surgical (p=0.033) and the non-surgical (p=0.028) group at the 12-month evaluation compared with the pre-injury value.

Table 9 shows the LSI values for the surgical and non-surgical groups at the 3-, 6- and 12-month evaluations. The LSI values were consistently higher in the surgical group compared with the non-surgical group, except for concentric and eccentric power at 6 months (Table 9), but these differences were non-significant, except for hopping and drop CMJ at 12 months (Table 9). The recovery of function in the heel-rise tests for both groups is presented in absolute values in Table 10. A comparison of the injured with the uninjured side in Table 10 shows that all the values were significantly (p<0.001-0.012) higher on the uninjured side at 3, 6 and 12 months.

There were no re-ruptures in the surgical group. However, one surgically treated patient sustained a partial re-rupture during a fall on level ground three weeks after the last day of immobilization. A clinical examination and MRI were used to diagnose this partial re-rupture. The tendon healed after additional treatment in a brace. Five patients (10%) in the non-surgically treated group sustained a re-rupture, all of which occurred between 5 and 12 weeks after the initial injury. All five patients were surgically treated with augmentation as previously described by Nilsson-Helander et al.[115] and the diagnosis was confirmed during surgery.

There was a numerical difference in re-rupture incidence between the two treatment groups (p=0.057). The patients who sustained a re-rupture were all tested 6 and 12 months after the re-rupture. After the treatment with augmented surgery and rehabilitation, there were no significant differences between the patients who sustained a re-rupture and patients with no re-rupture in all the functional tests except for heel-rise height at 6 months (p=0.011), which demonstrated that the mean (SD) results were higher for patients who sustained a re-rupture, LSI 87% (11), compared with those that did not sustain a re-rupture, 69% (15). No firm conclusions can be drawn from this single test.

Conclusion

The results of the present study demonstrate that stable surgical repair with early accelerated tendon loading is a safe method with a low risk of re-rupture. However, this treatment was not significantly superior to the non-surgical treatment in terms of functional results, physical activity or quality of life and, for this reason, non-surgical treatment is also a viable option.

TABLE 8 *Results of patient-reported outcome at the 3-, 6- and 12-month post-injury evaluation*

	Inclusion			3-month evaluation			6-month evaluation			12-month evaluation		
	Surgical n=49	Non-surgical n=51	p-value[a]	Surgical n=47	Non-surgical n=47	p-value[a]	Surgical n=47	Non-surgical n=46	p-value[a]	Surgical n=43	Non-surgical n=45	p-value[a]
ATRS				43 (20) 44 (11-86)	35 (14) 33 (6-73)	0.066	70 (23) 75 (0-99)	70 (19) 73 (33-97)	0.631	82 (20) 89 (0-100)	80 (23) 90 (2-100)	0.676
FAOS-ADL				78 (17) 81 (13-100)	77 (13) 79 (40-97)	0.425	90 (17) 96 (24-100)	92 (10) 96 (60-100)	0.586	94 (11) 99 (21-100)	94 (11) 100 (54-100)	0.374
FAOS-Sport&rec				34 (22) 30 (0-85)	28 (17) 30 (0-65)	0.239	68 (24) 70 (0-100)	69 (19) 70 (25-100)	0.829	83 (20) 90 (0-100)	83 (21) 90 (15-100)	0.703
FAOS-QOL				45 (18) 44 (0-81)	39 (15) 38 (6-69)	0.100	63 (20) 63 (0-100)	61 (16) 63 (25-94)	0.543	75 (21) 75 (0-100)	77 (21) 81 (25-100)	0.506
PAS	3.9 (1.1) 4 (2-6)	4.2 (1.0) 4 (2-6)	0.092	3.0 (0.8) 3 (1-5)	2.9 (1.1) 3 (1-6)	0.360	3.8 (1.0) 4 (1-6)	3.8 (1.1) 3 (2-6)	0.590	4.0 (1.1) 4 (1-6)	4.0 (1.0) 4 (2-6)	0.849
EQ-5D	0.95 (0.11) 1.00 (0.52-1.00)	0.95 (0.13) 1.00 (0.26-1.00)	0.816	0.77 (0.17) 0.73 (0.19-1.00)	0.72 (0.13) 0.73 (0.29-1.00)	0.135	0.88 (0.18) 1.00 (0.08-1.00)	0.86 (0.13) 0.82 (0.62-1.00)	0.240	0.91 (0.17) 1.00 (0-1.00)	0.90 (0.13) 1.00 (0.52-1.00)	0.295

For test variables n=/Mean (SD)/ Median (Min-Max), ATRS: Achilles tendon Total Rupture Score, FAOS (Foot and Ankle Outcome Score) and the subscales: ADL (Function in daily living), Sport&Rec (Function in sport and recreation) and QOL (Foot and ankle-related Quality of Life), PAS: Physical Activity Scale, EQ-5D: EuroQol Group, general health-related quality of life. **[a]Boldface type indicates a significant difference.**
The Mann-Whitney U-test was used to evaluate differences between the non-surgical and surgical group.

TABLE 9 *Functional test performance scores (LSI) for patients in the randomized, controlled trial (Study III)*

Test	3-month evaluation			6-month evaluation			12-month evaluation		
	Surgical	Non-surgical	p-value[a]	Surgical	Non-surgical	p-value[a]	Surgical	Non-surgical	p-value[a]
Hopping				n=42 82% (36) 0-173	n=42 76% (33) 0-115	0.434	n=37 103% (36) 0-200	n=43 86% (36) 0-147	**0.040**
Hopping quotient				n=42 82% (35) 0-153	n=42 78% (32) 0-114	0.656	n=37 101% (29) 0-174	n=43 88% (32) 0-127	0.055
Drop CMJ				n=45 81% (21) 0-112	n=45 74% (12) 49-98	0.058	n=40 91% (15) 70-131	n=43 82% (13) 59-123	**0.003**
Concentric power				n=47 75% (34) 0-147	n=46 78% (58) 0-380	0.783	n=40 95% (39) 40-200	n=44 84% (36) 34-216	0.171
Eccentric power				n=47 59% (21) 0-104	n=46 61% (33) 0-147	0.615	n=40 83% (29) 51-170	n=43 81% (35) 0-169	0.836
Heel-rise repetitions	n=26 54% (34) 10-129	n=20 38% (24) 0-75	0.081	n=47 89% (27) 22-193	n=46 81% (24) 24-122	0.116	n=41 93% (17) 52-138	n=45 90% (17) 26-120	0.344
Heel-rise height	n=26 59% (15) 34-95	n=20 50% (24) 0-87	0.120	n=47 72% (15) 40-107	n=46 66% (15) 35-98	0.059	n=41 80% (15) 46-116	n=45 79% (16) 28-105	0.931
Heel-rise work	n=26 34% (22) 5-89	n=20 23% (17) 0-62	0.096	n=47 65% (23) 7-127	n=46 56% (22) 8-107	0.086	n=41 76% (19) 21-120	n=45 71% (19) 7-105	0.204

For test variables n=/Mean (SD)/ Min-Max. Limb symmetry index = percentage (involved/uninvolved x 100). **Boldface type indicates a significant difference.** The independent-samples t-test was used to evaluate differences between the non-surgical and surgical group.

TABLE 10 *Performance on functional tests for the injured versus uninjured leg at the 3-, 6- and 12-month evaluations*

Test		3-month evaluation			6-month evaluation			12-month evaluation		
		Injured	Uninjured	p-value[a]	Injured	Uninjured	p-value[a]	Injured	Uninjured	p-value[a]
Heel-rise repetitions	Surgical	n=26 25 (18) 4-80	n=26 49 (22) 19-96	**<0.001**	n=47 27 (12) 6-64	n=47 31 (13) 14-96	**0.012**	n=41 30 (9) 16-54	n=41 32 (9) 19-61	**0.010**
	Non-surgical	n=20 16 (9) 0-31	n=20 51 (30) 22-145	**<0.001**	n=46 25 (12) 6-68	n=46 32 (17) 16-121	**<0.001**	n=45 30 (12) 5-69	n=45 34 (14) 15-89	**<0.001**
Heel-rise height	Surgical	n=25 7.1 (1.9) 3.8-11.0	n=25 12.0 (1.6) 8.9-16.5	**<0.001**	n=47 9.3 (2.3) 3.8-14.6	n=47 12.9 (2.1) 6.7-18.5	**<0.001**	n=41 10.2 (2.4) 4.5-14.3	n=41 12.8 (1.8) 9.1-19.6	**<0.001**
	Non-surgical	n=18 6.4 (2.8) 0-12.0	n=19 12.2 (1.7) 9.8-15.4	**<0.001**	n=46 9.1 (2.4) 3.6-15.0	n=46 13.8 (2.0) 9.7-19.5	**<0.001**	n=45 10.5 (2.3) 3.2-15.1	n=45 13.2 (1.7) 9.8-17.0	**<0.001**
Heel-rise work	Surgical	n=26 1226 (999) 95-4930	n=26 3667 (151) 1598-7275	**<0.001**	n=47 1703 (878) 172-3736	n=47 2609 (874) 756-4896	**<0.001**	n=41 2008 (747) 553-3742	n=41 2633 (679) 1109-3763	**<0.001**
	Non-surgical	n=20 740 (536) 0-2184	n=20 3556 (1543) 1790-7727	**<0.001**	n=46 1440 (698) 107-3285	n=46 2544 (906) 962-6086	**<0.001**	n=45 1883 (735) 93-3350	n=45 2642 (840) 972-5167	**<0.001**

For continuous variables n=/Mean (SD)/ Min-Max. **Boldface type indicates a significant difference.**
A paired t-test was used to evaluate differences between the injured and uninjured side.

7.4 STUDY IV

Predictors of clinical outcome after an acute Achilles tendon rupture

Purpose

The purpose of the present study was to investigate predictors of both symptomatic and functional outcome after an acute Achilles tendon rupture.

Introduction

It has not been possible to determine the superiority of one specific treatment modality over another with respect to symptoms and function, in patients with an acute Achilles tendon rupture. When several pertinent treatment protocols are available for an injury, it is of interest to understand how other variables, such as age, gender or physical activity level, affect outcome in order to individualize the treatment more effectively.

Method

Ninety-three patients (79 men and 14 women, mean age 40 years) were evaluated prospectively at 3, 6 and 12 months. The main outcomes in this study were Achilles tendon total rupture score (ATRS) and maximum heel-rise height. The independent variables evaluated as possible predictors of outcome included treatment, gender, age, body mass index (BMI), physical activity level, symptoms and quality of life.

Results

Of the 13 variables, 6 were eligible for further analysis (treatment, age, BMI, physical activity level, heel-rise height at 6 months and ATRS at 3 months) according to the inclusion criterion (correlation coefficient of ≥ 0.25 in the univariate analysis). Table 11 shows the results for the eligible and non-eligible variables.

Female and male gender resulted in opposite correlations in many of the variables, which indicates that gender is a confounding variable. The women were also limited in number and therefore excluded from further analysis and only male gender was included for the prediction models.

The four different multiple linear regression models (predicting ATRS at 6 and 12 months and heel-rise height at 6 and 12 months) were significant ($p < 0.001$-0.002) and the R-squared for the models was 0.222-0.409.

Surgical or non-surgical treatment is a moderate predictor of symptoms and a weak predictor of function after an acute Achilles tendon rupture. Another way of describing the effect of treatment is to compare the strength of the association with that of other variables. For example, a one-step difference in pre-injury physical activity level has a greater effect on patient-reported symptoms at 12 months, compared with the treatment

variable. Furthermore, the symptoms at 12 months are affected by the treatment to the same extent as a 1.5-unit difference in BMI.

Increasing age is a strong predictor of decreased heel-rise height and a 10-year increase in age reduces the expected heel-rise height by approximately 8%.

The degree of symptoms increases with age, but an increase in age of 10 years only predicts a 1-2 point reduction in ATRS.

Increased BMI is a significant predictor of more symptoms and a five-unit increase in BMI predicts a reduction of approximately 10 points in ATRS. BMI was, however, found to have a minimal impact on heel-rise height.

Conclusions

Surgical or non-surgical treatment is a moderate predictor of symptoms and a weak predictor of function after an acute Achilles tendon rupture. Other more important factors were identified. Increasing age is a strong predictor of reduced heel-rise height and a higher BMI is also a strong predictor of a greater degree of symptoms after an acute Achilles tendon rupture. This study could be an early step towards individualized treatment.

Univariate analysis								
	ATRS (6 months)		ATRS (12 months)		Heel-rise height-LSI (6 months)		Heel-rise height-LSI (12 months)	
	Correl coef.	p-value[a]	Correl coef.	p-value[a]	Correl coef.	p-value[a]	Correl coef.	p-value[a]
Eligible								
Age	0.01	0.851	-0.10	0.137	-0.56	**<0.001**	-0.50	**<0.001**
BMI	-0.30	**<0.001**	-0.13	**0.045**	-0.03	0.603	-0.03	0.647
PAS	0.07	0.307	-0.24	**<0.001**	0.27	**<0.001**	0.22	**0.001**
ATRS (3 months)					0.22	**<0.001**	0.15	**0.022**
Heel-rise height-LSI* (6 months)	0.24	**<0.001**	0.26	**<0.001**				
Non-eligible								
ATRS (6 months)							0.04	0.603
Pain (3 months)					0.01	0.842	-0.05	0.486
Pain (6 months)							-0.10	0.131
Weakness (3 months)					0.06	0.351	0.01	0.884
Weakness (6 months)							0.13	**0.046**
TSK-SV	-0.20	**0.002**	-0.16	**0.018**	-0.18	**0.007**	-0.09	0.186
EQ-5D	0.09	0.154	<0.01	0.964	0.05	0.451	-0.03	0.692

BMI: Body Mass Index, PAS: Physical Activity Scale, ATRS: Achilles tendon Total Rupture Score, Limb symmetry index = percentage (involved/uninvolved x 100), TSK-SV: Tampa Scale for Kinesiophobia Swedish Version, EQ-5D: EuroQol Group, general health-related quality of life, LSI: Limb symmetry index = percentage (involved/uninvolved x 100), Correl Coef: Correlation coefficient, **[a]Boldface type indicates a significant difference.**

TABLE 11 *The results for all the variables in the univariate analysis*

08 DISCUSSION

This thesis has evaluated the outcome after an acute Achilles tendon rupture and found major deficits in function and also a high degree of symptoms. In an attempt to reduce these impairments, a treatment protocol was designed, with stable surgical repair and accelerated rehabilitation in comparison with non-surgical treatment in a functional brace. We conclude that this surgical treatment is a safe method with a low risk of re-ruptures but without any statistically significant difference between the two treatments in terms of symptoms, physical activity or quality of life. There was a trend towards improved function in surgically treated patients, but it was only significant in two jump tests. On the other hand, treatment has a minor influence on the outcome compared with other variables such as age and body mass index.

8.1 SURGICAL OR NON-SURGICAL TREATMENT

There is an ongoing debate about the optimal treatment after an acute Achilles tendon rupture. Several randomized, controlled studies and meta-analyses can be found in the literature.[10, 41, 42, 55, 56, 143, 163] The general discussion has focused on surgical versus non-surgical treatment. Each type of treatment has some limitations. It can be concluded from the literature that open surgical repair carries a 2-4 times lower risk of re-rupture compared with non-surgical treatment, but the risk of surgery-related complications should not be ignored. These complications are superficial or deep infection, nervus suralis injury and scar problems. From a functional perspective, no treatment can be clearly shown to be superior to the other. The knowledge in the literature and the results from Studies I, II and III have shown that patients had not fully recovered in terms of symptoms and function and these deficits might be permanent.

The results of the two-year follow-up presented in Study I did not show any significant differences between surgical and non-surgical treatment. One exception is the heel-rise work test, where the non-surgical group has significantly lower LSI values after both the first and second year. The non-surgical group did, however, improve significantly in this test between the one- and two-year follow-up. This supports the interpretation that, after non-surgical treatment, the recovery appears to be slightly slower, even though the differences between the two treatment groups were small and statistically non-significant.

Due to the deficits in function seen in previous studies and the indication that tendon elongation might be a major issue, we designed a randomized, controlled study in which the aim was to improve function and patient-reported outcome (Studies I, II and III). This was done using a stable surgical technique that could be expected to tolerate an

accelerated rehabilitation protocol effectively. The tendon was thereby directly exposed to a mechanical load, which has been shown to be beneficial for tendon healing in animal studies.[2, 8, 45, 61, 157] The treatment protocol promoted immediate weight-bearing in both groups and controlled early range-of-motion and strength training in the surgical group.

The results of this randomized study are presented in Studies II, III and IV. We found that this type of stable surgical technique and accelerated rehabilitation, including immediate weight-bearing, range-of-motion and strength training, is a safe, well-tolerated method. However, there is no conclusive evidence that this treatment was superior to non-surgical treatment with immediate weight-bearing in a brace, when comparing functional results. In this randomized, controlled study with stable repair and accelerated rehabilitation in Study III, the LSI variables in the surgically treated group were numerically higher when assessed by the functional evaluation tests including jumping, power and endurance, at the 12-month follow-up, compared with the non-surgical group, although statistically significant differences were only verified for hopping and drop CMJ. Favorable functional results after surgical treatment at 12 months have also been reported in the study by Nilsson-Helander et al.[116] In that study, the same functional evaluations were used and the absolute values in the different tests were 4-11% higher in favor of surgical treatment compared with non-surgical treatment (both groups had identical rehabilitation), but in that study a statistically significant difference was only verified in the heel-rise work test. We report approximately the same results in the two studies, indicating a tendency towards superior results for surgical treatment.

This surgical treatment had no re-ruptures (0%), although there was one partial re-rupture, which is in contrast to other previous randomized studies comparing the open surgical technique with the non-surgical technique. We therefore concluded that this method of treatment is safe. The non-surgical treatment had five re-ruptures (10%), but this difference in absolute values was nevertheless non-significant (p=0.057). It is possible to speculate about what would have happened if one patient in either group had fallen and re-ruptured. If one more re-rupture had occurred in the non-surgical group, the p-value would have been 0.027 (0 vs. 6 re-ruptures), the study would have been significant and the impact on clinicians would probably have been profound. On the other hand, if one re-rupture in the surgical group had occurred (1 vs. 5 re-ruptures), the p-value would have been 0.205 and the incidence of re-ruptures would have increased from 0 to 2% and would still have been non-significant. It is important to take account of the fact that the sample size in this randomized, controlled study was set after power calculation of the ATRS and not for the re-ruptures. We nevertheless interpret the reason for the non-significant difference in re-ruptures as having a cohort that was too small for this dichotomous variable and that there was consequently a possible type II error for re-ruptures.

Animal studies show the importance of mechanical loading in tendon healing.[2, 8, 157] In the literature, there are no convincing results from randomized, controlled studies that show that a mechanical load is superior,[51] even though, from an historical perspective, the outcome appears to improve over time and we regard this as the result of more

functional bracing rehabilitation. The AAOS guidelines [19] recommend early, protected, postoperative weight-bearing. In the present study, both groups followed a treatment protocol that promoted immediate weight-bearing and also included controlled early range-of-motion and strength training in the surgical group. The results of this study support a shift towards early loading of the tendon.

There are potential advantages to surgical repair that include the opportunity to obtain what appears to be the optimal tendon length and tension, even though this is very difficult to measure intraoperatively and the ideal length and tension are not known. The surgeon can nevertheless put the tendon in tension and the correct length of the tendon is probably easier to achieve by surgical treatment compared with non-surgical. This could explain the difference in function, which tends to be in favor of surgical treatment.

In the treatment of Achilles tendon ruptures, there is a difficult balance between tendon load and the risk of complications, such as re-rupture. Stable surgical repair also has the advantage of allowing the tendon already to be loaded in the early phase in accordance with an accelerated rehabilitation protocol, which is not acceptable for non-surgical treatment. In this randomized, controlled study, it should be noted that the accelerated rehabilitation mobilized the patient and that the early range-of-motion and strength training resulted in a direct mechanical load on the tendon. There are difficulties when it comes to quantifying the actual tendon load and there is probably a wide variation between patients. It is possible to measure weight-bearing using pressure-sensitive soles, which can be used in future studies, but there are still difficulties involved in measuring the actual tendon load.

SUMMARY

The results of the randomized, controlled study presented in Study III demonstrate that stable surgical repair with early accelerated tendon loading is a safe method with a low risk of re-rupture. However, this treatment was not significantly superior to non-surgical treatment in terms of functional results, similar to what has previously been reported in the literature. Nevertheless, Study III showed a tendency towards superior functional results and also a lesser degree of symptoms at 12 weeks in patients treated with this type of stable surgical repair and accelerated rehabilitation.

8.2 COMPLICATIONS

The randomized, controlled study reported in Study III included five patients who sustained a re-rupture and were treated with the augmented surgical technique. The functional results at both 6 and 12 months after the re-rupture showed similar results compared with the non-re-rupture patients at 6 and 12 months post injury. Consequently, there is

no reason to suppose that these patients have inferior final results. From this perspective, a re-rupture might not produce an inferior final result, apart from a prolonged period of treatment and additional surgery. The clinical experience is that this "loss of time" will have varying implications for individual patients, mainly due to different demands in sports and work but also due to a mismatch in expectations regarding healing time.

In Study III, there were some complications that could be suspected of being related to immediate postoperative treatment in a brace. There were six superficial infections after surgical repair and they all healed within a few weeks with antibiotics and wound dressings. Willits et al.[164] used the same brace, starting after two weeks, when the surgical wound had healed, and they had four superficial infections and one deep infection in their group of 72 patients treated with open repair. A pooled analysis by the Cochrane collaboration[55] found six deep infections and one superficial infection in 197 patients treated with open surgical repair. The rate of superficial infections in the present study is higher and one reason for this might be stretching of the surgical wound due to the immediate weight-bearing and the humidity inside the brace. Metz et al.[102] also reported a high incidence of skin-related complications due to the occlusive environment and humidity produced by the brace. To some extent, the different rates of infection published in the literature might be due to different definitions of postoperative infection. Most studies, including the present one, have not provided a clear definition of deep and superficial infection and comparisons between studies may therefore be difficult.

SUMMARY

A re-rupture implies a prolonged period of treatment, but this does not appear to result in inferior final results. A comparison of infection rates between studies is methodologically difficult.

8.3 SYMPTOMS

There is a wide variation in the literature when it comes to reporting patients' symptoms. There is a trend towards more reliable, validated, injury-specific scores such as the ATRS and FAOS[117,128] which do not combine subjective and objective data. Due to heterogeneity in outcome measurements between different treatment studies, it is difficult to make direct comparisons. In this thesis, the ATRS was chosen as the main outcome measurement due to the fact that this is an injury-specific score, which has been shown to be reliable and valid and has good responsiveness.[50,117] This score is a self-administered instrument with high clinical utility.

In Study I, the mean (median, range) ATRS, two years after an acute Achilles tendon rupture, was relatively high, 89 (95, 12-100), for both treatment groups, indicating that the majority of the patients had a satisfactory outcome. Improvements were seen between the 1- and 2-year evaluations, but the changes were limited. This suggests that the recovery

reaches a stationary state with minimal improvements after 1 year. This indicates that the focus in treatment and rehabilitation should be on improvements within the first year. Interestingly, it was only in the non-surgical group that significant improvements were found with regard to the patient-reported symptoms. The functional test results in the non-surgical group also showed similar patterns, i.e. a greater degree of improvement between the 1- and 2-year evaluations. This could be interpreted as a slower yet progressive recovery in the non-surgically treated patients.

In Study II, it was shown that, 12 weeks after an acute Achilles tendon rupture, patients had a low ATRS indicating major symptoms from their Achilles tendon at this early stage of recovery. All the subscales on the FAOS showed a similar high degree of symptoms in this short-term follow-up. At the three-month follow-up, the ATRS showed a tendency towards a favorable result for surgical treatment, even though this was not statistically significant (p=0.066).

The mean ATRS in Study III shows similar results to those reported by Nilsson-Helander et al.,[116] one year after an acute Achilles tendon rupture and neither study found any significant differences between treatment groups. Willits et al.[164] used the Leppilahti score and reported similar symptomatic levels. At the one-year evaluation, the mean Leppilahti score was 79 in the surgically treated group and 76 in the non-surgically treated group and, after two years, the score was 83 in the surgical group and 82 in non-surgical group. Values between 75 and 85 are considered to be good, according to the Leppilahti score.[72] The disadvantage of the Leppilahti score is that it is not purely a patient-reported outcome, since it includes both subjective and objective parameters, and it has not been evaluated for reliability, validity and responsiveness. Nevertheless, the Leppilahti score is injury specific and has been used in previous Achilles tendon studies as an outcome measurement. In a randomized, controlled trial comparing surgical and non-surgical treatment, Keating et al.[52] used the Short Musculoskeletal Function Assessment (SMFA) questionnaire score [148] and they found a significant difference between the two treatment groups at 12 weeks in favor of surgical treatment. This difference was not seen later during rehabilitation and the score gradually improved and, by the one-year evaluation, only minor symptoms were reported. The SMFA is a reliable, validated score and has been tested for responsiveness in a group of various musculoskeletal disorders [148], but it is still not an injury-specific score for Achilles tendon ruptures.

SUMMARY

As expected, all the patients had pain and other symptoms related to the injury and the healing process, as indicated by the injury- and joint-specific questionnaires during the early period. Understanding that patients have significant symptoms and deficits in the early stages might give the physician, physical therapist and the patient realistic expectations. Closer to one year after injury, the patient-reported symptoms appear to be of less concern, even though there are major functional deficits in this group of patients at this time.

8.4 PHYSICAL ACTIVITY AND RETURN TO SPORTS

In Study I, one year after the injury, 51% of all patients had returned to their previous activity level or higher and, after two years, 48% of the patients had reached this level. For surgically treated patients, the results were 49% at one year and 50% after two years. The non-surgically treated patients show similar results, with 54% having returned to their previous activity level after one year and 45% after two years. Since patients with an Achilles tendon rupture have been found to have long-term functional deficits, it could be that this decrease in activity level is a mere adaptation to their current functional capacity. The adjustments to a lower physical activity level may occur not only in sport and recreational activities but also in activities of daily life. The long-term effects of a reduction in physical activity level are uncertain, but, in this middle-aged population, the change in weekly activity, as a result of the injury, may persist in the long term. Consequently, this could lead to an increased risk of general health-related disorders and an acute Achilles tendon rupture could therefore be detrimental to general health.

There is a variation in the definition of the concept 'return to sport and previous physical activity level', but, in spite of this, in all the studies, approximately half or two thirds of the patients returned to their previous activity level within one to two years after an acute Achilles tendon rupture. These studies include a span of thirty years and the results nevertheless remain fairly stable over time, despite different treatment protocols. The results for 'return to previous activity level of sports' are presented in Table 12.

It is interesting that Möller et al. found that, of the patients who did not return to their previous activity level, approximately 30% reported that they had the functional ability to resume sports but did not wish to do so due to fear of re-injury[108]. The question of whether this is similar in other studies has not been investigated in detail, but it might be of interest to evaluate in the future.

Return to previous activity level and sports		
	Surgical	Non-surgical
Nistor et al. 1981	82%	87%
Cetti et al. 1993	57% *	29% *
Möller et al. 2001	54%	54%
Metz et al. 2008	67%	82%
Keating et al. 2011	70%	64%
Study I (one year)	49%	54%
Study I (two years)	50%	45%
Study III (one year)	67%	62%
* Significant difference between groups		

TABLE 12 *Randomized, controlled studies reporting the return to previous level of sports*

In Study III, the aim was to optimize the treatment and it was shown that 65% of all the patients returned to their previous activity level or higher one year after the injury. The same score for physical activity level was used in both Study I and Study III. The different treatment in Study III showed that 67% of surgically treated patients returned to their previous activity level or higher, while the corresponding figure for non-surgically treated patients was 62% (Table 12). No statistically significant difference was found between the pre-injury level of physical activity and the corresponding level of activity after one year. It is interesting that some patients increased their physical activity level.

The accelerated rehabilitation protocol in Study III could be interpreted as a reason for the increased level of return to previous activities compared with the results from Study I. Perhaps these patients had a lower degree of fear of re-injury. This was not measured in previous studies and it is therefore not possible to compare between different studies. Study III shows no major functional outcome advantages compared with a previous study by Nilsson-Helander et al.[116] and this is therefore not thought to be the reason for the higher degree of return to previous physical activity level.

In general, most of the guidelines regarding a return to sports are time based and do not include any specific criteria with regard to strength or lower leg function. Studies normally recommend a return to running and non-contact sports between weeks 16 and 20.[85, 89] The Achilles Tendon Study Group have given guidelines for sport resumption in their book Achilles Tendon Rupture – current concepts [85]. They divide recovery into 4 levels of increasing activity; walking, running, return to non-contact sport and return to contact sport. Each phase must be fully accomplished prior to entering the next one. The first level ends when the patient is able to walk again normally. To achieve this, the difference in strength is said to be less than 25% compared with the uninjured side in repeated single heel rises and toe walking should also be possible. The proposed time for this level is 12 weeks but it is 8 weeks for operative treatment with a functional brace. Saxena et al.[133] have developed three criteria for surgically treated Achilles tendon ruptures that have to be accomplished in order to resume sports. 1. Ability to perform 5 sets of 25 single-legged heel rises. 2. Calf circumference: a difference of 5 mm or less between the injured and uninjured leg (10 cm distal to tibial tuberosity). 3. ROM within 5° of the uninjured leg. With these criteria, the mean (SD) return to sports and main daily activity was 21.8 (4.0) weeks in their cohort of 27 patients. In another study by Costa et al.,[23] the median time to return to normal walking was 12.5-18 weeks (depending on treatment). Based on the studies in this thesis, it is concluded that a functional perspective rather than a time perspective is of major importance when rehabilitation is advanced.

The results of Study II showed that only half the patients were able to perform a single heel rise after 12 weeks and, for this reason, half the patients would not be able to reach the Achilles Tendon Study Group's level 2 of rehabilitation at this time point, which also includes running. There is wide inter-individual variation and consequently the guideline expectations are not realistic for all patients.

SUMMARY

According to Study I, only half the patients returned to their pre-injury activity level within one to two years after injury, independent of treatment. With the new treatment protocol, Study III, we found an increase compared with Study I; two thirds of the patients returned to their previous activity level. Nevertheless, the fact remains that not all patients reached their pre-injury activity level. To ensure a safe return to sport, functional-based guidelines appear to be more appropriate than time-based guidelines. The heel-rise test appears to be useful in this context and can easily be implemented in the clinic.

8.5 FEAR OF MOVEMENT – KINESIOPHOBIA

Fear of movement (kinesiophobia) is a known complicating factor for rehabilitation and a return to previous activity level in different conditions.[67,80]

Even though early weight-bearing is allowed in patients with an Achilles tendon rupture, we do not know how much the patients actually load the tendon. The actual loading may be limited due to fear and the healing process and subsequent functional recovery may therefore be affected in a negative way. Identifying signs of kinesiophobia during the early stage of rehabilitation might be of great importance in order to achieve compliance with early weight-bearing and early exercise protocols. The outcome value of the TSK-SV in Study II does not show any major degree of kinesiophobia, but the same study shows that a high degree of kinesiophobia is a factor that correlates negatively with the physical activity level, the degree of symptoms and general health in patients 12 weeks after an Achilles tendon rupture. The instructions to the patients in this study were that full weight-bearing was allowed and promoted from the start. However, patients with a higher degree of fear of movement might not bear weight (less compliance) and load the tendon to the same degree as patients with less fear (high compliance). The findings in Study II imply that, during the rehabilitation process, the actual loading might need to be addressed separately in order to achieve an optimal outcome.

SUMMARY

Further studies are needed to evaluate whether the degree of weight-bearing and loading of the tendon is affected by kinesiophobia.

8.6 GENERAL HEALTH

In Study III, two different scores, the FAOS-QOL and EQ-5D, were used to evaluate quality of life. The EQ-5D is a measurement of general health, whereas the FAOS-QOL is a measurement of foot- and ankle-related quality of life. We were unable to find any differences between the treatment groups in terms of quality of life. The EQ-5D was evaluated at the time of inclusion and during the follow-up evaluations. The general health quality of life (EQ-5D) showed significantly lower values 12 months post injury compared with the pre-injury values, with no significant differences between the treatments. The FAOS-QOL at 12 months, with a mean of approximately 75 points for both groups, also indicates that the ankle- and foot-related quality of life is negatively affected. This indicates that an Achilles tendon rupture continues to affect a person's general health and quality of life one year after injury.

The patients' general health was also found to be significantly reduced at 12 weeks post injury compared with the baseline values (Study II). A mean EQ-5D of 0.75 three months after an acute Achilles tendon rupture is comparable to the age group of 80-88 years in the general population.[14] Interestingly, the mean (SD) baseline values for the EQ-5D in this study were higher, 0.97 (0.08), than in the normal population of a similar age. Burstrom et al.[14] report a mean (SD) EQ5D of 0.86 (SD 0.009) in a corresponding age group in a general population study. This might reflect the fact that patients with an Achilles tendon rupture are more active and healthier compared with the general population. Quality of life is rarely measured after an acute Achilles tendon rupture, but Costa et al.[23] reported a range in EQ-5D value of 0.69 to 0.73 around 2 months after an acute Achilles tendon rupture depending on the type of treatment. At 12 months, the EQ-5D was 1.00 in surgically treated patients and 0.85 in non-surgically treated patients. This corresponds well with the results in Study II. Möller et al.[108] measured quality of life on a VAS scale and, at the eight-week follow-up, they found a significant (p<0.001) difference between surgical and non-surgical treatment (91 vs. 73).

<div style="border:1px solid">

SUMMARY

This indicates that an Achilles tendon rupture affects not only lower limb function but also the patient's general quality of life.

</div>

8.7 FUNCTION IN THE SHORT TERM

Only half the patients in Study II were able to perform one single-legged heel rise 12 weeks after an acute Achilles tendon rupture, independent of treatment. We have only found one other publication presenting short-term data on one-legged heel rises after acute Achilles tendon rupture.[154] This study, by Uchiyama et al.,[154] also found that approximately half the patients were able to perform a single one-legged heel rise 12

weeks after the use of a modified surgical technique. They also reported that the mean period for achieving this critical function was 12 weeks after surgery, with a range of 7-25 weeks. Furthermore, in Study II, it was shown that the ability to perform a single heel rise was significantly related to higher physical activity and a lesser degree of symptoms. It was also shown that male gender and younger age were correlated with this ability. This deficit in calf muscle strength causing limitations in heel rises appears to have a great impact on patients' recovery and appears to be an important milestone for minimizing the patients' symptoms and returning to physical activity and sports.

SUMMARY

The ability to perform a heel rise appears to be an important advancement in patients' recovery following an Achilles tendon rupture and it needs to be addressed early in the rehabilitation process.

8.8 FUNCTIONAL DEFICITS PERSIST

Functional deficits persisted on the injured side two years after an acute Achilles tendon rupture and, in several of the tests, more than half the patients had not achieved an LSI of 85%. Despite stable surgical repair and accelerated rehabilitation in the new treatment protocol, the injured leg was significantly impaired when compared with the uninjured leg. It has been reported in the literature that patients with an Achilles tendon rupture have strength deficits, gait abnormalities and structural changes of the tendon that appear to become permanent.[55, 106, 112] The one-year results for LSI values in Study I and Study III were similar (Table 13). There were considerably large deficits in function on the injured side compared with the healthy side in both studies, with large variations in the degree of deficits between the different patients (Table 13). Based on these results, it appears safe to conclude that an Achilles tendon rupture is a serious lower leg injury.

test	Mean LSI values at the 12-month evaluation			
	Surgical		Non-surgical	
	Study I (n=40-41)	Study III (n=40-41)	Study 1 (n=37)	Study III (n=43-45)
Drop CMJ	87%(17)	91% (15)*	84%(15)	82% (13)*
Eccentric power	79%(19)	83% (29)	73%(20)	81% (35)
Heel-rise work	78% (20)#	76% (19)	69% (19)#	71% (19)

For test variables n=/Mean (SD), *Indicates significant difference between surgical and non-surgical treatment (p=0.003). #Indicates significant difference as reported in the original study using non-parametric statistics. No statistically significant difference was found using parametric statistics (p=0.056). An independent-samples t-test was used to evaluate differences between the non-surgical and surgical group.

TABLE 13 *Comparison of the functional results in Study I with those in Study III*

The results in Studies I and III are similar to what has previously been reported in the literature.[52, 106, 164] Möller et al.[106] showed strength deficits of at least 10% two years after injury and reported that 18% and 32% of the patients, surgical and non-surgical treatment respectively, were unable to perform more than five single-legged heel rises at the two-year follow-up. Keating et al.[52] reported deficits in plantar flexion peak torque of 20-25% one year after Achilles tendon rupture. Willits et al.[164] showed deficits in plantar flexion strength at a similar level, up to 20%, after one and two years respectively.

The recovery of muscle strength and endurance appears to be the most difficult in this patient population. However, there are large variations between the individual patients and some patients do regain full function. This implies that full recovery is possible and, with improved treatment protocols, it seems feasible that it would be possible to have a larger number of patients achieving full recovery.

Study I did not show any major improvements in function between the one- and two-year follow-up, even though the non-surgical group had improved in a few parameters. This could indicate a slower recovery in non-surgical patients. Similar results were also seen by Möller et al.[106] between the first and second year. In overall terms, it appears that the measurements of both symptoms and function plateau out after the first year following an Achilles tendon rupture and any major changes in function should probably not be expected in the future.

SUMMARY

Major functional deficits persist after an acute Achilles tendon rupture. It is important to understand why not all patients regain full function and also whether these deficits will predispose patients to other overuse-related injuries, in order to make it possible to further optimize the treatment. However, there are probably multiple reasons for these deficits in function that need to be addressed when designing new treatment protocols.

8.9 TENDON LENGTH

Studies emphasize the risk of tendon elongation during healing as an important cause of the long-term deficits and impaired function.[46, 98] Minimizing tendon elongation therefore appears to be an important treatment goal when aiming for full recovery.[140] In this thesis, there was no direct measurement of tendon length. However, Silbernagel et al.[140] found a significant correlation between tendon elongation and deficit in heel-rise height after an Achilles tendon rupture. Their recommendation was to use the maximum heel-rise height as an indirect measurement of tendon length.[140] The maximum heel-rise height has therefore been analyzed.

A comparison of the one-year results for heel-rise height from Study I with Study III shows that there are significant differences between the injured leg and the uninjured leg in both the surgical and non-surgical groups (Table 14). The mean (SD) difference (injured and uninjured side) in heel-rise height, absolute values, for both groups was 2.9 cm (1.9) in Study I and 2.7 cm (1.9) in Study III. The heel-rise test shows only minor differences between the groups and one reason for not detecting any differences between groups could be that we need a more exact measurement of tendon length.

Heel-rise height one year after an acute Achilles tendon rupture		
	Surgical	Non-surgical
Study I	2.7cm (1.9)	3.1cm (1.9)
Study III	2.6cm (1.8)	2.8cm (2.0)
Test variables reported as the mean (SD)		

TABLE 14 *Results for heel–rise height from Studies I and III*

It appears that this decrease in heel-rise height of approximately 3 centimeters, in both Study I and Study III, is caused to some extent by increased tendon length. Deficits in heel-rise height of three centimeters correlate to approximately 1.5 centimeters in tendon length in the study by Silbernagel et al.[140] Since Study I and Study III show impairments in all the functional tests, it is possible to speculate that the increase in tendon length is one important reason for these deficits. Increased tendon length could explain the deficits in strength in Study I and Study III due to non-optimal force production, as hypothesized by Mullaney et al.[112], as described above. If this hypothesis of non-optimal force production of the muscle-tendon complex were true, it would consequently lead to impairments in endurance as well. Increased tendon length could influence the stretch-shortening cycle and therefore affect not only eccentric load but also the jump tests. So, in future studies, measuring tendon length along with the measurements of symptoms and function might be beneficial when it comes to understanding how an Achilles tendon rupture affects the patient.

Previous studies have shown a tendon elongation of approximately 1 cm during the healing process after an Achilles tendon rupture[46, 110, 135] and there is also an indication of a biphasic separation of the tendon ends during the healing process.[120] A greater degree of tendon elongation has also been shown to correlate with a poorer clinical outcome measured by the Leppilahti score.[46] Mortensen et al.[110] found an elongation of approximately 1 cm in surgically treated patients, independent of early postoperative motion or not. Schepull et al. found a tendon elongation over time up to one year after surgical repair.[134, 135] In these studies, they used RSA and showed a tendon elongation in the early phase (3 to 7 weeks) of (median) 3.1 mm and, later in the healing process (7 to 19 weeks), an elongation of (median) 4.7 mm. In these studies, there were no differences between the surgical and non-surgical treatment with regard to tendon elongation. It is important to take account of the fact that these studies[46, 110, 135] measured elongation over the rupture site but not the whole

tendon length and not from the original anatomic length. Mullaney et al.[112] have shown plantar flexion strength deficits in heel-rise tests on a decline, but the same deficits could not be seen on an incline. They hypothesized that this was caused by tendon lengthening due to non-optimal force production at the end of plantar flexion when the tendon was lengthened.

SUMMARY

Increased tendon length could be an important reason for the deficits in function and further studies are needed to analyze tendon length in greater detail and determine the clinical relevance.

8.10 ADAPTATION

When evaluating various aspects of recovery after an acute Achilles tendon rupture, there is a noticeable discrepancy between the deficits seen in objective functional outcome and the patient-reported symptoms.[52, 116, 164] In Study I, it was shown that the patient-reported outcome (ATRS) was relatively high in both groups, but there were major deficits in function, as previously described. Patients appear to report a lesser degree of symptoms compared with the actual functional deficits measured objectively in the long term. Studies of other types of injury (anterior cruciate ligament, elbow trauma and knee arthroplasty) have also found a similar divergence between the functional tests and patient-reported outcomes.[4, 78, 104] This is interpreted as an adaptation and adjustment to the impaired function.[4, 78, 104]

In Study I, a reduced physical activity level two years after an Achilles tendon rupture was found. Since the physical activity level is reduced compared with prior to injury, the interpretation is that the patients adapt and adjust their physical activity level to match their functional capacity. In contrast to this, there was no significant reduction in physical activity level as described above in Study III and this is therefore interpreted as no adaptation to a lower level of physical activity in this randomized study. Study IV found that a higher pre-injury physical activity level was a negative predictor of the degree of symptoms at 12 months, but this was not seen at 6 months. The reason for this could be that patients with higher physical activity do not adapt to their impairments to the same extent as patients with fewer demands.

SUMMARY

Due to this discrepancy between symptoms and function, we prefer to report both the patient-reported outcomes and the functional tests, in order to obtain a wider perspective of the outcome after an Achilles tendon rupture and potential differences due to adaptation.

8.11 DIFFERENCE IN GENDER

Magnusson et al.[93] have found differences in outcome between genders in several studies. They found less tendon hypertrophy and collagen synthesis in response to exercise and also lower mechanical tendon strength in females. These findings of decreased tendon healing after exercise in females are supported by other studies.[103, 162]

Saxena et al.[133] reported several parameters for a return to activity after an acute Achilles tendon rupture and they found an increase in the time women needed to return to their activity. In contrast to this, female gender was found to be a positive factor for a return of calf muscle endurance in the study by Bostick et al.[11]

The results for gender difference in Study II showed that males had a significantly better functional outcome, based on the ability to perform a single heel rise, than females. In Study IV, we decided to exclude female gender from the multiple linear regression analysis due to the fact that this variable had shown the opposite correlation to male gender in the univariate analysis. There was a risk of female gender being a confounding factor and minimizing the predictive values of the other variables. There were only fourteen (14%) women in the randomized, controlled study, presented in Studies III and IV, and accordingly no further analysis was statistically meaningful in this small cohort. As a result, no conclusions could be drawn regarding tendon healing in females and any potential differences from males.

SUMMARY

The short-term follow-up in Study II shows a significantly higher degree of ability to perform a single heel rise in males. Female gender was excluded in Study IV due to the diversity of correlations compared with male gender and no further analysis was possible for females.

8.12 PREDICTORS

Many injuries can be treated with various available treatment options, which is also the case for acute Achilles tendon rupture. As stated above, patients have major functional deficits, prevailing symptoms and a lower physical activity level, including a wide inter-individual variation, 1 and 2 years after an Achilles tendon rupture. It is not clear why this patient group shows such heterogeneity in outcome and, to optimize the treatment for both the individual patient and design new treatment protocols, it is therefore essential to identify the predictors of outcome.

We have found only one study in the literature identifying factors associated with the outcome after an acute Achilles tendon rupture.[11] This study by Bostick et al.[11] evaluated the functional outcome (calf muscle endurance). They reported that female

gender, no pain at 3 months, higher physical function and improved calf endurance (maximum number of heel rises) at 6 months were associated with improved recovery of calf endurance 1 year after an acute Achilles tendon rupture. Other variables, such as fear of movement and quality of life, were not included in their study. Intrinsic factors, such as age, gender and body mass index, or extrinsic factors, such as activity level and compliance with treatment, might be one reason for the wide heterogeneity in patients.

In Study IV, we identified potential predictors of both patient-reported symptoms and function (measured as the heel-rise height). We found that the two different types of treatment had a moderate predictive ability for symptoms but were weak predictors of function. Other variables were more important for the outcome compared with surgical or non-surgical treatment. Increasing age is a relatively strong and significant predictor of reduced function and a higher BMI is a similarly strong and significant predictor of a greater degree of symptoms.

SUMMARY

Treatment was a weak predictor of function and a moderate predictor of symptoms, while age and BMI were strong predictors of function and symptoms respectively.

The sample size calculation was based on re-ruptures in the randomized, controlled trial reported in Study I and for ATRS in Studies II, III and IV. There is a potential limitation in terms of sample size, which is important when analyzing the superiority of either treatment in terms of function, patient-reported outcomes and re-rupture in the randomized, controlled trial (Studies II, III and IV) and the sample size is fairly small for prediction analysis. This leads to the conclusion that larger, randomized, controlled studies are needed.

Study I

Nine patients were not evaluated at 12 months in the initial study due to re-rupture (n=8) and Achilles tendon contracture (n=1), as previously reported. From the first to the second year, we lost another 7 patients from 88 (drop-out of 8%) to follow-up. However, we have no reason to believe that the characteristics of these patients deviated from the others; for this reason, this should not have any major influence on the outcome of this study. Having a 92% follow-up rate in a long-term follow-up can be considered high.

We have defined an acceptable post-injury LSI level of 85% for this group of patients based on recommendations in the literature. However, we have not evaluated how the functional deficits, as demonstrated with this test battery, affect gait and running kinematics. At this time, we do not know whether these deficits predispose the patients to other injuries or whether there is a level of deficit that can be considered acceptable.

Studies II, III and IV

The surgically treated group had both an accelerated rehabilitation protocol and surgery as different factors of intervention compared with the non-surgical group. It is possible to argue that it is not known which factor makes the difference, but we consider that surgery is necessary for this accelerated rehabilitation protocol and we therefore regard surgery and accelerated rehabilitation as two parts of the same unit.

Not having any biomechanical studies of the suture technique is a limitation. Studies of animal models and cadavers have specific drawbacks of not reproducing a real-life rupture with typical degenerative changes in the tendon. Instead, we used the knowledge in the literature to construct our technique.

This study is not blinded, which is an important limitation. We were not able to hide the treatment the patient received from the treating orthopedic surgeon, the patient and the treating physical therapist. The only person we could have blinded from knowing the treatment group was the evaluating physical therapist. However, when the study started,

only one experienced physical therapist was available to perform all the evaluations and this made correct blinding complicated. Inspecting both the scar and tendon and issuing instructions about the shoes was part of the evaluation process and this was not possible to perform without knowledge of the patient's treatment.

The instructions for the patients stated that full weight-bearing was allowed and encouraged from the first day, but we have no measurements documenting the extent to which the patients actually achieved this. We suggest that future studies of early mobilization and weight-bearing should include such measurements.

Since Achilles tendon ruptures occur more frequently in males and in these studies only 14-17% of the included patients were females, it is difficult to draw any conclusions regarding possible gender differences in tendon healing. Study IV did not analyze potential predictors related to female gender.

10 CONCLUSIONS

Significant deficits in function persist two years after an Achilles tendon rupture, regardless of surgical or non-surgical treatment, but the patients appear to have adjusted to these changes since the patient-reported outcome (ATRS) was reasonably high in both groups.

Only half the patients were able to perform a single-legged heel rise 12 weeks after the injury. The ability to perform a single heel rise at this time is significantly related to physical activity and patient-reported outcome. From a functional perspective, this test might be an important tool when it comes to monitoring and individualizing rehabilitation.

The results of Study III demonstrate that stable surgical repair with early tendon loading is a safe method. No re-ruptures occurred in the group of surgically treated patients. However, this treatment was not significantly superior to non-surgical treatment in terms of functional results, physical activity or quality of life.

In this study, surgical or non-surgical treatment was a moderate predictor of symptoms and a weak predictor of function. Other more important factors were identified. Increasing age is a strong predictor of reduced heel-rise height and a higher BMI is also a strong predictor of a greater degree of symptoms after an acute Achilles tendon rupture.

Study II demonstrated that kinesiophobia correlates with physical activity, patient-reported symptoms and general health. Fear of physical activity and movement needs to be addressed, especially during the early stages of the rehabilitation process.

The results of this thesis indicate that individualized treatment is a possible option.

11 FUTURE PERSPECTIVES

Future perspectives for optimizing the treatment of an Achilles tendon rupture

Increased tendon length is interpreted as a possible important potential variable for the deficits in function. Future studies therefore need to analyze tendon length and determine the clinical relevance. If the relevance of tendon length is determined, surgical treatment has the potential to correct for optimal length. A future goal would be to find a method to ensure that the appropriate tendon length is achieved during surgery and evaluate whether this results in a more normalized tendon length in the long term.

The most important drawback of surgical treatment is the risk of serious surgical complications. A mini-invasive technique might be an option to minimize these complications, but this has to be verified in randomized studies. A new surgical technique not requiring any immobilization might be a possibility in the future.

A measurement and identification of the optimal load on the tendon during the healing process is needed. The true tendon load at the rupture site during the healing process has not been identified and a stable surgical repair might even reduce the actual load within the rupture site. Future evaluation methods of tendon load need to separate the load over the rupture site from the load outside this area.

Larger sample sizes are required in order to determine the superiority of a specific treatment and identify the variables of importance for the outcome. Limitations in sample size have been found in the literature and also in the studies in this thesis. Larger multi-center, randomized, controlled studies with reliable, validated outcome measurements are crucial for future improvements. A national register for Achilles tendon ruptures could be an important tool. A register of this kind could have the potential to identify specific research questions that require a large sample size.

To obtain a deeper knowledge of the healing process, future clinical studies need to measure factors in the micro-environment that are important for tendon healing, such as growth factors and stem cells.

In this thesis, we conclude that future treatment protocols could probably be individually tailored based on identified predictors of outcome.

12 ACKNOW-LEDGEMENTS

I would like to thank all of you, mentioned or not, for making this thesis possible and in particular I wish to express my gratitude to:

Bengt Eriksson, professor, head tutor and great friend, for endless support and enthusiasm and by brilliant analyses lifting research to a higher level. I admire your way of giving things a wider perspective, not least outside the world of research

Jón Karlsson, professor, former head of the Department of Orthopaedics, Institute of Clinical Sciences, Sahlgrenska Academy, co-tutor and clinical mentor, for remarkable generosity and never-ending support in the field of research, clinical sports medicine and as a very dear friend

Karin Grävare Silbernagel, assistant professor, co-tutor, for sharing scientific expertise during work on this thesis. Your knowledge and energy-boosting approach makes working with you always fun and I appreciate being your friend

Katarina Nilsson Helander, MD, PhD, co-author, for support and valuable advice during this journey that you have already completed

Annelie Brorsson, PT, co-author, for skillful evaluations of participants and spreading enthusiasm valuable to patients and me. The baton is yours

Max Petzold, professor, co-author, for valuable discussions in the field of statistics and collaboration in Study IV

Roland Thomeé, professor, co-author, for sharing your scientific experience and giving patients in the study the opportunity for professional rehabilitation

Mari Lundberg, associate professor, co-author, for appreciated research collaboration in Study II

Mikael Sansone, MD, co-author, for valuable assistance in the randomized trial and being an appreciated colleague. Most of all a very dear friend

Eva Faxén, PT, co-author, for your valuable work and rehabilitation in Study I

Helena Brisby, professor, head of the Department of Orthopaedics, Institute of Clinical Sciences, Sahlgrenska Academy, for support and providing the opportunity to do this work

Björn Rydevik, professor, for your support and valuable advice

Lotta Falkheden Henning, PT, **Agneta Klang Björkeryd**, PT, and **Alexander Gustavsson**, PT, for your enthusiasm and professional rehabilitation of the patients

Elisabeth Hansson, RN, PhD, for valuable discussions in the field of quality of life measurements

13 REFERENCES

1. Aktas S, Kocaoglu B, Nalbantoglu U, Seyhan M, Guven O. End-to-end versus augmented repair in the treatment of acute Achilles tendon ruptures. J Foot Ankle Surg. 2007;46(5):336-340.

2. Andersson T, Eliasson P, Hammerman M, Sandberg O, Aspenberg P. Low-level mechanical stimulation is sufficient to improve tendon healing in rats. J Appl Physiol. 2012;113(9):1398-1402.

3. Aoki M, Ogiwara N, Ohta T, Nabeta Y. Early active motion and weightbearing after cross-stitch achilles tendon repair. Am J Sports Med. 1998;26(6):794-800.

4. Ardern CL, Webster KE, Taylor NF, Feller JA. Return to the preinjury level of competitive sport after anterior cruciate ligament reconstruction surgery: two-thirds of patients have not returned by 12 months after surgery. Am J Sports Med. 2011;39(3):538-543.

5. Arner O, Lindholm A. Subcutaneous rupture of the Achilles tendon; a study of 92 cases. Acta Chir Scand Suppl. 1959;116(Supp 239):1-51.

6. Arner O, Lindholm A, Orell SR. Histologic changes in subcutaneous rupture of the Achilles tendon; a study of 74 cases. Acta Chir Scand. 1959;116(5-6):484-490.

7. Aroen A, Helgo D, Granlund OG, Bahr R. Contralateral tendon rupture risk is increased in individuals with a previous Achilles tendon rupture. Scand J Med Sci Sports. 2004;14(1):30-33.

8. Aspenberg P. Stimulation of tendon repair: mechanical loading, GDFs and platelets. A mini-review. Int Orthop. 2007;31(6):783-789.

9. Bergkvist D, Astrom I, Josefsson PO, Dahlberg LE. Acute Achilles tendon rupture: a questionnaire follow-up of 487 patients. J Bone Joint Surg Am. 2012;94(13):1229-1233.

10. Bhandari M, Guyatt GH, Siddiqui F, et al. Treatment of acute Achilles tendon ruptures: a systematic overview and metaanalysis. Clin Orthop Relat Res. 2002(400):190-200.

11. Bostick GP, Jomha NM, Suchak AA, Beaupre LA. Factors associated with calf muscle endurance recovery 1 year after achilles tendon rupture repair. J Orthop Sports Phys Ther. 2010;40(6):345-351.

12. Bring DK, Kreicbergs A, Renstrom PA, Ackermann PW. Physical activity modulates nerve plasticity and stimulates repair after Achilles tendon rupture. J Orthop Res. 2007;25(2):164-172.

13. Brooks R. EuroQol: the current state of play. Health Policy. 1996;37(1):53-72.

14. Burstrom K, Johannesson M, Diderichsen F. Swedish population health-related quality of life results using the EQ-5D. Qual Life Res. 2001;10(7):621-635.

15. Carmont MR, Silbernagel KG, Nilsson-Helander K, Mei-Dan O, Karlsson J, Maffulli N. Cross cultural adaptation of the Achilles tendon Total Rupture Score with reliability, validity and responsiveness evaluation. Knee Surg Sports Traumatol Arthrosc. 2012.

16. Cetti R, Christensen SE, Ejsted R, Jensen NM, Jorgensen U. Operative versus nonoperative treatment of Achilles tendon rupture. A prospective randomized study and review of the literature. Am J Sports Med. 1993;21(6):791-799.

17. Cetti R, Henriksen LO, Jacobsen KS. A new treatment of ruptured Achilles tendons. A prospective randomized study. Clin Orthop Relat Res. 1994(308):155-165.

18. Chen TM, Rozen WM, Pan WR, Ashton MW, Richardson MD, Taylor GI. The arterial anatomy of the Achilles tendon: anatomical study and clinical implications. Clin Anat. 2009;22(3):377-385.

19. Chiodo CP, Glazebrook M, Bluman EM, et al. Diagnosis and treatment of acute Achilles tendon rupture. J Am Acad Orthop Surg. 2010;18(8):503-510.

20. Cook KD, Clark G, Lui E, Vajaria G, Wallace GF. Strength of braided polyblend polyethylene sutures versus braided polyester sutures in Achilles tendon repair: a cadaveric study. J Am Podiatr Med Assoc. 2010;100(3):185-188.

21. Coombs RRH. Prospective Trial of Conservative and Surgical-Treatment of Achilles-Tendon Rupture. Journal of Bone and Joint Surgery-British Volume. 1981;63(2):288-288.

22. Costa ML, Logan K, Heylings D, Donell ST, Tucker K. The effect of achilles tendon lengthening on ankle dorsiflexion: a cadaver study. Foot Ankle Int. 2006;27(6):414-417.

23. Costa ML, MacMillan K, Halliday D, et al. Randomised controlled trials of immediate weight-bearing mobilisation for rupture of the tendo Achillis. J Bone Joint Surg Br. 2006;88(1):69-77.

24. Cretnik A, Frank A. Incidence and outcome of rupture of the Achilles tendon. Wien Klin Wochenschr. 2004;116 Suppl 2:33-38.

25. Cretnik A, Kosanovic M, Smrkolj V. Percutaneous versus open repair of the ruptured Achilles tendon: a comparative study. Am J Sports Med. 2005;33(9):1369-1379.

26. Cretnik A, Zlajpah L, Smrkolj V, Kosanovic M. The strength of percutaneous methods of repair of the Achilles tendon: a biomechanical study. Med Sci Sports Exerc. 2000;32(1):16-20.

27. Eliasson P, Andersson T, Aspenberg P. Achilles tendon healing in rats is improved by intermittent mechanical loading during the inflammatory phase. J Orthop Res. 2012;30(2):274-279.

28. Fukashiro S, Komi PV, Jarvinen M, Miyashita M. In vivo Achilles tendon loading during jumping in humans. Eur J Appl Physiol Occup Physiol. 1995;71(5):453-458.

29. Gebauer M, Beil FT, Beckmann J, et al. Mechanical evaluation of different techniques for Achilles tendon repair. Arch Orthop Trauma Surg. 2007;127(9):795-799.

30. Ghazzawi A, Theobald P, Pugh N, Byrne C, Nokes L. Quantifying the motion of Kager's fat pad. J Orthop Res. 2009;27(11):1457-1460.

31. Grimby G. Physical activity and muscle training in the elderly. Acta Med Scand Suppl. 1986;711:233-237.

32. Herbort M, Haber A, Zantop T, et al. Biomechanical comparison of the primary stability of suturing Achilles tendon rupture: a cadaver study of Bunnell and Kessler techniques under cyclic loading conditions. Arch Orthop Trauma Surg. 2008;128(11):1273-1277.

33. Hirpara KM, Sullivan PJ, Raheem O, O'Sullivan ME. A biomechanical analysis of multistrand repairs with the Silfverskiold peripheral cross-stitch. J Bone Joint Surg Br. 2007;89(10):1396-1401.

34. Horstmann T, Lukas C, Merk J, Brauner T, Mundermann A. Deficits 10-years after Achilles tendon repair. Int J Sports Med. 2012;33(6):474-479.

35. Houshian S, Tscherning T, Riegels-Nielsen P. The epidemiology of Achilles tendon rupture in a Danish county. Injury. 1998;29(9):651-654.

36. Huffard B, O'Loughlin PF, Wright T, Deland J, Kennedy JG. Achilles tendon repair: Achillon system vs. Krackow suture: an anatomic in vitro biomechanical study. Clin Biomech (Bristol, Avon). 2008;23(9):1158-1164.

37. Hufner TM, Brandes DB, Thermann H, Richter M, Knobloch K, Krettek C. Long-term results after functional nonoperative treatment of achilles tendon rupture. Foot Ankle Int. 2006;27(3):167-171.

38. Inglis AE, Sculco TP. Surgical repair of ruptures of the tendo Achillis. Clin Orthop Relat Res. 1981(156):160-169.

39. Ingvar J, Tagil M, Eneroth M. Nonoperative treatment of Achilles tendon rupture: 196 consecutive patients with a 7% re-rupture rate. Acta Orthop. 2005;76(4):597-601.

40. Jaakkola JI, Hutton WC, Beskin JL, Lee GP. Achilles tendon rupture repair: biomechanical comparison of the triple bundle technique versus the Krakow locking loop technique. Foot Ankle Int. 2000;21(1):14-17.

41. Jiang N, Wang B, Chen A, Dong F, Yu B. Operative versus nonoperative treatment for acute Achilles tendon rupture: a meta-analysis based on current evidence. Int Orthop. 2012;36(4):765-773.

42. Jones MP, Khan RJ, Carey Smith RL. Surgical interventions for treating acute achilles tendon rupture: key findings from a recent cochrane review. J Bone Joint Surg Am. 2012;94(12):e88.

43. Jozsa L, Kannus P. Histopathological findings in spontaneous tendon ruptures. Scand J Med Sci Sports. 1997;7(2):113-118.

44. Jozsa L, Kvist M, Balint BJ, et al. The role of recreational sport activity in Achilles tendon rupture. A clinical, pathoanatomical, and sociological study of 292 cases. Am J Sports Med. 1989;17(3):338-343.

45. Jozsa LG, Kannus P. Human tendons : anatomy, physiology, and pathology. Champaign, Ill. ; Leeds: Human Kinetics; 1997.

46. Kangas J, Pajala A, Ohtonen P, Leppilahti J. Achilles tendon elongation after rupture repair: a randomized comparison of 2 postoperative regimens. Am J Sports Med. 2007;35(1):59-64.

47. Kangas J, Pajala A, Siira P, Hamalainen M, Leppilahti J. Early functional treatment versus early immobilization in tension of the musculotendinous unit after Achilles rupture repair: a prospective, randomized, clinical study. J Trauma. 2003;54(6):1171-1180; discussion 1180-1171.

48. Kannus P. Structure of the tendon connective tissue. Scand J Med Sci Sports. 2000;10(6):312-320.

49. Kastelic J, Galeski A, Baer E. The multicomposite structure of tendon. Connect Tissue Res. 1978;6(1):11-23.

50. Kearney RS, Achten J, Lamb SE, Parsons N, Costa ML. The Achilles tendon total rupture score: a study of responsiveness, internal consistency and convergent validity on patients with acute Achilles tendon ruptures. Health Qual Life Outcomes. 2012;10:24.

51. Kearney RS, McGuinness KR, Achten J, Costa ML. A systematic review of early rehabilitation methods following a rupture of the Achilles tendon. Physiotherapy. 2012;98(1):24-32.

52. Keating JF, Will EM. Operative versus non-operative treatment of acute rupture of tendo Achillis: a prospective randomised evaluation of functional outcome. J Bone Joint Surg Br. 2011;93(8):1071-1078.

53. Kerkhoffs GM, Struijs PA, Raaymakers EL, Marti RK. Functional treatment after surgical repair of acute Achilles tendon rupture: wrap vs walking cast. Arch Orthop Trauma Surg. 2002;122(2):102-105.

54. Kessler I. The "grasping" technique for tendon repair. Hand. 1973;5(3):253-255.

55. Khan RJ, Carey Smith RL. Surgical interventions for treating acute Achilles tendon ruptures. Cochrane Database Syst Rev. 2010(9):CD003674.

56. Khan RJ, Fick D, Keogh A, Crawford J, Brammar T, Parker M. Treatment of acute achilles tendon ruptures. A meta-analysis of randomized, controlled trials. J Bone Joint Surg Am. 2005;87(10):2202-2210.

57. Killian ML, Cavinatto L, Galatz LM, Thomopoulos S. The role of mechanobiology in tendon healing. J Shoulder Elbow Surg. 2012;21(2):228-237.

58. Kim PT, Aoki M, Tokita F, Ishii S. Tensile strength of cross-stitch epitenon suture. J Hand Surg Br. 1996;21(6):821-823.

59. Kjaer M. Role of extracellular matrix in adaptation of tendon and skeletal muscle to mechanical loading. Physiol Rev. 2004;84(2):649-698.

60. Kjaer M, Langberg H, Heinemeier K, et al. From mechanical loading to collagen synthesis, structural changes and function in human tendon. Scand J Med Sci Sports. 2009;19(4):500-510.

61. Kjaer M, Langberg H, Miller BF, et al. Metabolic activity and collagen turnover in human tendon in response to physical activity. J Musculoskelet Neuronal Interact. 2005;5(1):41-52.

62. Klenerman L. The early history of tendo Achillis and its rupture. J Bone Joint Surg Br. 2007;89(4):545-547.

63. Kocher MS, Bishop J, Marshall R, Briggs KK, Hawkins RJ. Operative versus nonoperative management of acute Achilles tendon rupture: expected-value decision analysis. Am J Sports Med. 2002;30(6):783-790.

64. Koivunen-Niemela T, Parkkola K. Anatomy of the Achilles tendon (tendo calcaneus) with respect to tendon thickness measurements. Surg Radiol Anat. 1995;17(3):263-268.

65. Komi PV. Stretch-shortening cycle: a powerful model to study normal and fatigued muscle. J Biomech. 2000;33(10):1197-1206.

66. Komi PV, Fukashiro S, Järvinen M. Biomechanical loading of Achilles tendon during normal locomotion. Clin Sports Med. 1992;11(3):521-531.

67. Kvist J, Ek A, Sporrstedt K, Good L. Fear of re-injury: a hindrance for returning to sports after anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc. 2005;13(5):393-397.

68. Labib SA, Rolf R, Dacus R, Hutton WC. The "Giftbox" repair of the Achilles tendon: a modification of the Krackow technique. Foot Ankle Int. 2009;30(5):410-414.

69. Lea RB, Smith L. Non-surgical treatment of tendo achillis rupture. J Bone Joint Surg Am. 1972;54(7):1398-1407.

70. Leadbetter WB. Cell-matrix response in tendon injury. Clin Sports Med. 1992;11(3):533-578.

71. Lee SJ, Goldsmith S, Nicholas SJ, McHugh M, Kremenic I, Ben-Avi S. Optimizing Achilles tendon repair: effect of epitendinous suture augmentation on the strength of achilles tendon repairs. Foot Ankle Int. 2008;29(4):427-432.

72. Leppilahti J, Forsman K, Puranen J, Orava S. Outcome and prognostic factors of achilles rupture repair using a new scoring method. Clin Orthop Relat Res. 1998(346):152-161.

73. Leppilahti J, Orava S. Total Achilles tendon rupture. A review. Sports Med. 1998;25(2):79-100.

74. Leppilahti J, Puranen J, Orava S. Incidence of Achilles tendon rupture. Acta Orthop Scand. 1996;67(3):277-279.

75. Leppilahti J, Siira P, Vanharanta H, Orava S. Isokinetic evaluation of calf muscle performance after Achilles rupture repair. Int J Sports Med. 1996;17(8):619-623.

76. Lim J, Dalal R, Waseem M. Percutaneous vs. open repair of the ruptured Achilles tendon--a prospective randomized controlled study. Foot Ankle Int. 2001;22(7):559-568.

77. Lin TW, Cardenas L, Soslowsky LJ. Biomechanics of tendon injury and repair. J Biomech. 2004;37(6):865-877.

78. Lindenhovius AL, Buijze GA, Kloen P, Ring DC. Correspondence between perceived disability and objective physical impairment after elbow trauma. J Bone Joint Surg Am. 2008;90(10):2090-2097.

79. Lo IK, Kirkley A, Nonweiler B, Kumbhare DA. Operative versus nonoperative treatment of acute Achilles tendon ruptures: a quantitative review. Clin J Sport Med. 1997;7(3):207-211.

80. Lundberg M, Larsson M, Ostlund H, Styf J. Kinesiophobia among patients with musculoskeletal pain in primary healthcare. J Rehabil Med. 2006;38(1):37-43.

81. Lundberg M, Styf J, Carlsson S. A psychometric evaluation of the Swedish version of the Tampa Scale for Kinesiophobia (TSK) from a physiotherapeutic perspective. Physiotherapy Theory and Practise. 2004;20:121-130.

82. Lundberg M, Styf J, Jansson B. On what patients does the Tampa Scale for Kinesiophobia fit? Physiother Theory Pract. 2009;25(7):495-506.

83. Lynch RM. Achilles tendon rupture: surgical versus non-surgical treatment. Accid Emerg Nurs. 2004;12(3):149-158.

84. Ma GW, Griffith TG. Percutaneous repair of acute closed ruptured achilles tendon: a new technique. Clin Orthop Relat Res. 1977(128):247-255.

85. Maayke N. van Sterkenburg BGD, C. Niek van Dijk. Guidelines for sport resumtion. In: C. Niek van Dijk JK, Nicola Maffuli, Hajo Thermann, ed. Achilles Tendon Rupture, Current Concepts: DJO Publications; 2008:108-117.

86. Maffulli N. The clinical diagnosis of subcutaneous tear of the Achilles tendon. A prospective study in 174 patients. Am J Sports Med. 1998;26(2):266-270.

87. Maffulli N. Rupture of the Achilles tendon. J Bone Joint Surg Am. 1999;81(7):1019-1036.

88. Maffulli N, Almekinders L. The Achilles tendon. New York ; London: Springer; 2007.

89. Maffulli N, Longo UG, Maffulli GD, Khanna A, Denaro V. Achilles tendon ruptures in elite athletes. Foot Ankle Int. 2011;32(1):9-15.

90. Maffulli N, Longo UG, Maffulli GD, Rabitti C, Khanna A, Denaro V. Marked pathological changes proximal and distal to the site of rupture in acute Achilles tendon ruptures. Knee Surg Sports Traumatol Arthrosc. 2010.

91. Maffulli N, Tallon C, Wong J, Lim KP, Bleakney R. Early weightbearing and ankle mobilization after open repair of acute midsubstance tears of the achilles tendon. Am J Sports Med. 2003;31(5):692-700.

92. Maganaris CN, Narici MV, Maffulli N. Biomechanics of the Achilles tendon. Disabil Rehabil. 2008;30(20-22):1542-1547.

93. Magnusson SP, Hansen M, Langberg H, et al. The adaptability of tendon to loading differs in men and women. Int J Exp Pathol. 2007;88(4):237-240.

94. Magnusson SP, Kjaer M. Region-specific differences in Achilles tendon cross-sectional area in runners and non-runners. Eur J Appl Physiol. 2003;90(5-6):549-553.

95. Mahler F, Fritschy D. Partial and complete ruptures of the Achilles tendon and local corticosteroid injections. Br J Sports Med. 1992;26(1):7-14.

96. Majewski M, Rickert M, Steinbruck K. [Achilles tendon rupture. A prospective study assessing various treatment possibilities]. Orthopade. 2000;29(7):670-676.

97. Majewski M, Rohrbach M, Czaja S, Ochsner P. Avoiding sural nerve injuries during percutaneous Achilles tendon repair. Am J Sports Med. 2006;34(5):793-798.

98. Maquirriain J. Achilles tendon rupture: avoiding tendon lengthening during surgical repair and rehabilitation. Yale J Biol Med. 2011;84(3):289-300.

99. McCoy BW, Haddad SL. The strength of achilles tendon repair: a comparison of three suture techniques in human cadaver tendons. Foot Ankle Int. 2010;31(8):701-705.

100. Melhus A. Fluoroquinolones and tendon disorders. Expert Opin Drug Saf. 2005;4(2):299-309.

101. Metz R, van der Heijden GJ, Verleisdonk EJ, Kolfschoten N, Verhofstad MH, van der Werken C. Effect of complications after minimally invasive surgical repair of acute achilles tendon ruptures: report on 211 cases. Am J Sports Med. 2011;39(4):820-824.

102. Metz R, Verleisdonk EJ, van der Heijden GJ, et al. Acute Achilles tendon rupture: minimally invasive surgery versus nonoperative treatment with immediate full weightbearing--a randomized controlled trial. Am J Sports Med. 2008;36(9):1688-1694.

103. Miller BF, Hansen M, Olesen JL, et al. Tendon collagen synthesis at rest and after exercise in women. J Appl Physiol. 2007;102(2):541-546.

104. Mizner RL, Petterson SC, Clements KE, Zeni JA, Jr., Irrgang JJ, Snyder-Mackler L. Measuring Functional Improvement After Total Knee Arthroplasty Requires Both Performance-Based and Patient-Report Assessments A Longitudinal Analysis of Outcomes. J Arthroplasty. 2010.

105. Moller M, Kalebo P, Tidebrant G, Movin T, Karlsson J. The ultrasonographic appearance of the ruptured Achilles tendon during healing: a longitudinal evaluation of surgical and nonsurgical treatment, with comparisons to MRI appearance. Knee Surg Sports Traumatol Arthrosc. 2002;10(1):49-56.

106. Moller M, Lind K, Movin T, Karlsson J. Calf muscle function after Achilles tendon rupture. A prospective, randomised study comparing surgical and non-surgical treatment. Scand J Med Sci Sports. 2002;12(1):9-16.

107. Moller M, Lind K, Styf J, Karlsson J. The reliability of isokinetic testing of the ankle joint and a heel-raise test for endurance. Knee Surg Sports Traumatol Arthrosc. 2005;13(1):60-71.

108. Moller M, Movin T, Granhed H, Lind K, Faxen E, Karlsson J. Acute rupture of tendon Achillis. A prospective randomised study of comparison between surgical and non-surgical treatment. J Bone Joint Surg Br. 2001;83(6):843-848.

109. Moore KL. Clinically Oriented Anatomy. Second edition ed. Baltimore, U.S.A.: Williams & Wilkins; 1985.

110. Mortensen HM, Skov O, Jensen PE. Early motion of the ankle after operative treatment of a rupture of the Achilles tendon. A prospective, randomized clinical and radiographic study. J Bone Joint Surg Am. 1999;81(7):983-990.

111. Mortensen NH, Saether J, Steinke MS, Staehr H, Mikkelsen SS. Separation of tendon ends after Achilles tendon repair: a prospective, randomized, multicenter study. Orthopedics. 1992;15(8):899-903.

112. Mullaney MJ, McHugh MP, Tyler TF, Nicholas SJ, Lee SJ. Weakness in end-range plantar flexion after Achilles tendon repair. Am J Sports Med. 2006;34(7):1120-1125.

113. Nagasawa K, Noguchi M, Ikoma K, Kubo T. Static and dynamic biomechanical properties of the regenerating rabbit Achilles tendon. Clin Biomech (Bristol, Avon). 2008;23(6):832-838.

114. Newnham DM, Douglas JG, Legge JS, Friend JA. Achilles tendon rupture: an underrated complication of corticosteroid treatment. Thorax. 1991;46(11):853-854.

115. Nilsson-Helander K N-K. A new surgical method to treat chronic ruptures and reruptures of the Achilles tendon. Knee surgery, sports traumatology, arthroscopy. 2008;16(6):614.

116. Nilsson-Helander K, Silbernagel KG, Thomee R, et al. Acute achilles tendon rupture: a randomized, controlled study comparing surgical and nonsurgical treatments using validated outcome measures. Am J Sports Med. 2010;38(11):2186-2193.

117. Nilsson-Helander K, Thomee R, Gravare-Silbernagel K, et al. The Achilles tendon Total Rupture Score (ATRS): development and validation. Am J Sports Med. 2007;35(3):421-426.

118. Nilsson-Helander K, Thurin A, Karlsson J, Eriksson BI. High incidence of deep venous thrombosis after Achilles tendon rupture: a prospective study. Knee Surg Sports Traumatol Arthrosc. 2009;17(10):1234-1238.

119. Nistor L. Surgical and non-surgical treatment of Achilles Tendon rupture. A prospective randomized study. J Bone Joint Surg Am. 1981;63(3):394-399.

120. Nystrom B, Holmlund D. Separation of tendon ends after suture of achilles tendon. Acta Orthop Scand. 1983;54(4):620-621.

121. O'Brien M. Structure and metabolism of tendons. Scand J Med Sci Sports. 1997;7(2):55-61.

122. Olsson N, Karlsson J, Eriksson BI, Brorsson A, Lundberg M, Silbernagel KG. Ability to perform a single heel-rise is significantly related to patient-reported outcome after Achilles tendon rupture. Scand J Med Sci Sports. 2012.

123. Olsson N, Nilsson-Helander K, Karlsson J, et al. Major functional deficits persist 2 years after acute Achilles tendon rupture. Knee Surg Sports Traumatol Arthrosc. 2011;19(8):1385-1393.

124. Olsson N, Silbernagel KG, Eriksson BI, et al. A randomized, controlled study comparing stable surgical repair, including accalerated rehabilitation, with non-surgical treatment for acute Achilles tendon rupture. Submitted for publication in Am J Sports Med. 2013.

125. Pajala A, Kangas J, Siira P, Ohtonen P, Leppilahti J. Augmented compared with nonaugmented surgical repair of a fresh total Achilles tendon rupture. A prospective randomized study. J Bone Joint Surg Am. 2009;91(5):1092-1100.

126. Petersen OF, Nielsen MB, Jensen KH, Solgaard S. [Randomized comparison of CAM walker and light-weight plaster cast in the treatment of first-time Achilles tendon rupture]. Ugeskr Laeger. 2002;164(33):3852-3855.

127. Quénu J S. Les ruptures du tendon d`Achilles. Rev Chir Paris. 1929;67:647-678.

128. Roos EM, Brandsson S, Karlsson J. Validation of the foot and ankle outcome score for ankle ligament reconstruction. Foot Ankle Int. 2001;22(10):788-794.

129. Rosso C, Schuetz P, Polzer C, Weisskopf L, Studler U, Valderrabano V. Physiological achilles tendon length and its relation to tibia length. Clin J Sport Med. 2012;22(6):483-487.

130. Sadoghi P, Rosso C, Valderrabano V, Leithner A, Vavken P. Initial Achilles tendon repair strength--synthesized biomechanical data from 196 cadaver repairs. Int Orthop. 2012;36(9):1947-1951.

131. Saleh M, Marshall PD, Senior R, MacFarlane A. The Sheffield splint for controlled early mobilisation after rupture of the calcaneal tendon. A prospective, randomised comparison with plaster treatment. J Bone Joint Surg Br. 1992;74(2):206-209.

132. Sargon MF, Ozlu K, Oken F. Age-related changes in human tendo calcaneus collagen fibrils. Saudi Med J. 2005;26(3):425-428.

133. Saxena A, Ewen B, Maffulli N. Rehabilitation of the operated achilles tendon: parameters for predicting return to activity. J Foot Ankle Surg. 2011;50(1):37-40.

134. Schepull T, Kvist J, Andersson C, Aspenberg P. Mechanical properties during healing of Achilles tendon ruptures to predict final outcome: a pilot Roentgen stereophotogrammetric analysis in 10 patients. BMC Musculoskelet Disord. 2007;8:116.

135. Schepull T, Kvist J, Aspenberg P. Early E-modulus of healing Achilles tendons correlates with late function: similar results with or without surgery. Scand J Med Sci Sports. 2012;22(1):18-23.

136. Schroeder D LM, Steinbrueck K. Treatment of acute achilles tendon ruptures: open vs. percutaneous repair vs. conservative treatment. A prospective randomized study [abstract]. Orthopaedic Transactions. 1997;21(4):1228.

137. Shepard ME, Lindsey DP, Chou LB. Biomechanical testing of epitenon suture strength in Achilles tendon repairs. Foot Ankle Int. 2007;28(10):1074-1077.

138. Silbernagel KG, Gustavsson A, Thomee R, Karlsson J. Evaluation of lower leg function in patients with Achilles tendinopathy. Knee Surg Sports Traumatol Arthrosc. 2006;14(11):1207-1217.

139. Silbernagel KG, Nilsson-Helander K, Thomee R, Eriksson BI, Karlsson J. A new measurement of heel-rise endurance with the ability to detect functional deficits in patients with Achilles tendon rupture. Knee Surg Sports Traumatol Arthrosc. 2010;18(2):258-264.

140. Silbernagel KG, Steele R, Manal K. Deficits in Heel-Rise Height and Achilles Tendon Elongation Occur in Patients Recovering From an Achilles Tendon Rupture. Am J Sports Med. 2012.

141. Silfverskiold KL, Andersson CH. Two new methods of tendon repair: an in vitro evaluation of tensile strength and gap formation. J Hand Surg Am. 1993;18(1):58-65.

142. Silfverskiold KL, May EJ. Flexor tendon repair in zone II with a new suture technique and an early mobilization program combining passive and active flexion. J Hand Surg Am. 1994;19(1):53-60.

143. Soroceanu A, Sidhwa F, Aarabi S, Kaufman A, Glazebrook M. Surgical versus nonsurgical treatment of acute achilles tendon rupture: a meta-analysis of randomized trials. J Bone Joint Surg Am. 2012;94(23):2136-2143.

144. Speck M, Klaue K. Early full weightbearing and functional treatment after surgical repair of acute achilles tendon rupture. Am J Sports Med. 1998;26(6):789-793.

145. Suchak AA, Bostick GP, Beaupre LA, Durand DC, Jomha NM. The influence of early weight-bearing compared with non-weight-bearing after surgical repair of the Achilles tendon. J Bone Joint Surg Am. 2008;90(9):1876-1883.

146. Suchak AA, Spooner C, Reid DC, Jomha NM. Postoperative rehabilitation protocols for Achilles tendon ruptures: a meta-analysis. Clin Orthop Relat Res. 2006;445:216-221.

147. Svantesson U, Österberg U, Thomeé R, Grimby G. Muscle fatigue in a standing heel-rise test. Scand J Rehabil Med. 1998;30(2):67-72.

148. Swiontkowski MF, Engelberg R, Martin DP, Agel J. Short musculoskeletal function assessment questionnaire: validity, reliability, and responsiveness. J Bone Joint Surg Am. 1999;81(9):1245-1260.

149. The EuroQol G. EuroQol--a new facility for the measurement of health-related quality of life Health Policy. 1990;16(3):199-208.

150. Theobald P, Benjamin M, Nokes L, Pugh N. Review of the vascularisation of the human Achilles tendon. Injury. 2005;36(11):1267-1272.

151. Thermann H, Zwipp H, Tscherne H. [Functional treatment concept of acute rupture of the Achilles tendon. 2 years results of a prospective randomized study]. Unfallchirurg. 1995;98(1):21-32.

152. Thompson TC, Doherty JH. Spontaneous rupture of tendon of Achilles: a new clinical diagnostic test. J Trauma. 1962;2:126-129.

153. Twaddle BC, Poon P. Early motion for Achilles tendon ruptures: is surgery important? A randomized, prospective study. Am J Sports Med. 2007;35(12):2033-2038.

154. Uchiyama E, Nomura A, Takeda Y, Hiranuma K, Iwaso H. A modified operation for Achilles tendon ruptures. Am J Sports Med. 2007;35(10):1739-1743.

155. Vailas AC, Tipton CM, Laughlin HL, Tcheng TK, Matthes RD. Physical activity and hypophysectomy on the aerobic capacity of ligaments and tendons. J Appl Physiol. 1978;44(4):542-546.

156. van Dijk CN, van Sterkenburg MN, Wiegerinck JI, Karlsson J, Maffulli N. Terminology for Achilles tendon related disorders. Knee Surg Sports Traumatol Arthrosc. 2011;19(5):835-841.

157. Virchenko O, Aspenberg P. How can one platelet injection after tendon injury lead to a stronger tendon after 4 weeks? Interplay between early regeneration and mechanical stimulation. Acta Orthop. 2006;77(5):806-812.

158. Voleti PB, Buckley MR, Soslowsky LJ. Tendon healing: repair and regeneration. Annu Rev Biomed Eng. 2012;14:47-71.

159. Wallace RG, Heyes GJ, Michael AL. The non-operative functional management of patients with a rupture of the tendo Achillis leads to low rates of re-rupture. J Bone Joint Surg Br. 2011;93(10):1362-1366.

160. Wang JH. Mechanobiology of tendon. J Biomech. 2006;39(9):1563-1582.

161. Waterston SW, Maffulli N, Ewen SW. Subcutaneous rupture of the Achilles tendon: basic science and some aspects of clinical practice. Br J Sports Med. 1997;31(4):285-298.

162. Westh E, Kongsgaard M, Bojsen-Moller J, et al. Effect of habitual exercise on the structural and mechanical properties of human tendon, in vivo, in men and women. Scand J Med Sci Sports. 2008;18(1):23-30.

163. Wilkins R, Bisson LJ. Operative versus nonoperative management of acute Achilles tendon ruptures: a quantitative systematic review of randomized controlled trials. Am J Sports Med. 2012;40(9):2154-2160.

164. Willits K, Amendola A, Bryant D, et al. Operative versus nonoperative treatment of acute Achilles tendon ruptures: a multicenter randomized trial using accelerated functional rehabilitation. J Bone Joint Surg Am. 2010;92(17):2767-2775.

165. Wong J, Barrass V, Maffulli N. Quantitative review of operative and nonoperative management of achilles tendon ruptures. Am J Sports Med. 2002;30(4):565-575.

166. Wren TA, Yerby SA, Beaupre GS, Carter DR. Mechanical properties of the human achilles tendon. Clin Biomech (Bristol, Avon). 2001;16(3):245-251.

167. Yildirim Y, Esemenli T. Initial pull-out strength of tendon sutures: an in vitro study in sheep Achilles tendon. Foot Ankle Int. 2002;23(12):1126-1130.

168. Yotsumoto T, Miyamoto W, Uchio Y. Novel Approach to Repair of Acute Achilles Tendon Rupture: Early Recovery Without Postoperative Fixation or Orthosis. Am J Sports Med. 2009.

169. Zandbergen RA, de Boer SF, Swierstra BA, Day J, Kleinrensink GJ, Beumer A. Surgical treatment of achilles tendon rupture: examination of strength of 3 types of suture techniques in a cadaver model. Acta Orthop. 2005;76(3):408-411.

170. Zhang J, Wang JH. Mechanobiological response of tendon stem cells: implications of tendon homeostasis and pathogenesis of tendinopathy. J Orthop Res. 2010;28(5):639-643.

TREATMENT PROTOCOL –
achilles tendon rupture surgically treated

Week 0-2: Visit orthopaedic surgeon

Treatment: Walker brace with 3 heel lifts, weight-bearing through the heel as tolerated, use of 2 crutches. Referral to orthopedic technician for shoe heel-lift (use shoe with heel-lift on the healthy side). Wearing the walker brace while sleeping for 6 weeks

Exercise program: Home exercises daily. Performed while wearing the walker brace

- Isometric submaximal plantar flexion (5x5 sec, once per hour)
- Toe exercises, flexion-extension (3x20 repetitions, once per hour)

After 2 weeks:

Treatment: Walker brace with 2 heel lifts (take off the upper lift), full weight-bearing, use of 2 crutches if needed. Allowed to take off the walker brace for washing and airing the foot. When the walker brace is removed, no weight-bearing or dorsiflexion of the foot is allowed

Exercise program: Home exercises daily as described above (increase the intensity)

Visit to physical therapist 2 times per week:
- Exercise bike wearing the walker brace
- Active range of motion (ROM) up to 15° plantar flexion without walker brace (the angle based on the heel-height)
- Active plantar flexion with yellow rubber-band (ROM as above)
- Sitting heel-rise – no weight-bearing (starting position from the heel-height)
- Gait training and balance exercises with the walker brace without crutches
- Squats (fitness ball behind the back)
- Other knee/hip-exercises with no ankle involvement

After 4 weeks:

Treatment: Walker brace with 1 heel lift (take off the upper lift), full weight-bearing

Exercise program: Home exercises daily as described above (increase the intensity)

Visit to physical therapist 2 times per week:
- Exercise bike wearing the walker brace
- Active range of motion (ROM) up to 10° plantar flexion without walker brace
- Active plantar flexion with green rubber-band (ROM as above)

- Sitting heel-rise – with light weight (starting position from the heel-height)
- Supination- and pronation–exercises with rubber-band
- Gait training and balance exercises with the walker brace
- Squats (fitness ball behind the back)
- Other knee/hip-exercises with no ankle involvement

After 5 weeks:

Treatment: Walker brace without heel lift, full weight-bearing

Exercise program: Home exercises daily as described above (increase the intensity)

Visit to physical therapist 2 times per week:
- Exercise bike wearing the walker brace
- Active range of motion (ROM) up to 0° plantar flexion without walker brace
- Active plantar flexion in a cable machine (ROM as above)
- Sitting heel-rise – with weight
- Supination- and pronation–exercises in a cable machine
- Gait training and balance exercises with the walker brace
- Squats (fitness ball behind the back)
- Other knee/hip-exercises with no ankle involvement
- Leg press

After 6 weeks: Visit orthopaedic surgeon

Treatment: Wean off walker brace. Use of shoes with heel-lift (bilateral) for 4 weeks, knee-high compression socks (17-20mm Hg) to prevent swelling

Exercise program: Important that all exercises are performed slowly and carefully

Home exercises:
- Active ankle exercises for ROM, ankle exercises (DF, PF, Sup, Pron) with rubber-band, balance exercises, sitting heel-rise, standing heel-rise (50% weight-bearing or less on the injured side), gait training

Visit to physical therapist 2 times per week:
- Exercise bike
- Active range of motion (ROM)
- Sitting heel-rise – with weight (starting position from the shoe heel-height)
- Standing heel-rise on two legs
- Active plantar flexion in a cable machine (max 0° plantar flexion)
- Heel-rise in leg press (max 0° plantar flexion)
- Supination- and pronation – exercises in a cable machine
- Gait training
- Balance exercises
- Squats
- Step (walk slowly)
- Other knee/hip-exercises with no ankle involvement

After 8 weeks:

Treatment: Use of shoes with heel-lift until 10 weeks after surgery, knee-high compression socks (17-20mm Hg) to prevent swelling

Exercise program: Important that all exercises are performed slowly and carefully

Home exercises: As described above and walking 20 min per day

Visit to physical therapist 2 times per week:

- As described above, increase the intensity
- Sitting heel-rise – with weight (increase the load)
- Standing heel-rise on two legs - transcend gradually to one leg
- Active plantar flexion, supination and pronation in a cable machine
- Heel-rise in leg press
- Cable machine standing leg lifts
- Balance exercises (wobble-board, balance pods - weight bearing in the middle of the foot)

After 12 weeks: Evaluation at research lab

Treatment: Use of regular shoes after 10 weeks, barefoot after 12 weeks, knee-high compression socks (17-20mm Hg) to prevent swelling

Exercise program: Important to gradually increase the load considering the patient´s status

Home exercise: Walking 20 min per day

Visit to physical therapist 2 times per week:

- Intensify the exercises by increasing load (as before)
- Increase the load gradually from two leg standing heel-rises to one leg standing heel-rises both concentrically and eccentrically
- Quick rebounding heel-rises (start with two legs)
- Start with gentle jog (thick mattress, in 8´s, zig-zag)
- Start with two-legged jumps and increase gradually

After 14 weeks: Evaluation at research lab 6 and 12 months after surgery, visit orthopaedic surgeon 6 months

- Running outdoors, if the patient has a good technique
- Group training (similar to aerobics, adapted for knee-injured patients)
- Return to sports earliest after 16 weeks (non-contact sports) and 20 weeks (contact sports)
- Possibility for the patient to be evaluated at the research lab before 6 months if needed to estimate the ability to return to sports

TREATMENT PROTOCOL –
achilles tendon rupture non-surgically treated

Week 0:

Treatment: Walker brace with 3 heel lifts, weight-bearing through the heel as tolerated, use of 2 crutches. Referral to orthopedic technician for shoe heel-lift (use shoe with heel-lift on the healthy side)

Walker brace: Allowed to take off the walker brace for washing and airing the foot. When the walker brace is removed, no weight-bearing or dorsiflexion of the foot is allowed. Walker brace is to be worn while sleeping

Exercise program: Home exercises daily wearing the walker brace – move the toes several times a day

After 2 weeks:

Treatment: Walker brace with 2 heel lifts (take off the upper lift), full weight-bearing, use of 2 crutches if needed

Exercise program: Home exercises as described above

After 4 weeks:

Treatment: Walker brace with 1 heel lift, full weight-bearing

Exercise program: Home exercises daily as described above

After 6 weeks:

Treatment: Walker brace without heel lift full weight-bearing

Exercise program: Home exercises daily as described above

After 8 weeks: Visit orthopaedic surgeon

Treatment: Wean off walker brace. Use of shoes with heel-lift (until 14 weeks after injury), knee-high compression socks (17-20mm Hg) to prevent swelling

Exercise program: *Important that all exercises are performed slowly and carefully*

Home exercises:

- Active ankle exercises for ROM, ankle exercises (DF, PF, Sup, Pron) with rubber-band, balance exercises, sitting heel-rise, standing heel-rise (50% weight-bearing or less on the injured side), gait training

Visit to physical therapist 2 times per week:
- Exercise bike
- Active range of motion (ROM)
- Sitting heel-rise – with weight (starting position from the shoe heel-height)
- Standing heel-rise on two legs

- Active plantar flexion with a rubber-band (max 0° plantar flexion)
- Supination- and pronation – exercises with a rubber-band
- Gait training
- Balance exercises (not wobble boards or balance pods)
- Squats (fitness ball behind the back)
- Other knee/hip-exercises with no ankle involvement

After 10 weeks:

Treatment: Use of shoes with heel-lift until 14 weeks after injury, knee-high compression socks (17-20mm Hg) to prevent swelling

Exercise program: *Important that all exercises are performed slowly and carefully*

Home exercises: As described above

Visit to physical therapist 2 times per week:

- As described above, increase the intensity
- Sitting heel-rise – with weight (starting position from the shoe heel-height)
- Standing heel-rise on two legs - progress gradually to one leg
- Active plantar flexion, supination and pronation in a cable machine
- Heel-rise in leg press
- Balance exercises (wobble-board, balance pods-weight bearing in the middle of the foot)
- Step (walk slowly)
- Cable machine standing leg lifts

After 12 weeks: Evaluation at the research lab

Treatment: Use of shoes with heel-lift until 14 weeks after injury, knee-high compression socks (17-20mm Hg) to prevent swelling

Exercise program: *Important that all exercises are performed slowly and carefully*

Home exercises: As described above and walking 20 min per day

Visit to physical therapist 2 times per week:

- As described above, increase the intensity

After 16 weeks:

Treatment: Use of regular shoes after 14 weeks, barefoot after 16 weeks, knee-high compression socks (17-20mm Hg) to prevent swelling

Exercise program: *Important to gradually increase the load considering the patient´s status*

Home exercise: Walking 20 min per day

Visit to physical therapist 2 times per week:

- Intensify the exercises by increasing the load (as before)
- Increase the load gradually from two leg standing heel-rises to one leg standing heel-rises both concentrically and eccentrically
- Start with gentle jog (thick mattress, in 8´s, zig-zag)

- Start with two-legged jumps and increase gradually

After 18 weeks: Evaluation at the research lab 6 and 12 months after injury, visit orthopaedic surgeon 6 months

- Running outdoors, if the patient has a good technique
- Group training (similar to aerobics, adapted for knee-injured patients)
- Return to sports earliest after 20 weeks (non-contact sports) and 24 weeks (contact sports)
- Possibility for the patient to be evaluated at Lundberg Lab before 6 months if needed to estimate the ability to return to sports