Acute Achilles Tendon Rupture: The impact of calf muscle performance on function and recovery

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"Egentligen gäller endast detta; att inte tröttna, aldrig bli ointresserad, likgiltig, tappa sin dyrbara nyfikenhet – då tillåter man sig att dö. Så enkelt är det, är det inte?"

Tove Jansson, Rent spel

"It is simply this: do not tire, never lose interest, never grow indifferent – lose your invaluable curiosity and you let yourself die. It's as simple as that."

Tove Jansson, Fair play

ABSTRACT

There is an ongoing debate about the optimal treatment for patients with an acute Achilles tendon rupture. The overall purpose of this thesis was to acquire a greater knowledge of the way patients recover at different time points after the injury when treated with the currently recommended treatment protocols. This knowledge will then form the basis of the further development of treatment strategies with the ultimate goal of minimizing the risk of permanent disability after an Achilles tendon rupture.

In Study I, a long-term follow-up of 66 patients included in a randomized, controlled trial revealed that, 7 years after the injury, there were continuing deficits in calf muscle endurance and strength. There was no continued improvement in calf muscle performance after the 2-year follow-up, apart from heel-rise height.

Study II, a clinical prospective comparative study of a cohort of 93 patients, performed 3 months after the injury, concluded that standardized seated heel-rises were a safe and useful tool for evaluating calf muscle endurance and predicting future function and patient-reported symptoms. No differences in early calf muscle recovery were found between patients treated with surgery and patients treated with non-surgery, but the question of whether women recovered in the same way as men remained unanswered.

In Study III, a clinical retrospective comparative study comprising 182 patients, it was found that female patients had a greater degree of deficit in heel-rise height compared with males, irrespective of treatment. Females had more symptoms after surgery, at both 6 and 12 months, but this difference was not found in non-surgically treated female patients.

In Study IV, the effect of continued heel-rise height deficits on biomechanics during walking, running and jumping was further evaluated. This study revealed that heel-rise height, obtained during the single-leg standing heel-rise test, performed 1 year after the injury, was related to the long-term ability to regain normal ankle biomechanics. In this cross-sectional study, comprising 34 patients, the conclusion was drawn that minimizing tendon elongation and regaining heel-rise height may be important for the long-term recovery of ankle biomechanics, particularly during more demanding activities such as jumping.

This thesis shows that the early recovery of heel-rise height and calf muscle endurance has a significant impact on lower leg function and patient-reported outcome in the long term after an acute Achilles tendon rupture. No differences in early or late calf muscle recovery were found between patients treated with surgery and patients treated with non-surgery. Furthermore, it is concluded that females have more symptoms after surgery, but this difference is not found in non-surgically treated female patients. This knowledge could now form a new basis for developing more effective, individualized treatment protocols with the aim of optimizing the treatment after an acute Achilles tendon rupture.

Keywords: Achilles tendon rupture, Rehabilitation, Heel-rise, Function, Recovery, Calf muscle, Ankle biomechanics, Endurance, Jump, Sex differences

SAMMANFATTNING PÅ SVENSKA

Akut hälseneruptur är en relativt vanlig skada hos både män och kvinnor i medelåldern. Män drabbas i högre utsträckning och incidensen rapporterades 2012 vara 55/100 000 invånare hos män och 14.7/100 000 invånare hos kvinnor. Majoriteten skadas under någon form av sportutövande. Tidigare studier har traditionellt ofta fokuserat på om skadan bör behandlats med eller utan operation utan att konsensus har uppnåtts. Andra variabler har visat sig vara av större betydelse för återhämtningen efter skadan så som ålder vid skadan och BMI (Body Mass Index). Hur rehabiliteringen bör se ut för att uppnå bästa möjliga återhämtning efter en hälseneruptur är inte känt.

Syftet med denna avhandling var att öka kunskapen om hur patienterna är återhämtade avseende tåhävningshöjd vid tåhävningar, styrka och uthållighet i vadmuskler, hoppförmåga och subjektiva symptom vid olika tidpunkter efter hälsenerupturen. Denna kunskap kan därefter utgöra en bas för att utforska hur rehabiliteringen kan optimeras så att patienterna snabbt och individuellt anpassat ska kunna återgå till sportutövande, motionsaktiviteter och arbete.

Studie I var en långtidsuppföljning av 66 patienter som ingått i en tidigare randomiserad studie där skillnader i variabler mellan patienter som opererats respektive inte opererats utvärderats 1 och 2 år efter hälsenerupturen. Patienterna utvärderades i genomsnitt 7 år efter skadan och det visade sig att vadmusklerna i det skadade benet uppvisade fortsatt signifikant lägre styrka och uthållighet jämfört med det friska benet. Ingen ytterligare signifikant förbättring hade skett efter 2-årsuppföljningen. Dock fortsatte tåhävningshöjden att öka mellan 1- och 7-årsuppföljningen men den största ökningen skedde mellan 1 och 2 år.

Studie II, en klinisk prospektiv jämförande studie av en kohort av 93 patienter som utvärderades 3 månader efter skadan, visade att standardiserade sittande tåhävningar kan vara ett användbart verktyg för att, i tidigt skede efter hälsenerupturen, kunna utvärdera vadmuskelfunktionen kliniskt. Dessutom kunde standardiserade sittande tåhävningar delvis förutsäga framtida funktion och symptom.

Studie III, där 182 patienter var inkluderade, indikerade att kvinnor eventuellt inte ska behandlas på samma sätt som män efter en hälseneruptur då det visade sig att kvinnor som behandlats med operation hade en högre besvärsnivå från sin skadade hälsena både 6 och 12 månader efter skadan. Denna skillnad fanns inte i gruppen som behandlats utan operation, dock uppvisade män bättre återhämtning av tåhävningshöjden än kvinnorna oavsett behandling 12 månader efter skadan.

I Studie IV undersöktes effekterna av en bestående nedsättning av tåhävningshöjden efter en hälseneruptur. Biomekaniska variabler tillsammans med vadmuskelfunktionen, patientrapporterade symptom och senlängd utvärderades under gång, jogging och hopp i genomsnitt 6 år efter skadan på 34 patienter. Utfallen jämfördes, mellan en grupp patienter som redan vid 1-årsuppföljningen hade <15% sidoskillnad i tåhävningshöjd mellan den skadade och friska foten och en grupp som hade >30% sidoskillnad vid samma tidpunkt. Resultatet visade att gruppen med den minsta sidoskillnaden i tåhävningshöjd vid 1-årsuppföljningen också 6 år efter skada uppvisade mindre sidoskillnad i biomekaniska variabler, underbensfunktion och senförlängning jämfört med gruppen med >30% sidoskillnad i tåhävningshöjd vid ettårsuppföljningen. Det förelåg däremot ingen skillnad mellan grupperna när det gällde patientrapporterade symptom.

Sammanfattningsvis visade denna avhandling att tidig återhämtning av tåhävningshöjd och uthållighet i vadmuskulaturen hade stor betydelse för god underbensfunktion och få patientrapporterade symptom på lång sikt efter en akut hälseneruptur. Varken i tidigt eller sent skede efter skadan kunde någon skillnad i vadmuskelns återhämtning påvisas mellan patienter som var behandlade med eller utan operation. Dock uppvisade kvinnor som behandlats med operation mer symtom jämfört med kvinnor som behandlats utan operation. Denna kunskap kan bidraga till att kunna utveckla mer effektiva och individualiserade behandlingsprotokoll med målet att kunna optimera behandlingen efter en akut hälseneruptur.

LIST OF PAPERS

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

I. Brorsson A, Silbernagel KG, Olsson N, Nilsson Helander K (2017).
Calf muscle performance deficits remain 7 years after an Achilles tendon rupture.
Am J Sports Med. doi: 10.1177/0363546517737055.

II. Brorsson A, Olsson N, Nilsson-Helander K, Karlsson J, Eriksson BI, Silbernagel KG (2016).
Recovery of calf muscle endurance 3 months after an Achilles tendon rupture.
Scand J Med Sci Sports;26(7):844-853.

III. Silbernagel KG, Brorsson A, Olsson N, Eriksson BI, Karlsson J, Nilsson-Helander K (2015).
Sex differences in outcome after an acute Achilles tendon rupture.
Orthop J Sports Med 3(6):2325967115586768. eCollection 2015.

IV. Brorsson A, Willy RW, Tranberg R, Silbernagel KG (2017).
Heel-rise height deficit 1 year after Achilles tendon rupture relates to changes in ankle biomechanics 6 years after injury.
Am J Sports Med. doi: 10.1177/0363546517717698.

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ABBREVIATIONS

a	acceleration
ADL	Activities of daily living
AT	Achilles tendon
ATRS	Achilles tendon Total Rupture Score
BMI	Body Mass Index
BW	Body weight
drop CMJ	drop countermovement jump
EMG	Electromyography
F	Force
GRF	Ground reaction force
ICC	Intraclass correlation coefficient
ICF	International Classification of Functioning, Disability and Health
IQR	Inter-quartile range
J	Joule
LSI	Limb Symmetry Index
m	mass
ma	moment arm
MLB	Major League Baseball
MTJ	Musculotendinous junction
N	Newton
NBA	National Basketball Association
NFL	National Football League
NHL	National Hockey League
Nm	Newton-meters
Ns	Newton-seconds
OTJ	Osteotendinous junction
PA	Physical Activity
PAS	Physical Activity Scale
PROMs	Patient-reported outcome measurements
RCT	Randomized Controlled Trial
RICE	Rest Ice Compression Elevation
SDC	Smallest Detectable Change
SEM	Standard Error of Measurement
US	Ultrasound
VAS	Visual Analog Scale
W	Watt
WHO	World Health Organization

BRIEF DEFINITIONS

BMI (Body Mass Index)	An index to relate an adult's weight to his/her height. BMI is defined as the quotient between a person's weight (kg) divided by his/her height in meters squared (m^2).
Impulse	Impulse is a force applied over a period of time, expressed as Newton-seconds (Ns). Impulse (Ns) = force (N) x time (s)
Kinematics	Describes the motion of a body part without any consideration of the mass of the body or the forces that cause the motion.
Kinetics	Describes the forces and torques acting on the body during motion.
Limb Symmetry Index (LSI)	The ratio of the injured limb score and the uninjured limb score x 100, expressed as percent (%).
Moment or Torque	Are the internal and external forces acting at a specific joint. Moment (Nm) = moment arm (m) x force (N)
Muscle force	When a muscle contracts or stretches, it creates muscle force. Force is expressed as Newton (N).
Negative predictive value	The proportion of individuals with a negative test result that do not have the specific condition.
Newton's second law	Also called "The law of acceleration". The acceleration of an object is proportional to the magnitude and direction of the forces acting on it and inversely proportional to the mass of that object: a (acceleration) = force(F)/mass (m)
Newton's third law	For every action there is an equal and opposite reaction.
Positive predictive value	The proportion of individuals with a positive test result that have the specific condition.
Power	Power is the product of force and velocity expressed as watts (W) or Newton-meters/second (Nm/s). Power (W) = force (N) x distance (m)/time (s)
Sensitivity	The proportion of individuals with the condition of interest that have a positive test result.
Specificity	The proportion of individuals without the condition of interest that have a negative test result.
Stiffness and Young's modulus	Young's modulus or elastic modulus is a measurement of the stiffness of a solid material. It defines the relationship between stress (force per unit area) and strain (proportional deformation) described as a quotient between the force per unit area (stress) and the proportional deformation (strain) of a material, for example, a tendon. Young's modulus = force (N)/area(mm^2)/change in length (ΔL)/original length (L_0)
Work	The product of the force and distance through which the body moves expressed in Joules (J). Work (J) = force (N) x distance (m)

01

INTRODUCTION

In 1693, the Dutch surgeon, Philip Verheyen, renamed the "tendo magnus of Hippocrates" as the "Achilles tendon" after Achilles, the Greek hero in Homer's Iliad, who was fatally injured by a poisoned arrow that hit his heel [172].

It is not known how much Hippocrates, the "father of modern medicine" [40], knew about rehabilitation after an Achilles tendon rupture when, approximately 2.400 years ago, he stated that "This tendon, if bruised or cut, causes the most acute fevers, induces choking, deranges the mind, and at length brings death". In 1736, Jean Louis Petit, a famous French surgeon in Paris at the beginning of the 18th century, was one of the first to describe the treatment and rehabilitation of a patient with bilateral Achilles tendon ruptures.

"The patient was treated prone with the knees flexed and the feet plantar flexed during which time a series of bandages soaked in alcoholic spirit was applied. A slipper on the foot was attached to the upper bandage with pins to maintain plantar flexion. The patient was turned with a pillow under the knees. The bandages were removed and re-applied after eight and 15 days. Healing was advanced at 22 days and weight-bearing commenced ten days later. The use of crutches was not mentioned, but a good result was claimed" [73].

Some years later (in 1766), John Hunter described the rehabilitation after his own Achilles tendon rupture. He used a bandage with the injured foot in plantar flexion for five days and, after that, he used Monro's bandage *(Figure 1)* for five weeks. He also describes how he uses a night splint for another five months [73].

Monro's bandage was one of the first known specially designed braces for Achilles tendon rupture and it was used during the 18th century. It was a slipper with a strap from the heel of the slipper up to a bandage around the calf muscle, allowing adjustable degrees of plantar flexion in the ankle *(Figure 1)* [73]. It is not known whether the injured persons were allowed weight-bearing during the six weeks for which the bandage was used, but a splint was recommended during daytime for five months after weaning off Monro's bandage *(Figure 1)* [73]. It was not until the first half of the 20th century that surgery started to become a more common treatment for Achilles tendon rupture and there is still no consensus on whether surgery or non-surgery should be the "golden standard" for this injury. Moreover, the impact of rehabilitation on function and recovery after an Achilles tendon rupture is even more unexplored.

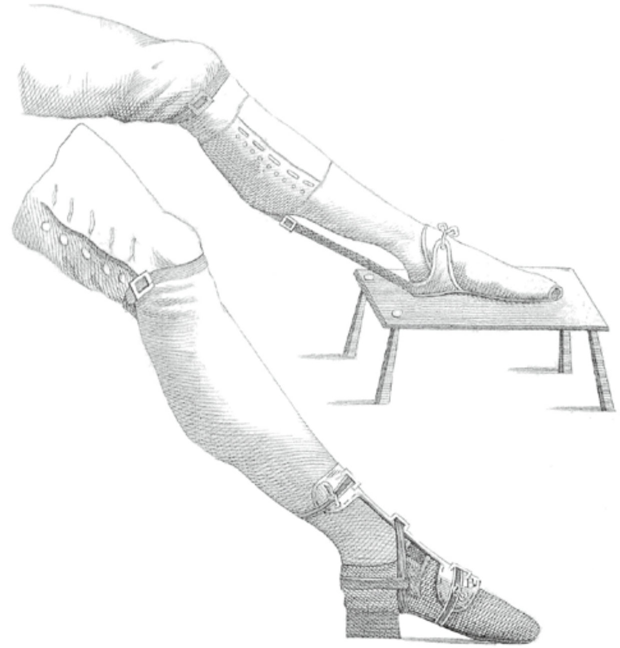


Figure 1. At the top, an illustration of Monro's bandage and, below, a splint for use during daytime. From the book Monro A. The Works of Alexander Monro MD. Charles Elliott and George Robinson. London 1781:661. By kind permission of the Royal Society of Medicine, London, United Kingdom.

Anatomy

It has been suggested that the Achilles tendon in humans gradually became longer and developed into today's anatomy around two million years ago in order to allow humans to run faster after having started to walk on two legs instead of four [97]. This tendon is the strongest tendon in the body and also one of the longest [58] and it is the common tendon of the medial and lateral gastrocnemius and soleus with its insertion into the calcaneus [60]. The medial and lateral gastrocnemius muscles, together with the soleus, are known as the triceps surae [60]. The medial head of the gastrocnemius arises proximal to the medial femoral condyle, while the lateral head of the gastrocnemius arises proximal to the lateral femoral condyle, allowing the gastrocnemius muscle to perform plantar flexion and supination in the ankle, as well as knee flexion [60]. The soleus muscle arises from the middle of the tibia, as well as from the head and upper third of the dorsal part of the fibula and also from the tendinous arch between the fibula and tibia, situated beneath the popliteus muscle [60]. The length of the gastrocnemius part of the Achilles tendon ranges from 11 to 26 cm and the soleus part of the tendon from 3 to 11 cm [28]. The plantaris muscle is a very thin, slender muscle arising close to the origin of the lateral gastrocnemius and from the dorsal part of the knee capsule and inserts anterior-medially or medially to the Achilles tendon or integrates and inserts together with the Achilles tendon into the calcaneus [60, 149]. Earlier, the plantaris muscle was reported to be missing in 7% of the population [28], but a recent review suggested that up to 19% of the population lack the plantaris muscle on one or both sides [149].

Apart from being the strongest plantar

flexor and supinator in the ankle, the design and structure of the Achilles tendon is also especially well-suited for jumping and hopping [3]. This is partly due to the form of the Achilles tendon; from the proximal part to the distal part, the medial part of the tendon rotates 90° clockwise in the left calf and 90° counter-clockwise in the right calf [89]. This shape might not be restored after an Achilles tendon rupture and this may partly explain the deficits in calf muscle performance and tendon elongation after the injury *(Figure 2)*.

The gastrocnemius muscle is mainly designed to move the body forwards during walking, running and jumping and, as a result, fast-twitch Type II muscle fibers are the most common muscle fibers. The soleus muscle is composed primarily of slow-twitch Type I fibers and this makes it more suitable for maintaining posture and stabilizing the foot during standing [24, 30]. The core task of the plantaris muscle is thought to be as a proprioceptive organ for the gastrocnemius and soleus muscles, as the plantaris muscle has a high density of muscle spindles [149].

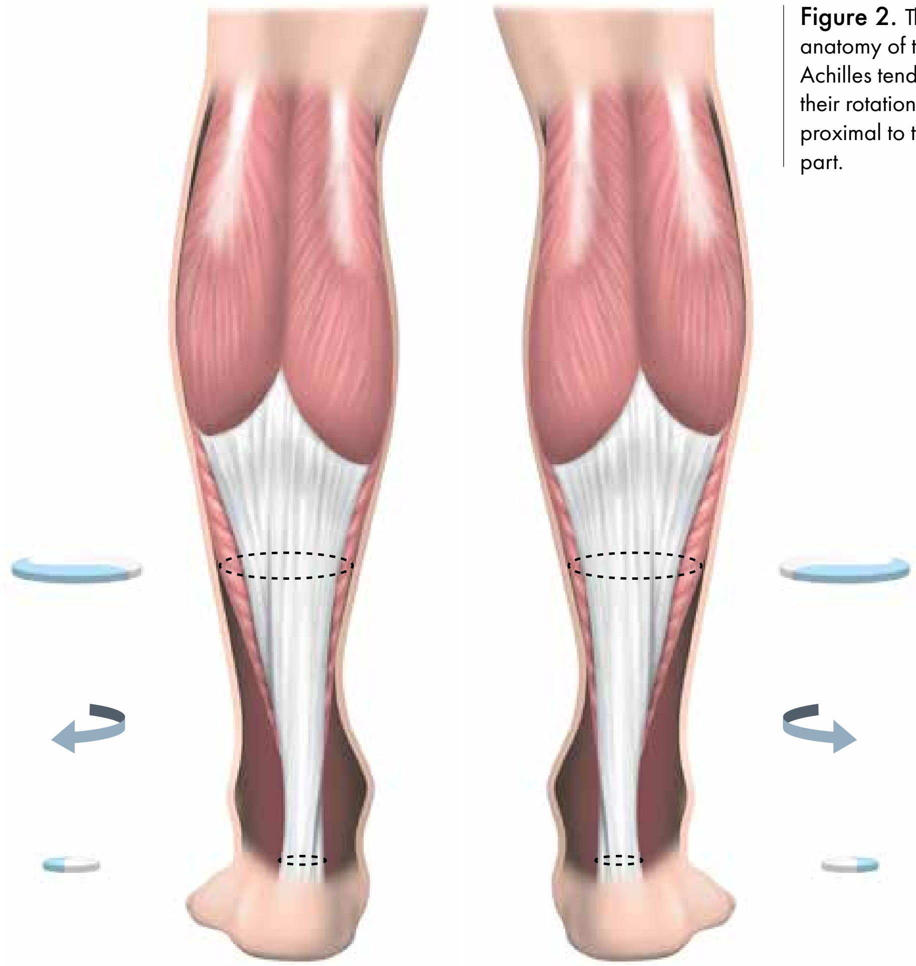


Figure 2. The anatomy of the Achilles tendons and their rotation from the proximal to the distal part.

Circulation, innervation and metabolism

The region of the mid-portion of the Achilles tendon, 2-6 cm above the calcaneus, is where the tendon ruptures in most cases. It has been proposed that the same area also has reduced vascularity compared with the rest of the tendon [20], but a more recent review [158] has concluded that there is limited information about vascularization. Furthermore, the primary blood supply in the Achilles tendon is thought to come from the paratenon [158]. It is not fully known how much vascularity is associated with the risk of Achilles tendon rupture. It has also been suggested that other factors, such as the tendon rotating and being thinner in the same area, contribute to the rupture risk [158]. Older age has been shown to reduce the vascularity in the Achilles tendon, while exercise can increase the blood flow up to 2.5-3 times compared with rest [81].

The nerve supply in the Achilles tendon arises mainly from the suralis nerve but also from other cutaneous nerves in the area [152]. The paratenon of the Achilles tendon has more innervation compared with the core of the tendon and both the paratenon and the tendon comprise mechanoreceptors and free nerve endings, significant for proprioception and pain experience [58, 90].

The oxygen consumption in the tendon is 7.5 times lower than in the muscle [168]. This can appear to be detrimental for the tendon; however, the oxygen consumption for collagen synthesis is strikingly lower than that for the equivalent occurrence in the skeletal muscle [118]. In a healthy tendon, there is a balance between collagen synthesis and collagen breakdown [118]. After an injury or exercise, the collagen synthesis increases [71, 118]. Insulin, testosterone and estrogen can also increase the collagen synthesis, while corticosteroids can reduce collagen production [118].

Structure of the tendon

A tendon comprises collagen and elastin embedded in a proteoglycan-water matrix. Collagen type I is the predominant structure, accounting for 65-80% of the dry mass of the tendon, while elastin accounts for 1-2% and collagen type III for 0-10% [62, 71, 117]. Injured Achilles tendons, on the other hand, contain a larger percentage of collagen type III compared with a healthy tendon [71, 91]. The structure of the tendon is shown in *Figure 3*, with the collagen fibrils organized in collagen fibers, primary, secondary and tertiary fiber bundles [62, 117].

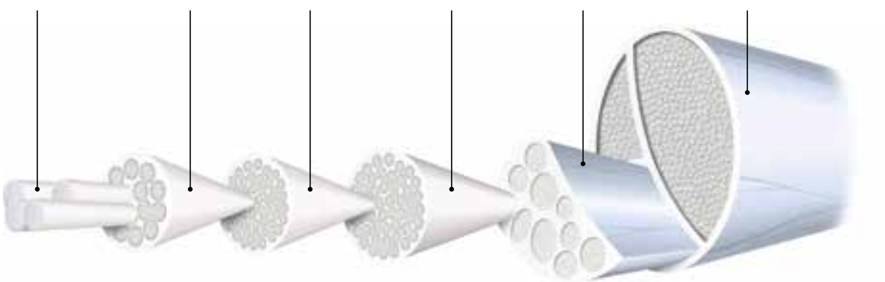


Figure 3. The structure of the tendon from the smallest collagen fibril to the entire tendon.

Biomechanics

Biomechanics of the Achilles tendon

The Achilles tendon is the strongest tendon in the body and its purpose is to transport high forces from the calf muscle to the calcaneus [58]. In addition to this function of helping the muscle to produce higher forces than are possible without a healthy tendon, another important function of the Achilles tendon and the triceps surae muscle is to store and release energy through the stretch-shortening cycle [36, 75]. This is what happens when people walk, run or jump up and down repeatedly, such as skipping with a rope. While performing these activities, the muscle-tendon complex has to shift between acting concentrically and eccentrically [75, 76].

A stress-strain curve is often used to describe the response of the collagen fibers to tension [58, 117] *(Figure 4)*. The gradient on the curve is a quotient between the force per unit area (stress) and the proportional deformation (strain) of the tendon and is called stiffness or Young's modulus [79].

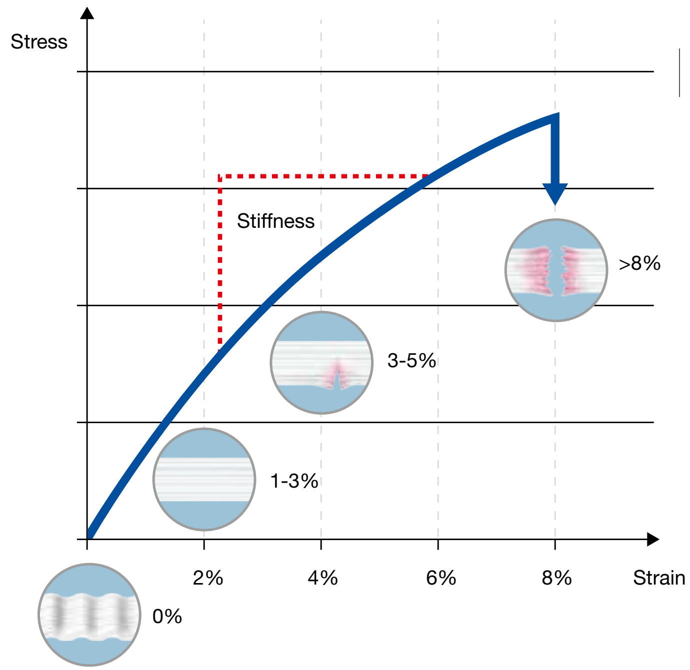


Figure 4. Stress-strain curve of a tendon.

When the tendon is relaxed, the collagen fibers are arranged like waves and there is a non-linear relationship between stress and strain, the so-called "toe region". When strained by 2%, this pattern disappears. Between 2-4% strain, the collagen fibers respond in linear fashion to the force, if the strain exceeds 4-8%, microscopic ruptures occur inside the tendon and, at > 8%, the tendon will rupture totally [117]. In vivo measurements with a transducer around the Achilles tendon have shown that the force in the Achilles tendon varies a great deal between activities *(Table 1)* and also between individuals [36, 77].

Table 1. In vivo measurements of forces in the Achilles tendon in individuals during different activities according to Komi et al. [77].

Activities	Force (Newton)	Times x body weight (BW)
WALKING	2600	3
RUNNING	9000	12.5
CYCLING	1000	1
HOPPING	4000	5

The concepts in biomechanics

Biomechanics can be divided into kinematic, kinetic and spatial and temporal variables *(Figure 5)*.

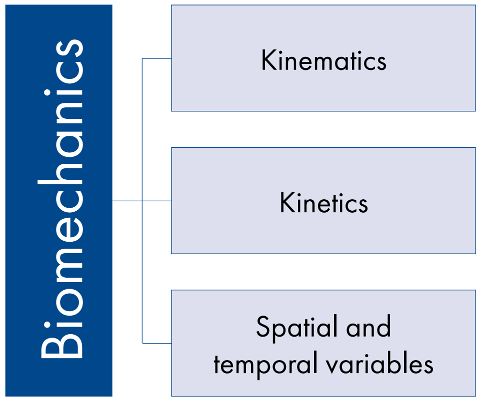


Figure 5. Different types of biomechanics.

Kinematics

Kinematics describes the motion of a body part without any consideration of the mass of the body or the forces that cause the motion. As a general rule, there are two different types of motion; translation and rotation. Translation describes a linear motion, while rotation is characterized as a circular movement around an axis. The variables in kinematics are linked to position, velocity and acceleration. Change of position relating to a joint is expressed in degree [110]. Velocity is the change in the position of a body over time expressed as meter/second or degree/second. Acceleration is the change in the velocity of a body over time and the units used are meter/second^2 or degree/second^2. [110]

Kinetics

Kinetics describes the forces and moments (torques) acting on the body or expressed by the body during motion. A force (F) applied to a body can be quantified as the product of the mass (m) receiving a push or pull and the acceleration (a) of the mass ($F = m \cdot a$). This is Newton's second law. The unit of force is Newton (N). Forces acting on the musculoskeletal system can be either internal or external. Internal forces are created within the body, while external forces are produced outside the body [110].

When a force is applied at a distance perpendicular from the axis of a joint, this distance is called a moment arm. Moment, or torque, is the product of the force and its moment arm. Moment is the rotatory equivalent of the force. Moreover, moment can be divided into internal and external moment. Internal moment is the product of the muscle and its moment arm within the body, while external moment is the product of the external force (for example, gravity) and the external moment arm. The unit of moment is Newton-meter (Nm) [110]. Other concepts used in kinetics are impulse, work and power. Impulse is what happens when a body is influenced by an amount of force during a certain time expressed in Newton-second (Ns). Joint work is when a force influences a body during a certain distance, expressed in Joules (J). Joint power is defined as angular velocity times joint moment and it is expressed in Watt (W) or Newton-meter/second (Nm/s) [110].

Force (N)
= mass (kg) x acceleration (meter/second^2)

Moment or torque (Nm)
= force (N) x moment arm (m)

Impulse (Ns)
= force (N) x time (s)

Work (J)
= force (N) x distance (m)

Power (W)
= force (N) x distance (m) / time (s)

Spatial and temporal variables

Spatial and temporal variables in biomechanics are measurements of distance and time related to walking, running and jumping [110]. Examples of spatial measurements of gait and running are stride length, step length and step width, whereas examples of temporal measurements are cadence, step time and stride time. Likewise, jump height is a spatial measurement, while contact time and flight time are examples of temporal measurements during jumping. Walking and running speed are considered to be spatial-temporal variables [110].

Biomechanics of a heel-rise

Moment is the quantification of a force times its moment arm to rotate a body segment around an axis, in the ankle joint, for example. The moment arm of a muscle changes as a function of joint position [110].

The larger the moment arm of the muscle, the greater moment it will produce, provided muscle length is kept constant. During an isometric contraction, the internal moment inside the body is equal to the external moment outside the body and both moments are in opposite rotary directions. This is an example of the angular version of Newton's third law that says that, for every action, there is an equal and opposite reaction [110]. Another example is the ground reaction force that is the equal, and in the opposite direction, response to the force from the body weight.

The force in the Achilles tendon is many times greater than the body weight during different activities such as walking and running [77] and due to the anatomy and size of different moment arms in the foot. Performing a heel-rise is facilitated by the two co-existing internal moments needed for a maximum heel-rise; one at the talocrural joint and one at the metatarsophalangeal joints [110] *(Figure 6)*. The mechanics of a heel-rise are comparable to lifting a load with a wheelbarrow, where the metatarsophalangeal joints correspond to the center of the wheel and the triceps surae muscle-tendon complex is comparable to the handles of the wheelbarrow *(Figure 6)*.

However, the greatest force in the Achilles tendon during a heel-rise is created when the foot is in dorsiflexion, since the external moment arm of the ground reaction force is many times larger compared with the moment arm of the Achilles tendon in this position *(Figure 7)*. As the moment arm of the ground reaction force decreases, while the moment arm of the Achilles tendon increases slightly, the higher the heel is lifted, the more the Achilles tendon force decreases through the heel-rise. Moreover, the Achilles tendon is ingeniously designed in the human body in the way it is attached to the calcaneus, so the moment arm of the Achilles tendon increases slightly during a heel-rise, a mean of approximately two millimeters from a position at 20° dorsiflexion to 10° plantarflexion [98] *(Figure 8)*. This would not be the case if the attachment to the calcaneus was in a more ventral position.

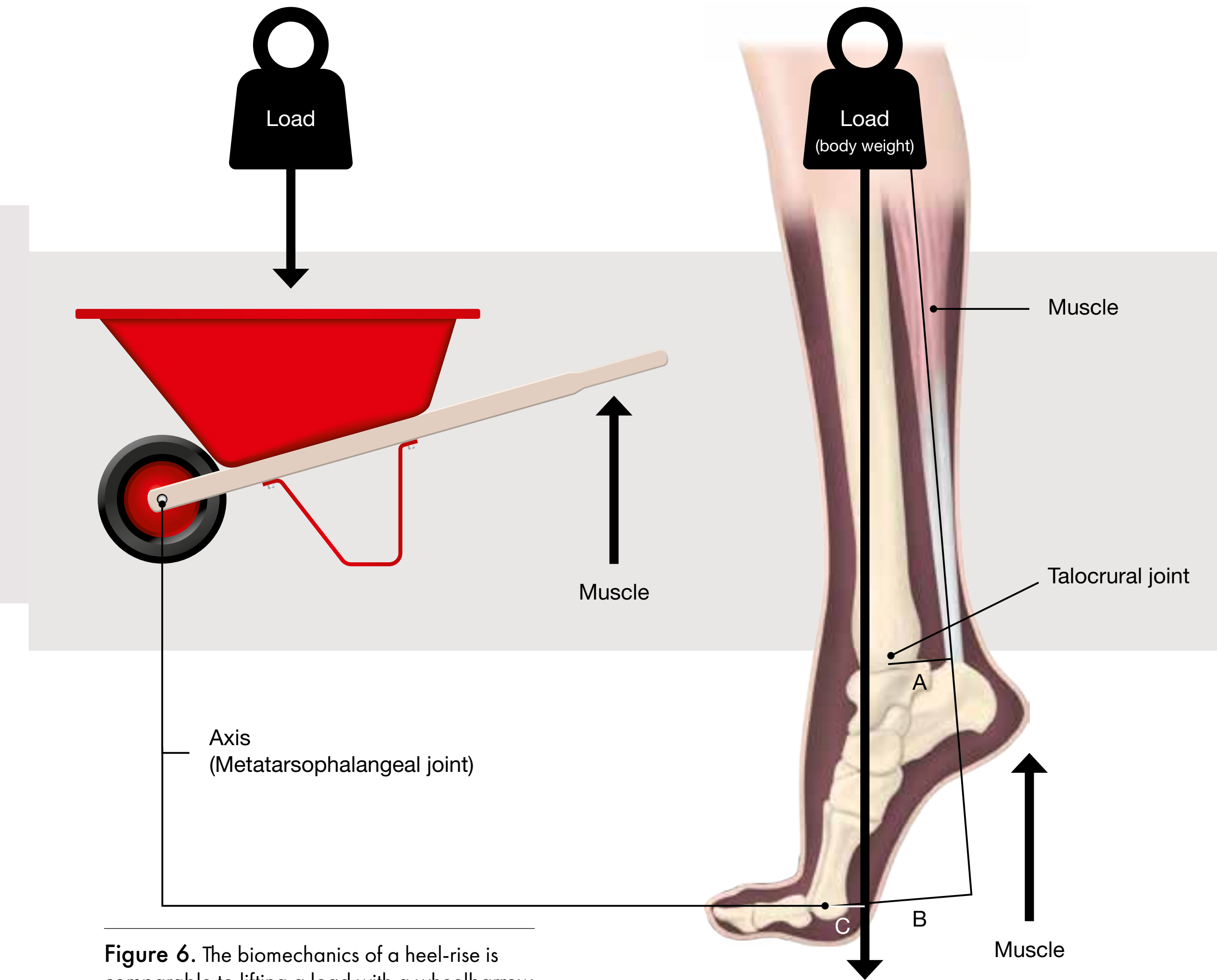


Figure 6. The biomechanics of a heel-rise is comparable to lifting a load with a wheelbarrow.

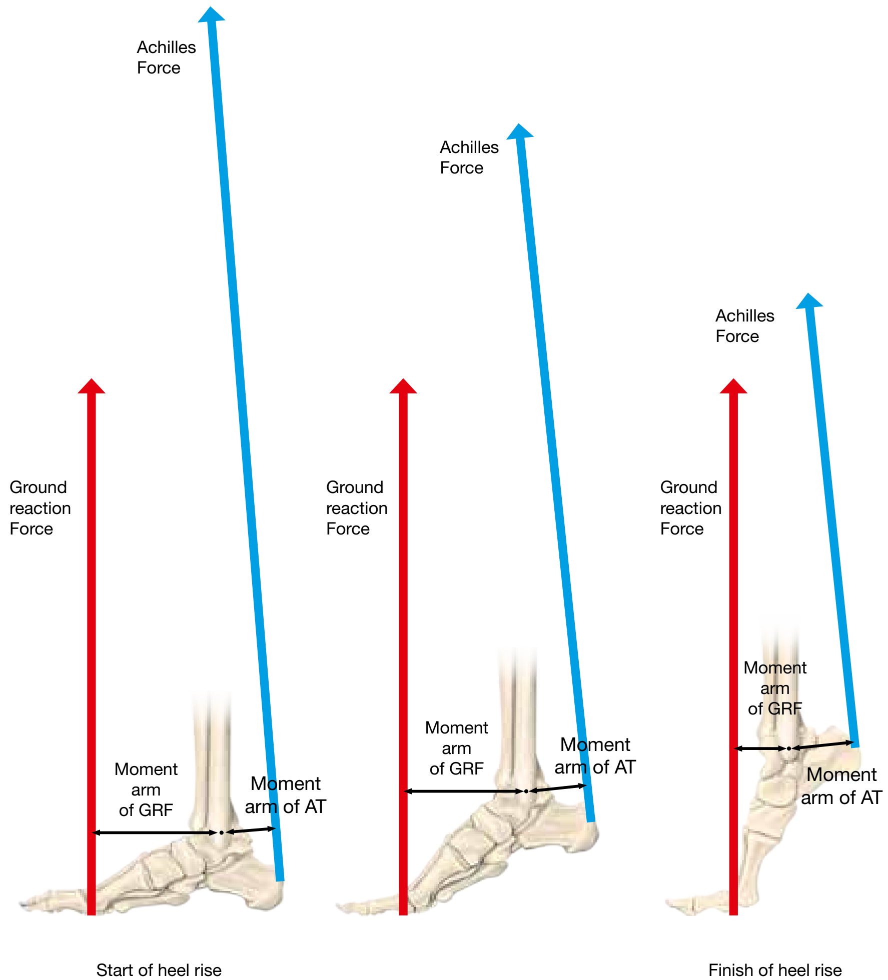


Figure 7. The moment arm of the ground reaction force (GRF) is many times larger compared with the moment arm of the Achilles tendon (AT). This leads to higher forces in the Achilles tendon when the foot is in dorsiflexion compared with in plantar flexion.

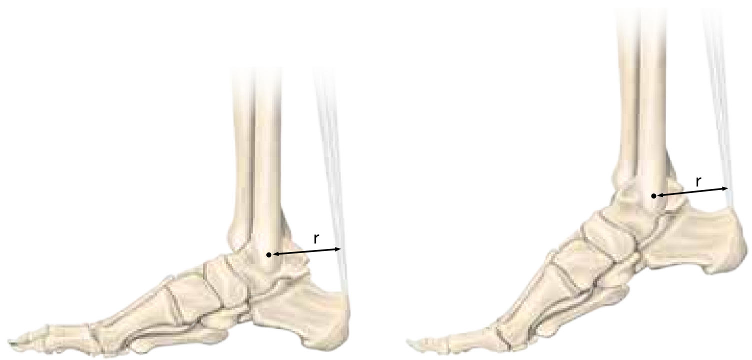


Figure 8. The attachment of the Achilles tendon dorsally on the calcaneus is designed so that the moment arm increases slightly during a heel-rise.

ACHILLES TENDON RUPTURE

Epidemiology

Achilles tendon rupture is a common injury among physically active individuals and the incidence is reported to be between 6 and 55/100.000 inhabitants and rising [38, 52, 58, 59]. The typical patient is male, in his forties and the injury often occurs suddenly and unexpectedly, while playing a sport that requires quick changes of direction, such as racket sport, basketball or soccer. It has been reported that 73% of all Achilles tendon ruptures are sports related and, in this group, the injury occurs in the age group of 30-49 years [50]. Other causes of injury, not associated with sport, can include jumping ashore from a boat or pushing or lifting something heavy when the foot is at the end range of dorsiflexion. Patients who have an Achilles tendon rupture due to these causes are often a bit older; a mean age of 53 years has been found in this group [85].

Etiology

The reason for incurring an Achilles tendon rupture is thought to be multifactorial [22]. The most frequent theories are that the patient suffers from either some kind of degenerative change in the Achilles tendon and/or that the injury is due to mechanical disorders such as a malfunction in inhibitory mechanisms for protecting the tendon against extremely high internal forces during a sporting performance or other highly demanding activities [22, 159]. Today, there is only moderate evidence that a reduced fibril size in the tendon increases the risk of causing an Achilles tendon rupture [22, 96, 135]. The decrease in fibril size is thought to be partly due to aging, as the ability to adapt to loading decreases with age [164]. However, it has also been suggested that exercise can prevent the aging process in the tendon to some extent [71, 156]. Other risk factors that have shown limited evidence of causing an Achilles tendon rupture are being male compared with being female [22], the use of oral fluoroquinolone and corticosteroids [22, 139, 171, 182], increased body weight [22, 139, 171] and living in an urban area [22, 116].

Patients who have an Achilles tendon rupture are often younger and are more frequently injured during sport activities compared with patients suffering from other tendon ruptures [57, 63].

Mechanisms of injury

The mechanical explanation for having an Achilles tendon rupture in a seemingly healthy tendon has been described as comprising three different types of injury mechanisms [8].

1) A push-off with the weight-bearing foot while the knee on the same limb is extended. This can, for example, be the case in running and some types of jumping, as well as in racket sports when a person takes a step backwards and immediately changes direction pushing the body forward again with the load on the rear foot *(Figure 9)*.

2) Sudden dorsiflexion of the foot in an unexpected way. This type of injury can occur when a person slips from a ladder or the stairs and the heel suddenly sinks down without the person being prepared. It can also occur if a person suddenly falls forward during cross-country skiing *(Figure 9)*.

3) Powerful dorsiflexion of the foot while in plantar flexion. This can be the case when a person falls or jumps from a height and the ankle is in plantar flexion on landing *(Figure 9)*.

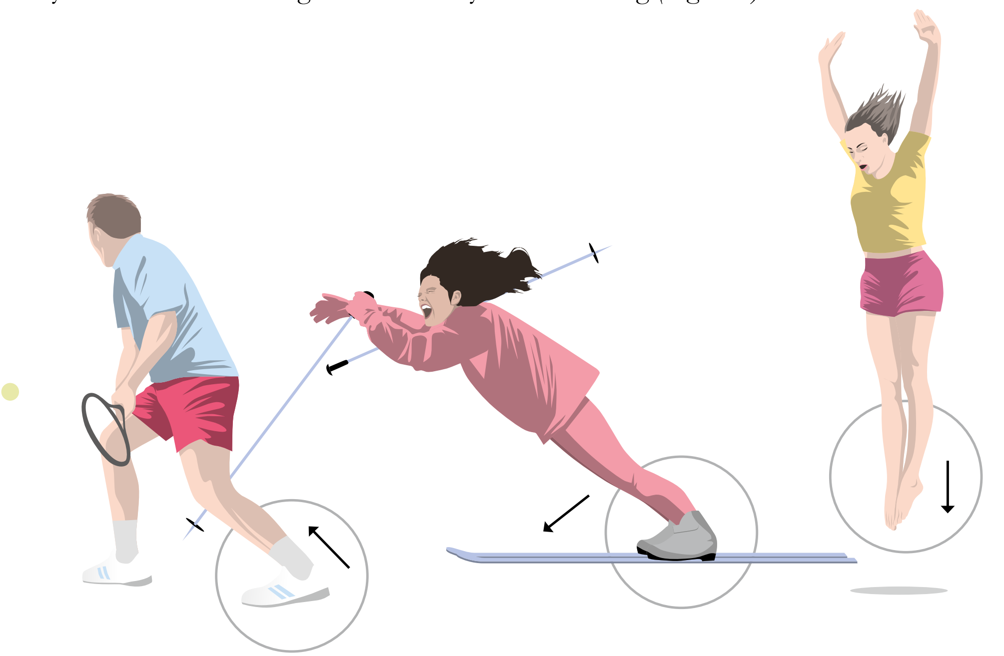


Figure 9. Three different types of mechanical mechanism that can lead to an Achilles tendon rupture.

Diagnosis

The diagnosis of an Achilles tendon rupture can and should almost always be established clinically [88]. The patients' description of the injury is often very similar, describing an unexpected, sudden "pop" – sometimes with a loud sound – and pain in the back of the heel. "It was like someone hit me with a baseball bat, but nobody was behind me" is a frequent description. The most common test to verify the diagnosis is the calf squeeze test (also called Thompson's test or Simmond's test [162]) and Matles test [88, 101]. The calf-squeeze test *(Figure 10)* has high sensitivity (0.96) and specificity (0.93), as does the Matles test *(Figure 11)* (sensitivity 0.88 and specificity 0.85), and they are both easy to perform, non-invasive and no equipment is needed [88]. If an Achilles tendon rupture occurs, the best primary management is to use the Rest Ice Compression Elevation (RICE) principle, as in all soft-tissue injuries [41] and in this case with the foot kept in plantar flexion. The injured person should not walk on the injured leg. The next step should be to transport the patient to the nearest hospital.

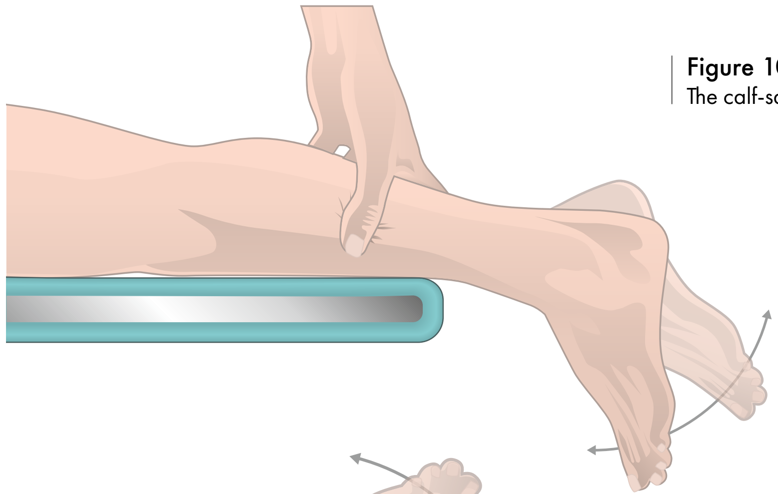


Figure 10.
The calf-squeeze test

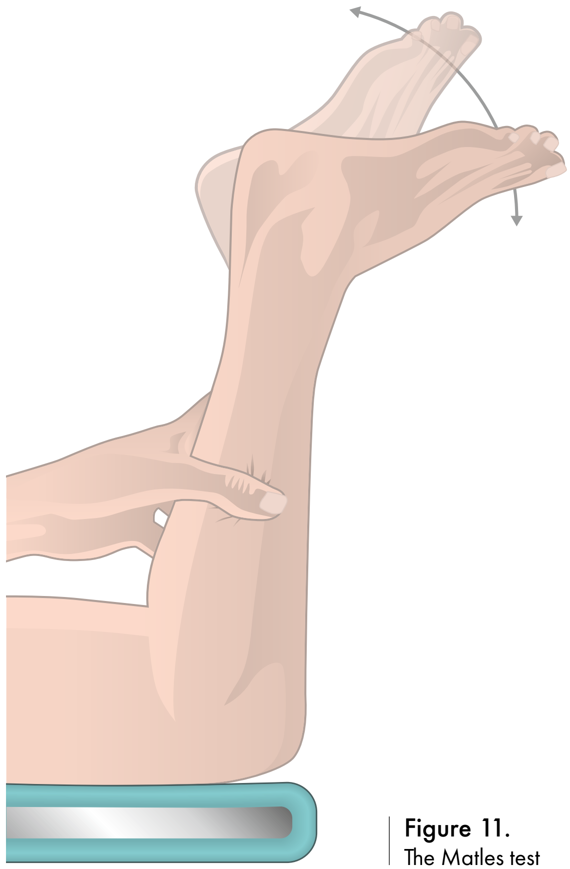


Figure 11.
The Matles test

Initial treatments; surgery or non-surgery

The initial treatments after an Achilles tendon rupture can be either surgical or non-surgical. The surgical treatment can be either open or minimally invasive and it is followed by casting and/or bracing for 6-8 weeks, in most cases, while non-surgical treatment only involves casting and/or bracing for 6-8 weeks. Modern treatment includes early weight-bearing and early rehabilitation [47]. There are systematic reviews and meta-analyses of randomized, controlled trials (RCTs) evaluating whether surgical or non-surgical treatment results in a superior outcome [11, 53, 55, 69, 148, 179, 184, 188].

There is still no consensus on which treatment that is the best for the individual patient. Historically, the primary outcome variable has been the re-rupture rate. Unfortunately, the reports that include evaluations of calf muscle recovery are difficult to compare, due to inconsistent evaluation methods.

There are pros and cons with both treatments; most systematic reviews and meta-analyses report that the re-rupture rate is 2-4 times lower when treated with surgical treatment, even if it is necessary to consider the risk of infection, sural nerve disorders and scar problems related to the surgical procedure [11, 53, 55, 69, 179]. However, more recent reports state that the re-rupture rate is equal between the two treatments, when functional rehabilitation, including early weight-bearing, is used in non-surgical treatment [176, 184, 188]. Unfortunately, the studies are not able, with a high evidence level, to conclude which treatment is the best for lower leg function and the recovery of tendon structure either in the short term or in the long term.

This is mainly due to the inconsistency of methods and different functional outcome measurements used in the included randomized, controlled trials.

Tendon healing

The mechanism of tendon healing is a complex process and it is not as yet fully understood [48, 140, 174]. Generally, the healing process is divided into three overlapping phases [48, 140, 174].

The first acute inflammatory phase that only lasts for a few days or up to a week starts with a hematoma, platelet activation and vasodilation in the injured area [174]. The purpose is to start the healing process and remove dead tissue. As this happens, a fibrin cloth is developed for temporary stiffness, the macrophages start to support the reconstruction of the tendon and mesenchymal stem cells begin to proliferate to build up a matrix around the injured area [174].

In the second phase – the proliferative or repair phase – the cells mature into fibroblasts and start to produce collagen, in the beginning type III and later on type I. This phase lasts approximately 1-8 weeks after the injury [83, 140, 174].

The last phase – the remodeling or maturation phase – starts in the fourth to eighth week after injury and in this phase the matrix is slowly dissolved and replaced by collagen type I and the tendon reshapes. This phase can last up to a year or longer [140, 174]. However, the mechanical properties in a ruptured tendon will always be inferior to the mechanical properties of an uninjured tendon [83, 140, 174]. The reason for not achieving full recovery is not completely known. A need for better markers of tendon healing in order to predict functional outcome and optimize treatment during all the rehabilitation phases has been suggested [1].

The impact of mechanical loading on tendon healing

Even though it has been concluded that mechanical loading plays an important role in tendon healing, there is no consensus about when and how much the Achilles tendon should be loaded to heal in the most optimal way after it has ruptured [1, 10].

Animal studies have shown that immobilization is detrimental to the healing tendon after an injury and a small amount of daily loading can improve the mechanical properties of the tendon [6, 14]. After 90 days of bed rest in 18 healthy men, it was found that, due to changes in the material properties of the Achilles tendon, the stiffness decreased by 58% in those who had only bed rest and 37% in those who were allowed to perform daily heel-rises lying down in a flywheel machine [128].

Moreover, it has been shown that patients who were allowed to exercise the injured ankle using a pedal every day from two weeks after the Achilles tendon rupture experienced a greater improvement in the material properties of the injured tendon compared with a control group [137]. In an animal study, it was indicated that loading the tendon without restrictions in the first inflammatory phase could prolong the inflammatory phase in the tendon healing of rats compared with 15 minutes of loading once a day [5]. This finding may indicate that there might be an optimal dosage of loading in order to achieve the most positive outcome. A prolonged inflammatory phase may produce a thick, strong tendon without improved material properties [5]. However, it is still unknown whether this is the case in the human tendon. In a systematic review comprising 424 patients, Kearney et al. [66] concluded that early weight-bearing is safe within the context of re-rupture and tendon lengthening.

A recent study claimed that patients who were allowed weight-bearing at two weeks as compared with at four weeks after surgery for an Achilles tendon rupture were able to return to work earlier and had higher Achilles tendon Total Rupture Scores (ATRS) [70]. However, no difference was seen in calf muscle recovery evaluated with a heel-rise test [70].

The effect of allowing immediate weight-bearing on the early tendon healing response was investigated in a prospective RCT and it was found that immediate weight-bearing significantly increased the levels of the metabolite, glutamate, compared with those who were allowed weight-bearing after 6 weeks [169]. Glutamate is thought to play a role in early tendon repair that is connected with cell proliferation and energy provision [1, 169]. Moreover, in this study, the levels of glutamate correlated to the concentration of markers of procollagen type I which may indicate that glutamate regulates the synthesis of collagen I. The levels of glutamate also correlated to improved functional outcome 6 months after the injury [169].

Sex differences in tendon healing

The difficulty when comparing sex

differences in patients with an Achilles tendon rupture is that women only account for approximately 20% of the injuries [50, 52]. One possible reason for fewer injuries in women could be that, in healthy women, the Achilles tendon has reduced stiffness, a greater response to stretch regarding tendon stiffness and lower stiffness after fatigue and during plantar flexion compared with men [18, 34, 56, 78]. Taken together, this may protect the Achilles tendon in women from injury.

In terms of the healing process, it has been reported that collagen synthesis is significantly elevated in men compared with women after exercise and this may indicate that women could have a poorer ability for tendon healing [105]. Moreover, it has been concluded that the Achilles tendon may not adapt as well in response to loading in women compared with men, which may be a problem after an Achilles tendon rupture [177]. It has also been suggested that estrogen influences the mechanical behavior of the Achilles tendon [17]. A difference in outcome after an Achilles tendon rupture between the sexes has also been found [13, 136]. Olsson et al. [120] showed that being able to perform a single-leg standing heel-rise 3 months after injury was more likely if you were male.

Another study found greater calf muscle weakness in women [86], while Bostick et al. [13] concluded that being male predicted a greater degree of calf muscle weakness 1 year after an Achilles tendon rupture. Taken together, there appear to be sex differences in terms of tendon healing and recovery after a rupture, but it is still not clear whether this means that the treatment should be different for males and females in order to optimize outcome.

Tendon elongation during healing

Regardless of treatment with or without surgery, the tendon elongates while going through the healing process [108, 115, 138]. It has been suggested that the ends of the tendon separate during the first 5-8 weeks of healing, but early weight-bearing can attenuate the elongation [61]. However, how and when mechanical loading has the greatest influence on the elongation process is not fully known. Moreover, there are different methods for measuring tendon elongation and unfortunately these methods are often not comparable [61, 109, 115, 133, 138, 145, 155, 178].

Back in 1983, Nyström and Holmlund found that an Achilles tendon rupture in rabbits healed with a biphasic tendon elongation [114]. They repeated the study in 10 human beings with an Achilles tendon rupture, treated surgically and with 6 weeks' immobilization in a cast. The tendon elongation was measured with repeated radiographic examinations of markers at the tendon ends. It was found that the human Achilles tendon healed with a mean of 3 mm (range 2-4 mm) of elongation during the first days and a second elongation occurred between the 10th and the 40th day. The total elongation was a mean of 11 mm (range 10-12 mm)[115].

Almost 20 years later, Kangas et al. [61] evaluated 50 patients with an Achilles tendon rupture and concluded that there was no biphasic elongation, but the elongation increased significantly during the first 6 weeks and then slowly decreased again. Titanium markers had been placed on both sides of the ruptured tendon ends at the same time as the surgery for the Achilles tendon rupture was performed and the elongation was then evaluated with repeated radiographs. The total elongation after 60 weeks was 2.0 mm (range –2.0 to 5.5) in patients allowed early motion and 5.0 mm (range 2.0-10.0) in patients treated with a cast for 6 weeks post-surgery [61]. Furthermore, the authors concluded that the tendon elongation was correlated to clinical outcome but not to age, BMI or isokinetic strength in ankle plantar flexion. Schepull et al. [138] used the same method as Kangas et al. [61] for measuring the tendon elongation and found a similar pattern when it came to the way the tendon elongated during the healing process, but they were unable to confirm any correlation between tendon elongation and heel-rise index, even if a correlation was present between the modulus of elasticity (Young's modulus, stiffness) at 7 weeks after injury and the heel-rise index at 18 months. Silbernagel et al. [145] used a different method with ultrasound to measure tendon elongation and measured the whole Achilles tendon from the osteotendinous junction (OTJ) at the calcaneus bone to the musculotendinous junction (MTJ) of the gastrocnemius. It was concluded that the difference in tendon length between the healthy and injured side was an average of 3.1 cm at 3 months, 2.9 cm at 6 months and 2.6 cm at 12 months after injury. Moreover, the tendon elongation correlated with heel-rise height at both 6 and 12 months after the injury and with the patient-reported outcome 6 months after the injury [145].

It has also been found that the tendon elongation correlates with muscle activation in the triceps surae and kinematics during walking and running [2, 147, 155]. Mullaney et al. [109] concluded that tendon elongation in patients treated with surgery had a negative impact on calf muscle strength at a mean (min-max) of 1.8 (0.5-9) years after the injury.

It has also been reported that the degree of tendon end separation after injury, in non-surgically treated patients, correlates with the risk of re-rupture, as well as increased symptoms and decreased heel-rise height 12 months after injury [178].

Tendon elongation is also reported to remain in the long term [133]. The authors found that, 7 years after the injury, the tendon on the injured side was still significantly elongated compared with the healthy side [133].

It appears that avoiding tendon elongation after an injury is of great importance in order to optimize the recovery of the patient's bodily functions and structure, activities and participation [99].

The role of rehabilitation after an Achilles tendon rupture

According to the International Classification of Functioning, Disability and Health (ICF) developed by the World Health Organization (WHO), the role of rehabilitation is to coordinate efforts to improve the patient's bodily functions and structure, activities and participation and also to consider additional information on severity and environmental factors [183] *(Figure 12).*

The role of rehabilitation after an Achilles tendon rupture is therefore to evaluate and treat impairments in lower leg function and Achilles tendon structure, as well as being aware of and providing information about necessary modifications to activity and participation during rehabilitation. A knowledge and understanding of the mechanisms of tendon healing and how different exercises and loading affect tendon healing is of great importance. Extended knowledge in this field can eventually lead to improved and optimized rehabilitation protocols. However, the way rehabilitation protocols for patients with an Achilles tendon rupture should be designed for optimized recovery is still not well known, for either the early or the later stages of rehabilitation [35, 47, 66].

In order to design new, improved and optimized rehabilitation protocols, there is a need for a deeper understanding of the way an Achilles tendon rupture affects the muscles, the tendon and the biomechanics in the foot and leg in patients with this injury. This knowledge can then form the basis of the further development of treatment strategies for this injury with the objective of reducing the number of patients who suffer from permanent disability after an Achilles tendon rupture.

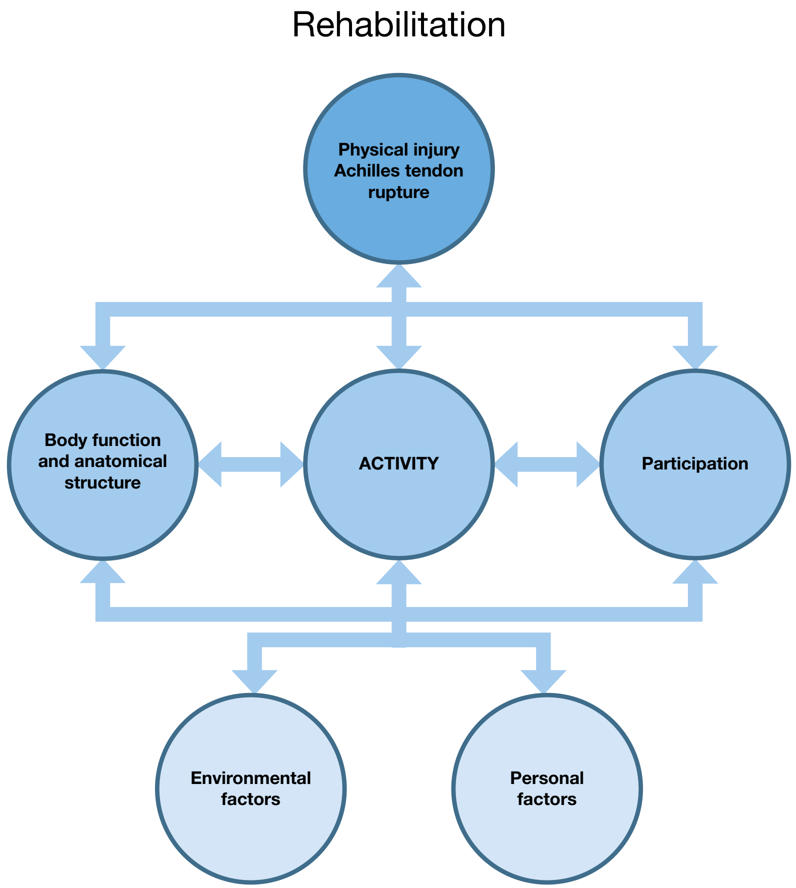


Figure 12. The role of rehabilitation is to coordinate efforts to improve the patient's bodily functions and structure, activities and participation and also to consider additional information on severity and environmental factors [183].

The rehabilitation is often lengthy (6-12 months) and many patients do not fully recover, despite similar initial treatment and rehabilitation [32, 47, 111, 121, 123].

Permanent impairments are reported, regardless of whether the patients are treated with surgery or non-surgery [2, 32, 47, 49, 69, 82, 111, 121, 123, 133]. It is not known how important the choice of surgical or non-surgical treatment is for the individual patient.

Holm et al. [47] claim that the rehabilitation protocol could be more important for the final outcome after the injury than the initial treatment with surgery or non-surgery. Moreover, Zhang et al. [188] suggest that non-surgical treatment should be recommended at centers where functional rehabilitation – in terms of being given a brace where early ankle mobilization is possible – can be offered, while initial surgical treatment should be used when functional rehabilitation is not available. Historically, the primary outcome after an Achilles tendon rupture has been the re-rupture rate showing that the re-rupture rate is lower with surgical compared with non-surgical treatment [11, 53, 55, 68, 69, 148, 179]. However, more recent studies show no significant differences in re-rupture rate between these groups when all patients receive early weight-bearing and early ankle motion exercises [67, 104, 111, 123, 165, 180].

In addition to the re-rupture rate, there are other outcome measurements, in particular tendon elongation and calf muscle recovery, which could be as important for the patient. Regardless of surgical or non-surgical treatment, there appears to be consensus that early weight-bearing and early ankle mobilization are beneficial for superior calf muscle recovery and less tendon elongation during the rehabilitation after an Achilles tendon rupture [16, 47, 51, 100, 170, 188, 189]. Unfortunately, there is a lack of evidence both about dosage and when weight-bearing and early ankle mobilization should be introduced.

It has also been suggested that immediate physical therapy treatment from day 1-84 compared with from day 29-84 is beneficial in terms of the effects on medial gastrocnemius myotendinous junction displacement (the mean difference between the location of the myotendinous junction of the medial gastrocnemius at maximum contraction compared with at rest), isometric plantar-flexion strength and ATRS four weeks after the injury [29].

The effect on myotendinous junction displacement was still present 12 weeks after the injury [29]. Two hundred and thirteen rehabilitation protocols throughout Germany were recently surveyed and the findings were that there was immense variation in the timing of weight-bearing, the onset of physical therapy treatment and the duration of fixed plantar flexion of the foot [35]. It has not been reported whether this variation in rehabilitation protocols is the same in other countries, but there is a lack of well-performed studies evaluating different rehabilitation protocols after Achilles tendon ruptures.

Taken together, there is a need for well-performed prospective studies with the aim of optimizing as well as individualizing rehabilitation after an Achilles tendon rupture.

Rehabilitation phases

After an Achilles tendon rupture, it has been suggested that the rehabilitation can be divided into four different phases; the controlled mobilization phase, early rehabilitation phase, late rehabilitation phase and return to sport phase [141] *(Figure 13)*.

It is suggested that the progress from one phase to the next should be based on both the time since injury and the recovery of the individual patient.

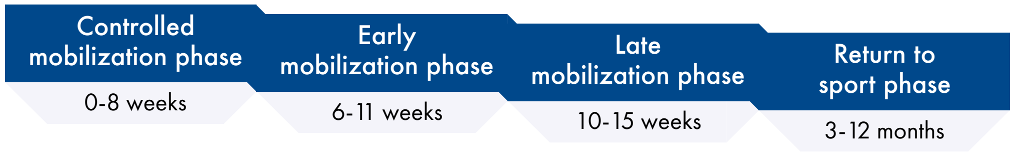


Figure 13. The rehabilitation phases.

The controlled mobilization phase: 0-8 weeks

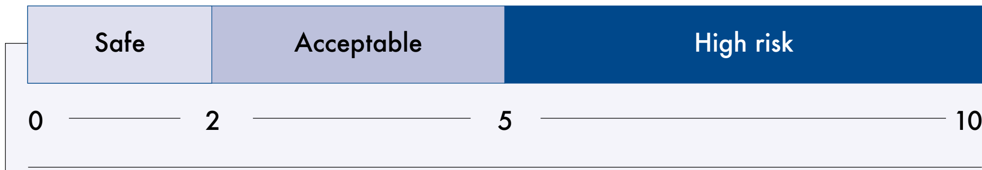
There is evidence that treatment with early weight-bearing (within the first 6 weeks) and accelerated rehabilitation (starting specific rehabilitation exercises while still in a brace) is beneficial to a patient with an Achilles tendon rupture [16, 51, 100]. A systematic review concluded that immediate weight-bearing appears to be safe, but the kind of brace that is superior to another, the optimal time for wearing the brace and the degree of plantar flexion in which the foot should be kept while in the brace all remain unclear [66]. In addition, a meta-analysis concluded that the re-rupture rate was lower in the group using functional bracing compared with the group using a cast after the injury [69]. This applied when treated with both surgery (2.3% for the functional brace group versus 5% for the cast group) and non-surgery (2.4% for the functional brace group versus 12.2% for the cast group). Other studies have shown that patients treated with a functional brace and early weight-bearing had a shorter rehabilitation period and were also able to return to daily activities such as walking and stair-climbing earlier than patients treated with a cast [26, 93]. However, the results were more convincing for surgically treated patients compared with patients treated non-surgically, although no disadvantages were found when wearing a functional brace compared with a cast [26, 93].

Suchak et al. [153, 154] have evaluated differences between early weight-bearing and non-weight-bearing. Patient-reported outcomes and patient satisfaction were examined. The conclusion was that the patients treated with early weight-bearing had higher scores in terms of health-related quality of life and were more satisfied with the treatment at the early stage of rehabilitation.

The early rehabilitation phase: 6-11 weeks

During this phase, it is important to be aware that the risk of re-rupture is the greatest [107, 124, 130]. Nevertheless, walking without a brace is generally initiated at this stage. Komi et al. showed that walking loads the tendon with 3 times the body weight and it can therefore also be considered safe to start performing double-leg standing heel-rises at a slow, controlled speed [77, 141]. The dosage of walking has to be adapted to any eventual swelling or pain in the Achilles tendon. The use of a compression stocking during the daytime may be beneficial at this stage in order to reduce the swelling in the lower leg, as a recent report found that microcirculation in the Achilles tendon correlated with function after a rupture [126]. Pain is not often a problem after an Achilles tendon rupture, but, if needed, a pain-monitoring model can be a very useful tool to control the dosage of walking and other physical activities *(Figure 14)* [160]. To avoid elongation, it is recommended not to stretch the tendon during this rehabilitation phase [141]. A general rehabilitation program during this early rehabilitation phase has been suggested [141] *(Figure 15)*.

Figure 14. Pain monitoring system according to Thomeé et al. [160]



1. Pain in the tendon up to 2 on the visual analog scale (VAS) is safe. Pain up to 5 is a warning of overuse, but it can be permitted during an activity if the pain disappears immediately after the end of the activity. Pain over 5 on the VAS is not allowed.
2. If the pain or swelling increases after an activity, it should have abated before the same activity is allowed again.
3. Pain and swelling are not allowed to increase from day to day or from week to week.

Figure 15. A general rehabilitation program during the early rehabilitation phase ad modum Silbernagel et al. [141]

Early rehabilitation phase (6-11 weeks)

Visit for physical therapy 2-3 times a week and home exercises daily

Exercise programme:
- Exercise bike
- Ankle range of motion
- Ankle strengthening using a resistance band or cable machine
- Sitting heel-rise with external load (25-50% of body weight)
- Standing heel-rise progressing from two legs to one leg
- Gait training
- Balance exercises
- Leg presses
- Leg extensions
- Leg curls
- Foot exercises

If the patient meets the criteria of five single leg heel-rises at 90% of height, then start:
- Bilateral rebounding heel-rises
- Bilateral hops in place
- Gentle jogging in place

The late rehabilitation phase: 10-15 weeks

In this phase, the goal is to strengthen and prepare the calf muscles for more demanding activities. Furthermore, general leg and core strengthening should be added. It has been suggested that this phase includes single-leg standing heel-rises to the beginning of running and jumping [141]. A suggestion for criteria that can be used to start a running progression program are as follows [141].

1. To be at least 12 weeks after injury and be able to perform 5 single-leg standing heel-rises at 90% of the maximum heel-rise height on the injured side.

2. If unable to achieve the above criteria by week 14-15, the patient can start running progression if he/she is able to lift at least 70% of his/her body weight during one single-leg heel-rise.

During this phase, it is suggested that there should be 3 days between running activities to allow the muscles and Achilles tendon to recover.

Return to sport phase: 3-12 months

The patients are expected to be able, if desired, to start running activities 12-16 weeks after the injury [92]. The time depends on the treatment and rehabilitation they have undergone [173]. It is important to choose valid, reliable test methods to be able to evaluate the patients' functional outcome prior to returning to sport. A test battery including valid, reliable tests for calf muscle strength, calf muscle endurance and jumping ability has been used in several studies [111, 121, 123, 142, 143].

Impairments after an Achilles tendon rupture

Regardless of surgical or non-surgical treatment, permanent impairments on the injured side, such as decreased calf muscle function, decreased jumping ability and changes in gait and running pattern, are described in the literature [2, 32, 47, 49, 69, 82, 111, 121, 123, 133, 147]. These impairments can have a negative impact on the patients' function and daily activities.

Impairments in the short term

There are only a few studies reporting the short-term outcome (<4 months) in patients after an Achilles tendon rupture and, in these studies, function is mainly evaluated with a single-leg standing heel-rise [54, 70, 120, 166, 185]. Three of these studies reported that patients were able to perform a single-leg standing heel-rise at an average of 12 weeks after injury [54, 70, 166]. Although the average time to being able to perform the standing heel-rise was 12 weeks, there was a considerable range between 7 and 25 weeks [166]. One study reported more optimistic findings for the standing heel-rise test in which patients were able to perform 20 single-leg standing heel-rises at an average of 10 weeks after surgical treatment [185]. An important result in one study was that only 50% of patients were able to perform a standing single-leg heel-rise 3 months after injury, regardless of treatment [120]. Ankle range of motion was also evaluated in two studies [166, 185]. In these studies, all the patients were treated with surgery. Uchiyama et al. [166] found that ankle range of motion was comparable to that on the healthy side a mean of 10 weeks after the injury, while Yotsumoto et al. [185] claimed the same result after only a mean of 3.2 weeks. In the latter study, no brace was used after surgery.

It may be difficult to determine the effectiveness of treatments in the early stages due to the lack of tests appropriate to the healing Achilles tendon. In order to individually adapt the dosage of activity and exercises, it appears that there is a need for methods to evaluate calf muscle endurance earlier in the rehabilitation phase.

Impairments in the long term

Calf muscle function

Calf muscle function can include strength, endurance and heel-rise height during a single-leg standing heel-rise. Many studies evaluate calf muscle function 1 year after the injury, although it is likely that the calf muscle will not have recovered fully at that stage. In a 2-year follow-up study, it was shown that there was still a 13-15% deficit on the injured side when performing a concentric heel-rise strength test, an 18-23% deficit when performing an eccentric heel-rise strength test and a 16-17% deficit in heel-rise height on the injured side [121]. Even 10 years after the Achilles tendon rupture, Horstmann et al. [49] concluded that patients had a significantly lower heel-rise height and concentric and eccentric plantar flexion strength on the injured side. A recent long-term follow-up study also found that patients had a 5% deficit in isokinetic plantar flexion peak torque and an 8% deficit in plantar flexion work, in the injured limb, 11 years after the injury, while isometric plantar flexion strength showed a 2.4% deficit compared with the healthy side [82]. The reasons for these continuing deficits after an Achilles tendon rupture are not fully known. It is possible that calf muscle strength will continue to improve over time, but there is a lack of long-term follow-up studies evaluating the progression of calf muscle function. In addition, the other foot and ankle muscles might adapt to the changes that occur in calf muscle strength and function due to the injury. In patients with symptomatic Achilles tendinosis, it has been found that the injury leads to a compliant Achilles tendon and that the compliant tendon evokes adaptations from muscle-tendon interaction, central nervous system control and muscle activation pattern in the lower leg [21].

Jumping ability

Needless to say, jumping ability after an Achilles tendon rupture is dependent not only on calf muscle recovery but also on balance, coordination, strength and endurance in the lower limb and core muscles [74]. The recovery of jumping ability can also be dependent on whether the Achilles tendon rupture occurs in the dominant or non-dominant limb [151]. Olsson et al. [121] found that, 2 years after an Achilles tendon rupture, the patients had a 10-12% deficit in performance on their injured side during a drop countermovement jump (drop CMJ) from a 20-cm-high box. On the other hand, Vadalà et al. [167] found no side-to-side differences in jumping ability when three different vertical jumps were tested in professional athletes 28 months after their injury. Another study compared jumping ability 24 months after injury between two groups treated with different surgical techniques and a healthy control group and found no major differences, except that the control group had better coordination between the limbs in the take-off phase in the jumps compared with the groups with an Achilles tendon rupture [127]. Furthermore, Willy et al. [181] concluded that ankle joint kinetics were reduced, while knee joint loads were increased in the injured limb during hopping after an Achilles tendon rupture. Taken together, jumping ability is a multifactorial skill and there is a need for different valid, reliable methods to evaluate the impact of an Achilles tendon rupture on jumping ability.

Gait and running biomechanics

There are reasons to believe that an Achilles tendon rupture has an impact on ankle biomechanics during gait and running [25, 32, 147, 157, 181]. Costa et al. [25] found changes in gait biomechanics in patients 6 months after the injury compared with healthy controls. Similarly, Tengman et al. [157] found significantly lower values for ankle biomechanics in patients treated with non-surgery 2-5 years after an Achilles tendon rupture compared with healthy controls. In a case study, where running biomechanics were evaluated before and 1 year after an Achilles tendon rupture, increased dorsiflexion, eversion and rear-foot abduction were found in the injured ankle compared with the healthy ankle during running [147]. A long-term follow-up, a mean of 6 years after the injury, reported considerable deficits in plantar flexor function compared with the healthy limb, during both walking and jogging [181]. Additionally, significantly higher knee-joint loads were found in the injured limb during jogging but not during walking [181]. Considering the importance of being able to perform physical activity in order to maintain health, there is a need for well-performed studies to evaluate the impact of an Achilles tendon rupture on gait and running biomechanics. With greater knowledge in this field, clinicians would be able to individualize the advice to maintain physical activity in patients with an Achilles tendon rupture.

Predictors of outcome after an Achilles tendon rupture

One of the first research groups that evaluated predictors of outcome after an Achilles tendon rupture were Leppilahti et al. [84]. They found that a late return to physical exercise, activity level, systemic disease and previous Achilles tendon symptoms were predictors of isokinetic ankle strength, while older age was a predictor of poorer outcome in terms of isokinetic ankle strength, as well as ankle range of motion and patient-reported outcome [84]. Olsson et al. [122] also concluded that older age was a strong predictor of inferior calf muscle recovery evaluated with heel-rise height, while a high BMI was a predictor of worse symptoms measured with the ATRS. In a recent study, age over 40, together with having a deep vein thrombosis and being of male gender, was once again determined as a predictor of a poorer outcome in the ATRS, limb symmetry index in heel-rise height and single-leg standing heel-rise test [9]. Previously, Bostick et al. [13] evaluated the factors that were associated with calf muscle endurance recovery 1 year after the injury and concluded that being female, having no pain at 3 months, improved calf muscle endurance and high physical function at 6 months were beneficial for a good outcome at 1 year [13]. Moreover, it has been shown that high scores in the ATRS at 3 months after the Achilles tendon rupture is a predictor of returning to sports 1 year after the injury [44]. Moreover, high scores in the ATRS 1 year after the injury were associated with being active in sports and work [44].

Taken together, it appears that age is a strong predictor of calf muscle recovery measured by a single-leg standing heel-rise test, while high scores in patient-reported outcome at the early stages of rehabilitation is a predictor of both calf muscle recovery and an early return to sports. However, further studies are needed in this field in order to detect risk factors for unsatisfactory outcome and thereby improve rehabilitation protocols.

Return to sports

A systematic review has reported that approximately 20% of patients are unable to return to their previous level of physical activity after an Achilles tendon rupture, but the results are naturally affected by the quality of the methods used to evaluate return to sports [186]. Regardless of whether or not the athletes are able to return to full sports participation, their performance is often affected [4, 125, 163]. In a study evaluating 18 Achilles tendon-injured basketball players in the National Basketball Association (NBA) in the USA, it was found that 39% of the athletes were unable to return to play and those players who returned showed a significant decline in performance and playing time compared with healthy controls [4]. Parekh et al. [125] investigated 28 American football players with a total of 31 Achilles tendon ruptures and found that 32% were unable to return to play in the National Football League (NFL) in the USA. Furthermore, even if 68% of the injured athletes returned to play, they perceived a mean of more than a 50% decline in their power ratings over a 3-year period. In a recent study, 63 athletes with an Achilles tendon rupture from different sports were included; they came from the NBA, the NFL, Major League Baseball (MLB) and the National Hockey League (NHL) in the USA [163]. It was found that, 1 year after the injury, the athletes had poorer performance statistics and both fewer games played and reduced playing time compared with matched controls. This difference was not seen 2 years after the injury. To summarize, it seems that, even if athletes manage to return to sports, their performance is often affected. There is a need for further research into the reasons and deficits responsible for not being able to return to sport performance.

Gaps in knowledge

- Is there any evidence relating to the way calf muscle recovery develops over time in patients with an Achilles tendon rupture?

- Which valid and reliable evaluation methods can be used to evaluate calf muscle endurance in the early phases of rehabilitation?

- Is there any evidence relating to the best way to individualize the treatment and rehabilitation?

- How does tendon elongation correlate to function and symptoms in the long term?

- How do the rehabilitation protocols and outcome measurements used today influence and relate to the biomechanics in the lower leg?

- How do the rehabilitation protocols and outcome measurements used today influence and relate to tendon length in the long term?

- What are the reasons for reduced sports performance or a delayed return to sports after an Achilles tendon rupture?

03

AIMS

Aims and objectives

The overall purpose of this thesis was to acquire a greater knowledge of the way patients with an Achilles tendon rupture recover at different time points after the injury when treated with the currently recommended treatment protocols. This knowledge will then form the basis of the further development of treatment strategies with the objective of reducing the risk of suffering permanent disability after an Achilles tendon rupture.

Objectives

- To perform a long-term follow-up of patients treated either surgically or non- surgically after an Achilles tendon rupture and treated with exactly the same rehabilitation protocol (Study I)

- To evaluate calf muscle endurance in a seated position early in the rehabilitation process after an Achilles tendon rupture and to assess how standardized seated heel-rises 3 months after the injury relate to the ability to perform single-legged standing heel-rises and patient-reported symptoms 3 and 6 months after the injury (Study II)

- To evaluate differences in outcome between men and women 6 and 12 months after an acute Achilles tendon rupture (Study III)

- To evaluate how the performance of the single-leg standing heel-rise test 1 year after an Achilles tendon rupture corresponds to the biomechanics of walking, jogging and jumping 6 years after the injury (Study IV)

- To evaluate the biomechanics of walking, jogging and jumping in patients 6 years after an Achilles tendon rupture and how it correlates to tendon length, function and patient-reported outcome (Study IV)

04

METHODS

Patient-reported outcome measurements (PROMs)

In this thesis, three different questionnaires were used to evaluate the patients' symptoms and physical activity levels; the Achilles tendon Total Rupture Score (ATRS) [112], Physical Activity Scale (PAS) [42, 134] and Foot and Ankle Outcome Score (FAOS) [132]. *Table 2* shows the studies in which the questionnaires were used.

Table 2. Patient-reported outcome measures used in the different studies in this thesis.

PROMS	Study I	Study II	Study III	Study IV
ATRS	X	X	X	X
PAS	X	X		X
FAOS				X

The Achilles tendon Total Rupture Score (ATRS) [112]

The ATRS is an injury-specific questionnaire developed for patients with an Achilles tendon rupture. It evaluates symptoms and physical activity, consists of 10 items of which each ranges between 0-10 and are answered using a Likert scale. The maximum score is 100 meaning no symptoms and full physical activity (Appendix). The ATRS has been shown to have good reliability (Intra-class correlation coefficient (ICC)=0.98) and internal consistency (Cronbach alfa = 0.96), good construct validity (the correlation coefficient was between 0.60-0.85 compared with other patient-reported outcomes) and responsiveness (effect size between 3 and 6 months = 2.21 and between 6 and 12 months = 0.87). The ATRS has been translated and culturally adapted to Danish [37], Turkish [65], Persian [7] and English [19] and has been found to be reliable and valid. According to a recent literature review, the ATRS is the most appropriate outcome measurement for patients after an Achilles tendon injury [150].

Physical Activity Scale (PAS) [42, 134]

A four-level questionnaire for evaluating physical activity (PA) was published in 1968 [134]. It was developed for a study in which physiological outcome was compared between middle-aged persons and athletes who were still active and of the same age. It has been widely used and modified over the years, but it has not been especially evaluated for patients with an Achilles tendon rupture [43]. However, developed for the same age groups as patients with an Achilles tendon rupture, it was decided that it was appropriate for our studies. In the studies in this thesis, a modified six-level questionnaire, originally designed for measuring physical activity among elderly people, was used [42]. The reason for choosing the six-level instead of the four-level questionnaire was that the six-level questionnaire allowed us to look for changes in physical activity in patients who were almost non-active after the Achilles tendon rupture. It consists of a six-grade scale where 1 means hardly any physical activity at all and 6 means heavy physical exercise several times a week (Appendix).

Foot and Ankle Outcome Score (FAOS)[132]

The FAOS was originally developed for evaluating symptoms, pain, activities of daily living (ADL), symptoms during sport and recreation activities and ankle-related quality of life in patients who had undergone ankle ligament reconstruction [132]. The questionnaire consists of 42 questions divided into five subscales (Appendix). The maximum score on each subscale is 100, which is equal to no pain or symptoms. This score has been found to be reliable and valid, but it has not been evaluated in patients with an Achilles tendon rupture. In Study IV, it was used for comparisons of ankle pain, symptoms, ADL, symptoms during sport and recreation and ankle-related quality of life between two groups with different heel-rise heights after their injury.

Evaluation of calf muscle endurance, strength and jumping performance

Equipment

For the evaluation of calf muscle endurance, strength and jumping performance, standardized footwear was used in all the tests. All evaluations took place at the same orthopedic laboratory. In Studies I, II and IV, the same physical therapist performed all the evaluations and she was also one of two different physical therapists who performed the evaluations in Study III. The MuscleLab® (Ergotest Technology, Oslo, Norway) measurement system was partly used for these evaluations. This measurement system consists of different sensors connected to a computer *(Figure 16)*. For the heel-rise tests and the strength and power evaluations of the calf muscles, a linear encoder (*Figure 17)* connected to the MuscleLab® was used. A string was attached to a sensor inside the linear encoder unit. During the evaluations, the string was attached to the heel of the patient's shoe as well and, as the string was pulled, the sensor gave off a series of digital pulses that were proportional to the distance carried. The resolution was approximately one pulse every 0.07 mm. Calculations of velocity, force and power (force x velocity) were made by recording the displacement as a function of time that was possible when counting the numbers of pulses/time.

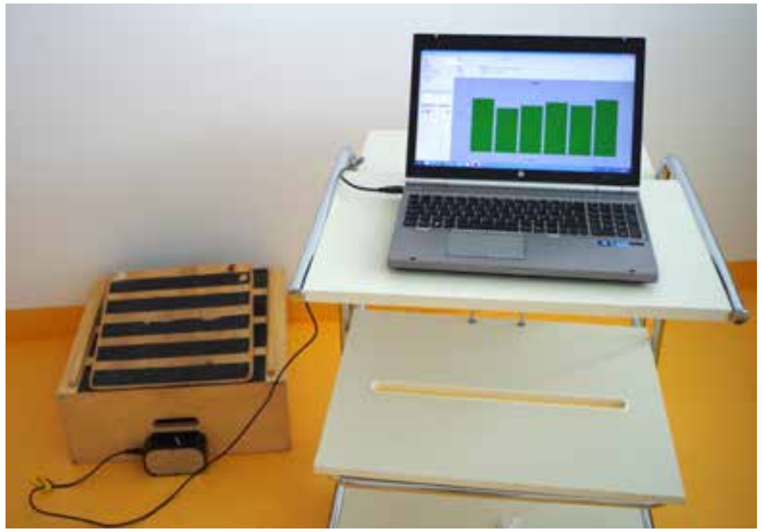


Figure 16. The MuscleLab® (Ergotest Technology, Oslo, Norway) measurement system.

Figure 17. A linear encoder.

Before the evaluations, the patients warmed up for five minutes on a stationary bike, followed by three sets of 10 two-legged heel-rises. In all the tests, the healthy side was evaluated before the injured one.

Single-leg standing heel-rise

A single-leg standing heel-rise was used for evaluation of calf muscle endurance in Study I-IV. It is a well-known functional test that is widely used in studies evaluating patients' calf muscle endurance and has been found to be reliable and valid for patients with an Achilles tendon rupture [143]. The criterion for a normal number of heel-rises is regarded as 25, but there is a wide range from 6 to 70 in healthy individuals [87]. During the test, the patient stands on one foot on a flat box or with a 10-degree incline *(Figures 18 and 19)* The patient is allowed to use balance support with the fingertips on the wall at shoulder height and is told to go as high as possible for each heel-rise, keeping the knee straight. A metronome is used to keep the pace at 30 heel-rises a minute. The test is finished when the patient is unable to perform more heel-rises, unable to rise above 2 cm or unable to keep the pace. The linear encoder unit that is connected to the MuscleLab® measurement system measures the height of every heel-rise and counts the number of heel-rises. Since the body weight of the patient is known, it is also possible to calculate the work (Joules) the patient performs on each side. Maximum heel-rise height, numbers of repetitions and total work were used for data analyses.

Figure 18. Single-leg standing heel-rise with no incline.

Figure 19. Single-leg standing heel-rise with 10° incline.

Standardized seated heel-rise

Evaluations of calf muscle endurance in a seated position were used in Study II. The reliability has been evaluated on healthy subjects and found to be good (ICC height (cm) = 0.606 and ICC reps = 0.701). The smallest detectable change ($SDC_{95\%}$) for individuals was 35 reps and 3.5 height (cm), and 9 reps and 0.9 height (cm) respectively at group level. The standardized seated heel-rises are performed in a seated position with the hip and knee at 90 degrees *(Figure 20)*. The same equipment is used as for the single-leg standing heel-rise. The evaluation in the seated position is finished when the patient is unable to perform more heel-rises, performs more than 100 repetitions, is unable to rise above 2 cm, or is unable to maintain the tempo.

Figure 20. Standardized seated heel-rise.

Strength and power evaluation of calf muscles

The strength and power tests of the calf muscles in Study I were performed as a standing single-leg heel-rise in a weight-training machine *(Figure 21)*. This test has been shown to be a reliable and valid evaluation for patients with Achilles tendinopathy [142] and is also used in studies evaluating patients after an Achilles tendon rupture [111, 123]. The patient is asked to raise his/her heel as quickly and powerfully as possible and the patient's knee is not allowed to bend more than 20 degrees in flexion. Shoulder and hand positions, as well as foot placement, are standardized. The heel-rise is performed three times for every weight starting at 13 kg plus body weight. Between the heel-rises, the patients have a 15-second rest. If possible, the load is increased by 10 kg and another three heel-rises are performed. The evaluation stops when a decrease in the patients' power output is noted or the patient is unable to perform the heel-rise. The linear encoder unit connected to the heel of the patient's shoe measures the length and time of heel displacement during the heel-rise and the MuscleLab® measurement system calculates the peak power in watts. The trial – without taking any consideration of the limb – with the highest power was compared with the corresponding (the same load) trial in the other limb and was chosen for data analyses.

Figure 21. Concentric strength power heel-rise test.

Jumping performance

Jumping performance was evaluated with hopping and drop CMJ in Study IV and one force plate obtaining biomechanical data (Kistler AG, Winterthur, Switzerland) and 12 Oqus 4 cameras (Qualisys AB, Gothenburg, Sweden) were used for data collection, see "Biomechanical analyses". Hopping and drop CMJ have been found to be reliable and valid for patients with an

Achilles tendon injury [111, 123, 142]. Hopping is performed standing on one leg on the floor with the arms along the sides. The patient is instructed to jump "as if you are using a skipping rope" at a self-selected speed *(Figure 22)*. The evaluator stops the test after 25 jumps.

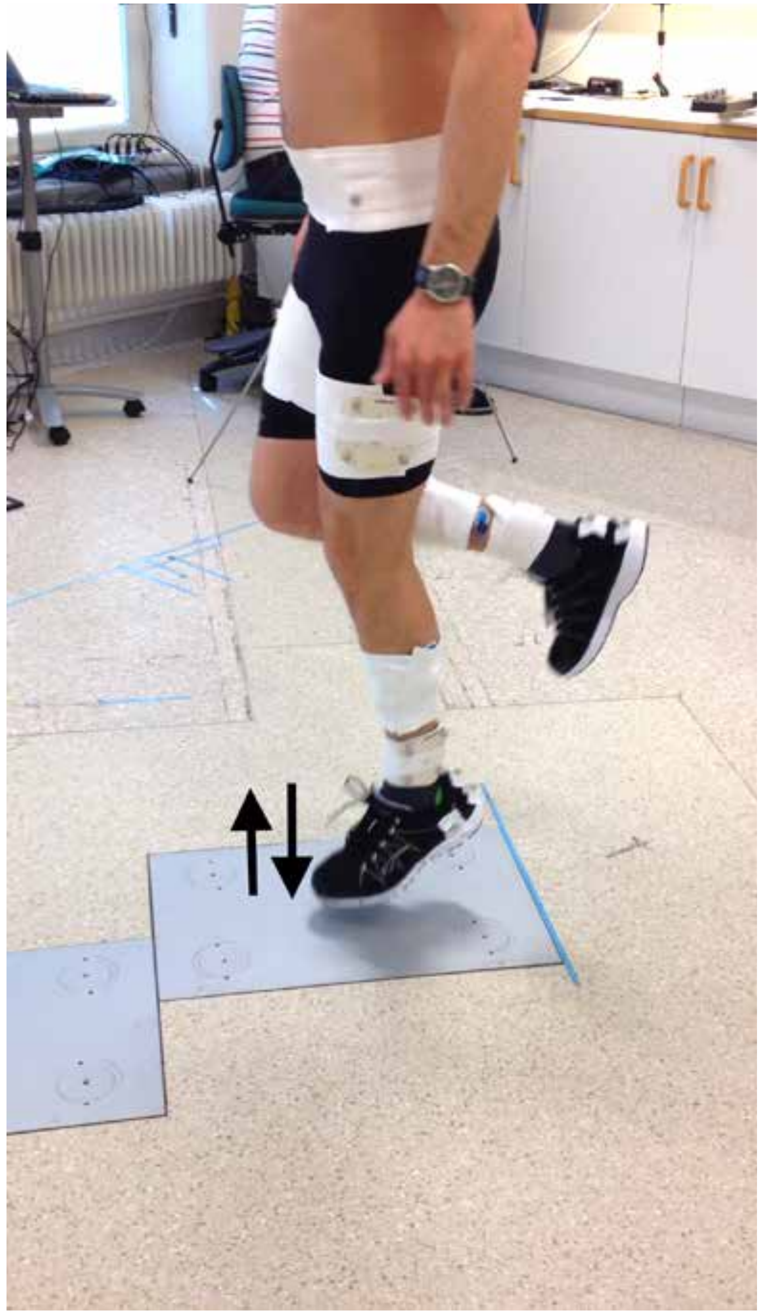


Figure 22. Hopping.

The drop CMJ is a jump test during which the patient stands on a 20-cm-high flat box on one leg, with his/her hands behind his/her back. The box is placed in front of a force plate. The patient is instructed to jump down to the force plate on one leg and directly use the contact landing force to perform a maximum vertical jump *(Figure 23)*. Three to five jumps were performed on each leg.

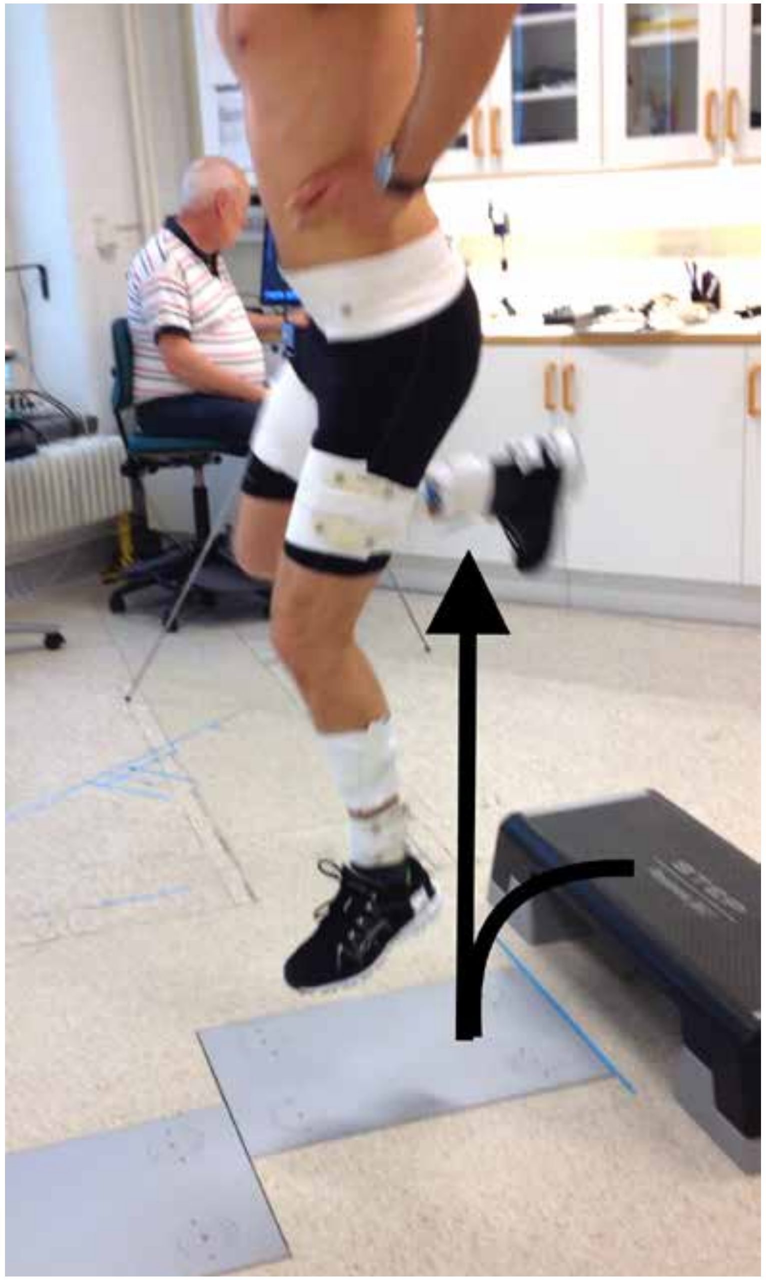


Figure 23.
Drop CMJ.

At the 1-year [111] and 2-year [121] follow-ups of the patients included in Study I, hopping and the drop CMJ were used for evaluation of jumping performance. However, at the 7-year follow-up, a different jump test, the one-leg hop for distance, was used in the belief that hopping and the drop CMJ would not be sensitive enough to detect side-to-side differences 7 years after the injury. Furthermore, part of the reason for choosing a different jump test in this study was the assumption that the one-leg hop for distance was more functionally related to the activities the patients were performing, for example, jogging. The one-leg hop for distance has been found to be a reliable measurement for the lower extremities [12]. It has, however, not been evaluated for patients with Achilles tendon injuries. The one-leg hop for distance is performed standing on one leg behind a line on the floor. The patients are instructed to keep their hands behind their back, jump as far as possible and land on the same foot standing still *(Figure 24)*. The patients are allowed to familiarize themselves with the test and the jump is performed at least three times on each leg, starting on the healthy leg. A measuring tape is used to measure the distance from the line to the heel counter on the patient's shoe.

Figure 24.
One-leg hop for distance.

Achilles tendon length

In Study IV, the Achilles tendon length, on both the healthy and the injured side, was measured between the calcaneal osteotendinous junction (OTJ) and the gastrocnemius musculotendinous junction (MTJ) using extended field of view ultrasonography (Logiq E Ultrasound; GE Healthcare Sweden AB) using a wideband array linear probe (5.0-13.0 MHz). The B-mode at 10 MHz and a depth of 3 cm were used to record the images *(Figure*

25). This measurement method has been found to have excellent test-retest reliability (ICC=0.898-0.97) [144, 145] and it has also been found to be valid when the Achilles tendon length is compared between cadaveric measurements and ultrasound images (ICC=0.895) [144]. Three images of each Achilles tendon were recorded and the mean value was used for data analyses *(Figure 26)*.

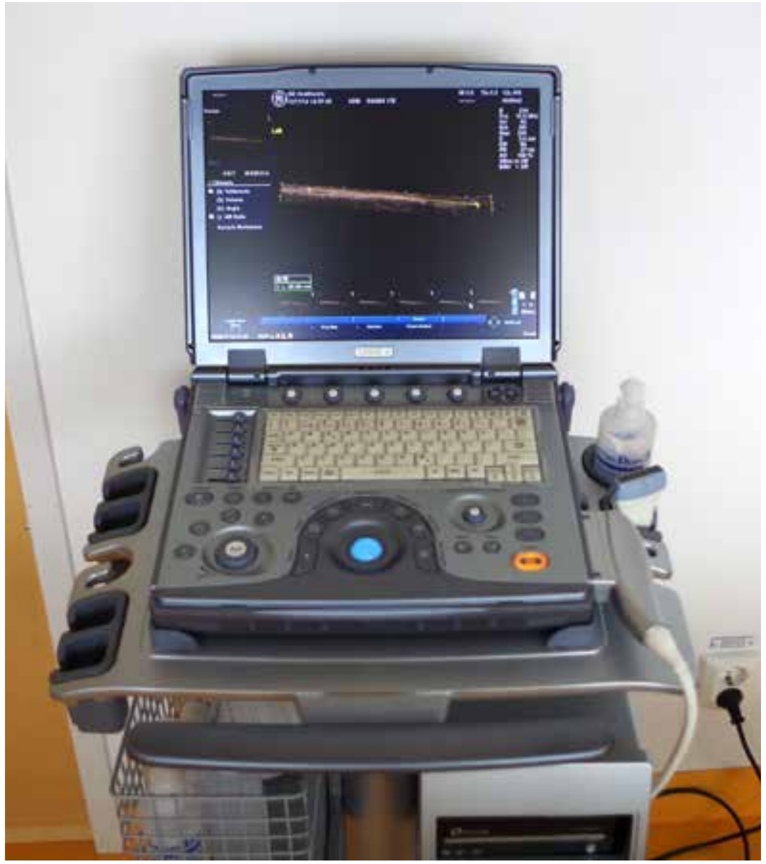


Figure 25.
The Logiq E Ultrasound machine used to record the images.

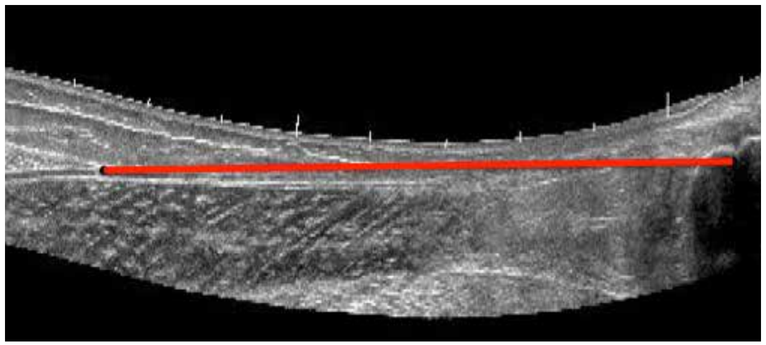


Figure 26.
An example of an image of an Achilles tendon using extended field of view ultrasonography.

Biomechanical analyses

During walking, jogging and jumping, the biomechanical data in Study IV were sampled at 200 Hz for motion capture and 1600 Hz for force data using 12 Oqus 4 cameras (Qualisys AB, Gothenburg, Sweden) and two force plates (Kistler AG, Winterthur, Switzerland). Before the data collection, the patients were able to familiarize themselves with their self-selected speed while walking and jogging along a distance of 10 meters. Gait and jogging speed were then evaluated with timing gates and a ± 5% difference in speed between the trials was permissible. Five trials of walking and jogging were carried out. In order to establish segmental coordinate systems for each body segment, a static calibration trail was obtained.

Stance phases were determined via a 20-Newton threshold of the vertical ground reaction forces. Ground reaction forces and marker trajectories were filtered with a 15-Hz cutoff, Butterworth 4th order frequency. Internal joint moments were normalized to the patient's height and body weight. The equation for the internal moment of plantar flexion (which is the same size as the external moment of dorsiflexion while standing still) is: internal moment (Nm) = moment arm (m) x Achilles force (N). The value of the moment arm for the Achilles tendon in Study IV is an estimated value based on measurements from embalmed specimens of the lower leg [72]. During the stance phase, the Achilles tendon impulse (Ns) was calculated as the time integral of the Achilles tendon force curve. The product of the ankle sagittal plane angular velocity and the plantar flexor moment was expressed as concentric and eccentric ankle powers normalized to the weight and height of the patient (W/kg*m).

A musculoskeletal model was used to estimate the peak Achilles tendon force [31]. Both the marker setting used in this study and the musculoskeletal model used to calculate the kinetics and kinematics in this study have been found to have good to excellent reliability and validity [33, 113] *(Figure 27)*.

Figure 27 *(p. 59-60)*.
Marker settings used in Study IV.

The data analysis process

During the biomechanical data collection, four different activities were evaluated; walking, jogging, drop CMJ and hopping. The collected data were processed in three different data programs before the numerical analyses began.

- QTM, Qualisys Track Manager (Qualisys AB, Gothenburg, Sweden): this software performs the data acquisition, the labeling of markers and exports files in the C3D format. The C3D format is a format designed to record synchronized three-dimensional and analog data. The markers placed on the patient that are used for the calculations are labeled and the files are scaled down so that only the data planned for analysis are exported. During walking and jogging, only the standing phase was used for calculations and, during the jump tests, the time between the patient hitting the force plate and shortly after leaving the force plate was used for calculations.

– MotionMonitor® software (Innovative Sports, Chicago, IL, USA): all C3D files from each patient were imported into this software, together with the demographic data for each patient. In this software, the biomechanical calculations were performed. Data were then exported as EXP files (EXPorted files), which made it possible to explore the data in Excel software. One file from each trial was then exported to LabVIEW for further calculations.

– LabVIEW program (National Instruments™, Austin, Tx, USA): this is a custom-written script, used to extract the discrete variables as shown below and obtained from the MotionMonitor data.

- GAIT: the mean value from five trials was used and the ankle angles, moment, power and ground reaction forces were calculated.
- JOGGING: the mean value from five trials was used and the ankle angles, moment, power and ground reaction forces were calculated.
- DropCMJ: three to five trials were used and the mean value was used. Ankle angles, moment, power and ground reaction forces were calculated.
- HOPPING: The first three and the last two jumps were removed from the calculations. The mean values of the 10-20 jumps were used for calculation and ankle angles, moment, power and ground reaction forces were calculated.

05

SUBJECTS

All the patients included in this thesis were from two different randomized, controlled trials [111, 123] and the distribution of the patients in the four different studies is shown in *Figure 28*. The demographics of all the patients participating in this thesis can be found in *Table 3*.

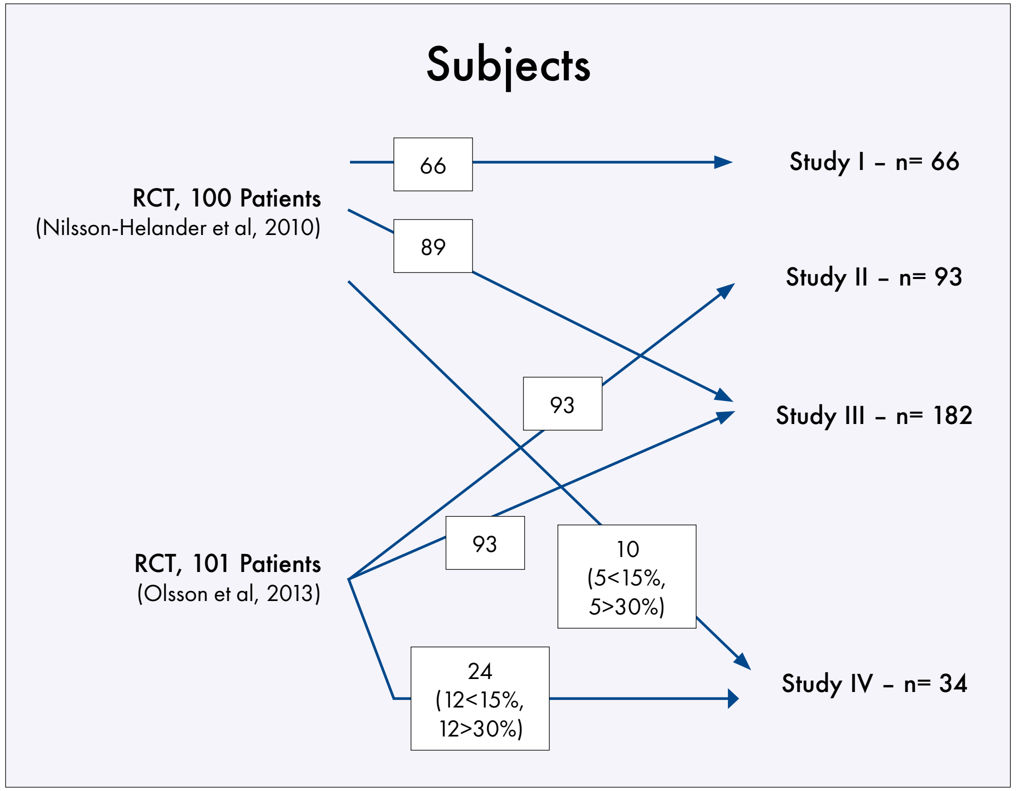


Figure 28. All the included patients came from two different randomized, controlled trials [111, 123]. In Study IV, < 15% and > 30% represent the number of patients who had less than 15% or more than 30% side-to-side difference in terms of heel-rise height at the 1-year follow-up.

Table 3. Demographics of all patients participating in Studies I-IV.

	Study I	Study II	Study III	Study IV
Patients included (n)	66	93	182	34
Age mean (SD), median, min-max	 50(8.5) 48.5 35–69	 40 (9.3) 40 20-63	 41 (9.3) 40 20-64	 48 (11) 46 30-72
Height mean (SD), median, min-max	 178(9.7) 180 153–197.5	 179 (8.2) 180 160-200	 178 (8.6) 180 153-200	 179 (8.9) 180 152-196
Weight mean (SD), median, min-max	 85.9(13.5) 85.3 55.7–117	 86.3 (13.1) 84.5 57.7-118.6	 85.7 (13) 85.7 56.5-118.6	 85.7 (12.8) 84.7 61.8-119.5
Male/female	53/13	79/14	152/30	31/3
Treatment surgery/ non surgery	34/32	47/46	94/88	17/17
Time since injury mean (SD), median, min-max	 7(1) years 7 5-9	 12 (0.7) weeks 12 11-15	 6 and 12 months	 6 (2) years 5.2 4.2-10

Study I

The patients in this study originated from a cohort of 100 patients included in an RCT, where the patients received either surgical or non-surgical treatment after an Achilles tendon rupture [111]. A flowchart of the cohort included in Study I is shown in *Figure 29*.

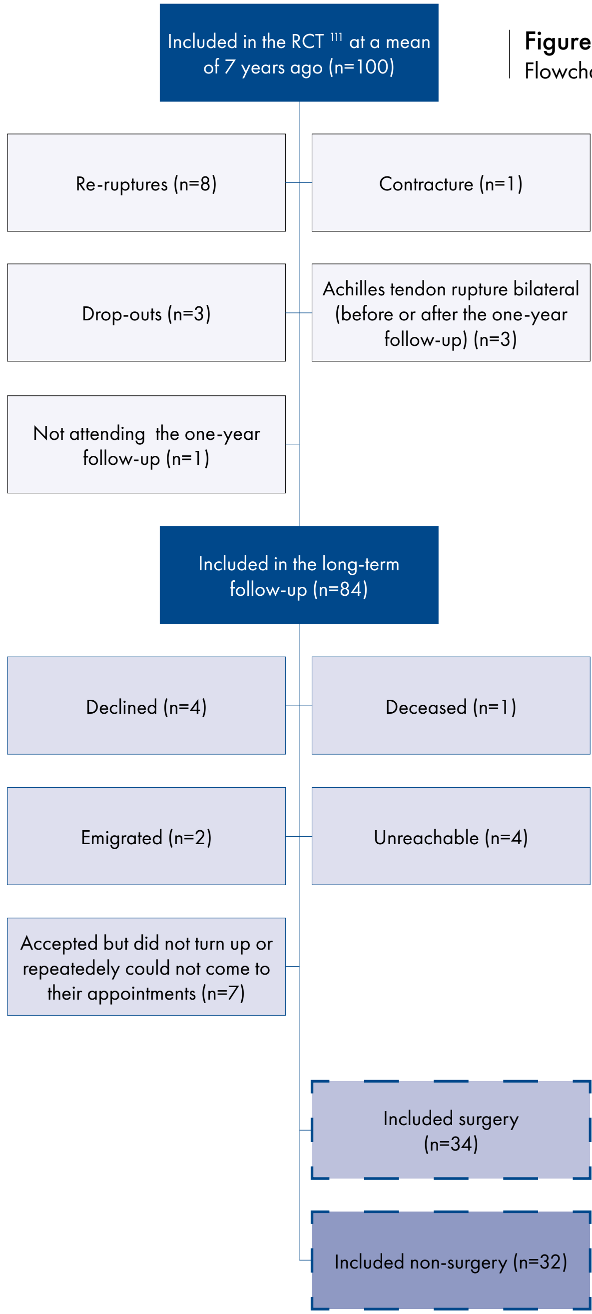


Figure 29.
Flowchart of the cohort included in Study I.

A comparison of the 1-year follow-up results between the group included in the long-term follow-up and the group that was unavailable or declined to participate was performed in order to evaluate differences between the groups *(Table 4)*. The only difference was age.

Table 4. Comparison at one year after injury of included and missing subjects at the seven-year follow-up.

Variables	Included subjects (n=66)	Subjects unavailable or declined to participate (n=18)	*p-value*
Age			
mean (SD)	44(9)	38(10)	
median	42	36	**0.024**
min-max	28-65	24-58	
Weight (kg)			
mean (SD)	84(13.6)	88.9(10.5)	
median	85	86	*n.s.*
min-max	55-110.8	67.4-111.5	
Length (cm)			
mean (SD)	178(9.7)	179.5(6.2)	
median	180.3	181	
min-max	153-197.5	168-188.5	*n.s.*
LSI heel-rise reps (%)			
mean (SD)	95(21)	89(21)	
median	94	88	
min-max	49-166	52-125	*n.s.*
LSI heel-rise height (%)			
mean (SD)	78(13)	80(13)	
median	77	83	
min-max	47-113	48-100	*n.s.*
LSI heel-rise work (%)			
mean (SD)	73(20)	72(22)	
median	74	76	
min-max	28-119	20-103	*n.s.*
Diff in heel-rise height (cm)			
mean (SD)	-3.0(2.0)	-3.0(2.2)	
median	-3.2	-2.5	
min-max	-8.6-1.8	-8.4-0	*n.s.*
ATRS			
mean (SD)	88(17)	79(21)	
median	93	87	
min-max	13-100	33-100	*n.s.*
PAS			
mean (SD)	3.7(1.0)	3.6(1.6)	
median	4	3	
min-max	1-6	2-6	*n.s.*
Treatment surgery/non surgery	34/32	10/8	*n.s.*
Sex man/woman	53/13	16/2	*n.s.*
Injured side right/left	30/36	10/8	*n.s.*

Study II

All the patients in this study were originally (n=101) included in an RTC where they were randomized to receive non-surgical treatment or stable surgical repair together with accelerated rehabilitation after an acute Achilles tendon rupture [123]. All 93 patients who attended the 3-month follow-up were included in this study. The reason for not participating in the 3-month follow-up is given in the flowchart below *(Figure 30)*.

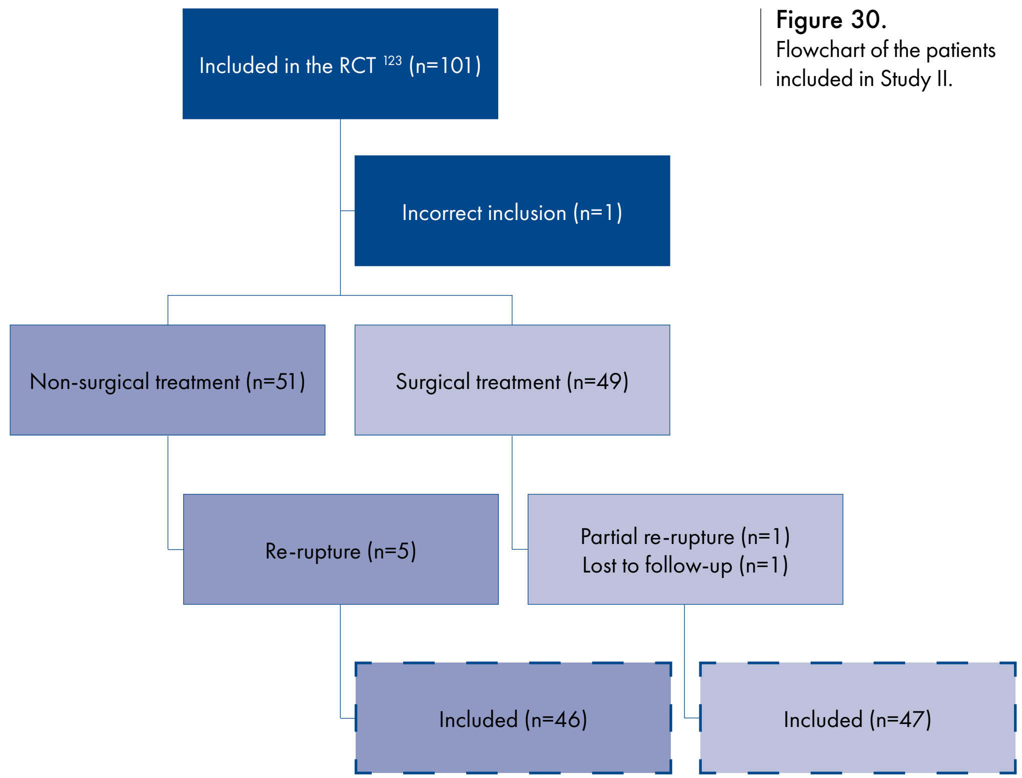


Figure 30. Flowchart of the patients included in Study II.

For the demographic data in Study II, please see *(Table 5)*. Forty-seven patients were unable to perform the single-leg standing heel-rise (lifting the heel more than 2 cm) at the 3-month follow-up (heel-rise NO) and 46 patients were able to (heel-rise YES). The demographics for these two groups are shown in *Table 5*.

Table 5. Demographic data of the patients included in Study II divided in the group who could (Heel-rise YES) and the group who cold not (Heel-rise NO) perform a single-leg standng heel-rise 3 months after the injury.

Variable	Heel-rise YES (n=46)	Heel-rise NO (n=47)	*p-value*
Age Mean (SD) Median Min-max	 37.3 (8) 38 20–58	 42.6 (9.6) 42 27–63	*0.010*
Height Mean (SD) Median Min-max	 180 (7.5) 181 165–200	 177 (8.8) 177 160–196	*n.s*
Weight Mean (SD) Median Min-max	 85.7 (11.2) 84.5 65–112	 86.1 (14.4) 84.5 57.7–118.6	*n.s*
Male/female (n)	42/4	37/10	*n.s*
Treatment surgery/ non-surgery (n)	26/20	21/26	*n.s*

Study III

In Study III, 182 patients from two different RCTs were included [111, 123]. They were randomized to receive surgical or non-surgical treatment. The inclusion criteria were the same in the two studies, whereas the treatment protocols were slightly different. The exclusion criterion in Study III was a re-rupture. The demographics for all patients are given in *Table 3* and, in *Table 6*, the distribution of the patients in each study is presented. *Figure 31* shows how many men and women respectively were treated surgically or non-surgically.

Table 6. The distribution of the patients in Study III who were primarily included in the two different RCTs divided into which treatment, sex and mean age they had.

Treatment group	Study 2010 [111] (n=89)	Study 2013 [123] (n=93)
Surgical treatment Male/female (n) Age (year), mean (SD)	 39/8 40 (10)	 37/10 39 (9)
Non-surgical treatment Male/female (n) Age (year), mean (SD)	 34/8 39 (14)	 42/4 40 (10)

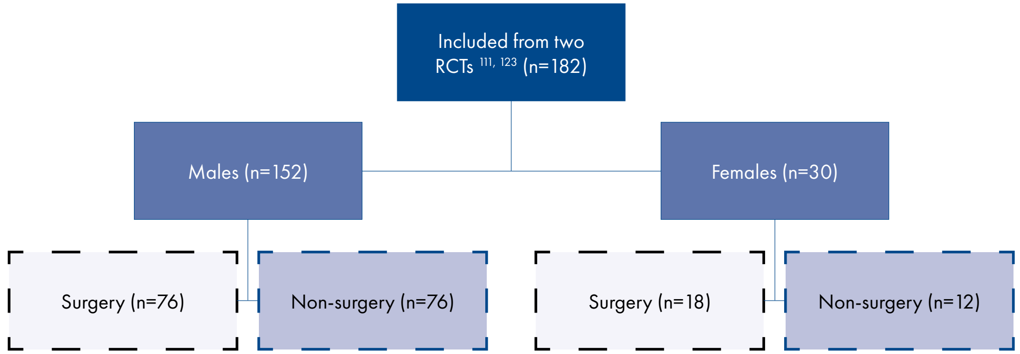


Figure 31. The numbers of males and females treated surgically or non-surgically.

Study IV

All the participants (n=34) in this study came from a cohort of 201 patients included in the two RCTs mentioned before [111, 123]. All the patients had been treated by one of four experienced physical therapists and had also been evaluated by one of two evaluators, who were not involved in the rehabilitation. The evaluation protocol was identical for all the patients and the result from the 1-year follow-up was used to rank the patients according to their LSI heel-rise height. The exclusion criteria in the present study were having a new ankle injury that would limit the ability to participate in the evaluation, having a re-rupture or a new Achilles tendon rupture or not having participated in the 1-year follow-up. This left 173 patients, who were ranked according to their LSI heel-rise height and 65 patients (35 treated with surgery) had a < 15% (LSI=>85%) and 45 patients (19 treated with surgery) had a > 30% (LSI=<70%) side-to-side difference in heel-rise height. The patients were contacted consecutively and 17 patients were recruited from each group. The patients were evaluated a mean of 6 years after their Achilles tendon rupture and they were blinded to the group (<15% or >30%) to which they belonged. The demographics for each group are presented in *Table 7*. *Figure 32* shows the distribution of the patients included in Study IV.

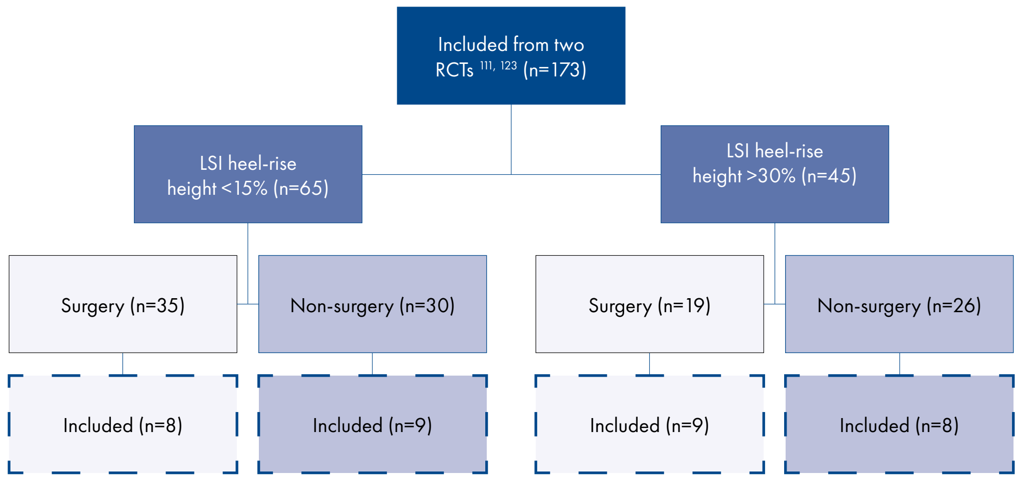


Figure 32. Patients included in the < 15% and > 30% group who were treated surgically or non-surgically.

Table 7. The demographics of the included patients in Study IV divided in the <15%- and the >30%-groups.

Variables	<15%-group (n=17)	>30% group (n=17)	*p-value*
Age (years) Mean (SD) Median Min-max	 40 (5) 41 30-50	 56 (9) 58 42-72	*< 0.001*
BMI Mean (SD) Median Min-max	 25.8 (2.9) 24.4 22.1-35	 27.9 (3.6) 26.8 21.8-35.2	*n.s.*
Years since injury Mean (SD) Median Min-max	 6.2 (2.1) 5.2 4.2-10.1	 5.9 (1.9) 5.2 4.2-9.3	*n.s.*
Treatment surgery/ non-surgery	8/9	9/8	*n.s.*
Sex	15 men, 2 women	16 men, 1 woman	*n.s.*
Heel-rise height 1-year follow- up, INJURED limb (cm) Mean (SD) Median Min-max	 12.2 (1.6) 12.0 9.6-16.2	 7.9 (2.0) 8.4 4.5-11.9	*< 0.001*
Heel-rise height 1-year follow- up, HEALTHY limb (cm) Mean (SD) Median Min-max	 12.7 (1.3) 12.8 10.6-15.3	 13.2 (2.3) 13.2 9.1-17.8	*n.s.*
Heel-rise height 1-year follow- up, LSI (%) Mean (SD) Median Min-max	 95 (5) 94 88-109	 60 (9) 63 37-69	*<0.001*
ATRS 1-year follow-up Mean (SD) Median Min-max	 88 (14) 93 47-100	 78 (24) 87 2-100	*n.s.*
PAS 1-year follow-up Mean (SD) Median Min-max	 4.1 (0.9) 4 3-6	 3.8 (1.0) 3 3-6	*n.s.*

06

STATISTICAL METHODS

SPSS statistics (IBM Corp. Released 2012. IBM SPSS Statistics for Macintosh, Version 21.0. Armonk, NY: IBM Corp) were used for analyses of all data. The LSI was defined as the side difference (injured side/ non-injured side) x 100 and expressed as a percentage (%). The level of significance was set at $p < 0.05$.

Study I

All the available patients included in the original RCT [111] were considered for inclusion in this study. Ratios, intervals and ordinal data were all reported as the mean (SD), median and range. For dichotomous variables (treatment, sex and injured/ non-injured side), the chi-square test was used. A paired t-test was used for comparisons between injured and non-injured limbs. A repeated measure of ANOVA was performed in order to calculate the main difference over time in calf muscle performance on the injured side between the 1-, 2- and 7-year follow-ups. The main difference over time was expressed as Sphericity Assumed and Greenhouse-Geisser correction was performed when Mauchly's test of sphericity was significant. Pairwise comparisons between the 1-year and 2-year follow-ups, the 2-year and 7-year follow-ups and between the 1-year and 7-year follow-ups were calculated if the main difference over time was significant.

Study II

All the available patients included in the original RCT [123] were considered for inclusion in this study. Descriptive data were reported as the mean, median, standard deviation (SD) and range (min-max). Ratios and interval data were reported and the mean (SD) and ordinal data were reported both as the median (min-max) and the mean (SD). Non-parametric statistics were used for ordinal data and for data that were not normally distributed. The Mann-Whitney U-test was used to compare the groups treated with surgery and non-surgery and also the groups which were and were not able to perform a single-leg standing heel-rise at the 3-month evaluation (heel-rise YES, heel-rise NO). Wilcoxon's signed rank test was used to compare the injured and non-injured sides. The chi-square test was used for dichotomous variables (men and women). Spearman's rank correlation was used to analyze the correlations between patient-reported outcome and functional tests. The intra-class correlation coefficient ($ICC_{2,1}$) was calculated for test-retest reliability. The standard error of measurement (SEM) was calculated in order to determine the smallest detectable change (SDC). SEM = s $\sqrt{1 - ICC}$, s = the standard deviation in the baseline measurements. SDC at group level is calculated as follows: $2.77 \times SEM/\sqrt{n}$ and at individual level: $2.77 \times SEM$.

Study III

All the available patients included in the two original RCTs [111, 123] were considered for inclusion in this study. Descriptive data were reported as the mean ± SD, the median (inter-quartile range (IQR)) and frequency. The Mann-Whitney U test was used to compare the ATRS scores between groups. The independent-samples t-test was used to compare the heel-rise test between groups.

Study IV

An à priori power calculation (90% power and α=0.05) based on a previous study [147] indicated that 13 patients were needed to detect side-to-side differences in peak Achilles tendon force and ankle plantar flexion power between injured and healthy limbs while walking.

Ratios, intervals and ordinal data were all reported as both the mean (SD) and the median (min-max). For dichotomous variables (treatment and sex), the chi-square test was used. For comparisons between injured and non-injured limbs, a paired t-test was used. The Mann Whitney U-test was used for comparisons between the < 15% group and > 30% group in patient-reported outcome measurements, since these were ordinal data. Pearson's correlation coefficient was used for correlation calculations between LSI heel-rise height at 1 year and kinematics and kinetics. In order to reduce the risk of a type 1-error, a multivariate analysis of variance (MANOVA) test was performed before calculating p-values and effect sizes (Cohen's d) in kinematics and kinetics during the activities. MANOVA was used to compare the variables during walking, jogging, drop CMJ and hopping between the < 15% group and the > 30% group. When performing MANOVA, the difference between the injured and healthy sides in degrees was used for the kinematic calculations and LSI values (%) were used for the kinetic calculations.

07

SUMMARY OF THE PAPERS

Study I

Calf muscle performance deficits remain 7 years after an Achilles tendon rupture

Introduction: Optimizing calf muscle performance appears to play an important role in minimizing the impairments and symptoms after an Achilles tendon rupture. There is a lack of long-term follow-up studies describing calf muscle performance over time after the injury.

Purpose: The primary aim of this study was to evaluate calf muscle performance and patient-reported outcome a mean of 7 years after an Achilles tendon rupture in patients included in a prospective, randomized controlled trial (RCT). A secondary aim was to evaluate whether there was a continued improvement in calf muscle performance after the 2-year follow-up.

Methods: Sixty-six (13 women) subjects at a mean (SD) age of 50 (8.5) years were evaluated a mean of (SD) 7 (1) years after their Achilles tendon rupture. Thirty-four received surgical and 32 non-surgical treatment. Patient-reported outcome was evaluated with the Achilles tendon Total Rupture Score (ATRS) and the Physical Activity Scale (PAS). Calf muscle performance was evaluated with the single-leg standing heel-rise test, concentric strength power heel-rise test and one-leg hop for distance. The Limb Symmetry Index (LSI=injured side/healthy side x 100) was calculated for side differences.

Results: 7 years after the Achilles tendon rupture, the injured side showed decreased values in all calf muscle performance tests ($p<0.001$-0.012) *(Table 8)*.

Table 8. Comparison between injured and non-injured sides 7 years after an Achilles tendon rupture.

Variables	Injured side	Non-injured side	*p-value*
Heel-rise height (cm) mean (SD) median min-max	11.5 (2.3) 11.5 6.4–17.7	13.5 (2.2) 13.4 7.3–20.4	*<0.001*
Heel-rise repetitions (n) mean (SD) median min-max	30 (12) 27 11–85	32 (13) 30 16–81	*0.012*
Heel-rise work (J) mean (SD) median min-max	2084 (770) 2017 719–4504	2712 (847) 2680 810–4386	*<0.001*
Concentric strength power (W) mean (SD) median min-max	258 (118) 247 60–596	326 (135) 301 112–777	*<0.001*
One-leg jump for distance (cm) mean (SD) median min-max	120 (25) 116 66–178,5	126 (24) 124 63–182	*<0.001*

There was no continued improvement in calf muscle performance after the 2-year follow-up (p=0.271-0.434). However, heel-rise height increased significantly (p=0.002) between the 1-year (10.8 cm) and the 7-year follow-ups (11.5 cm), but the increase was not significant after the 2-year follow-up *(Figure 33)*.

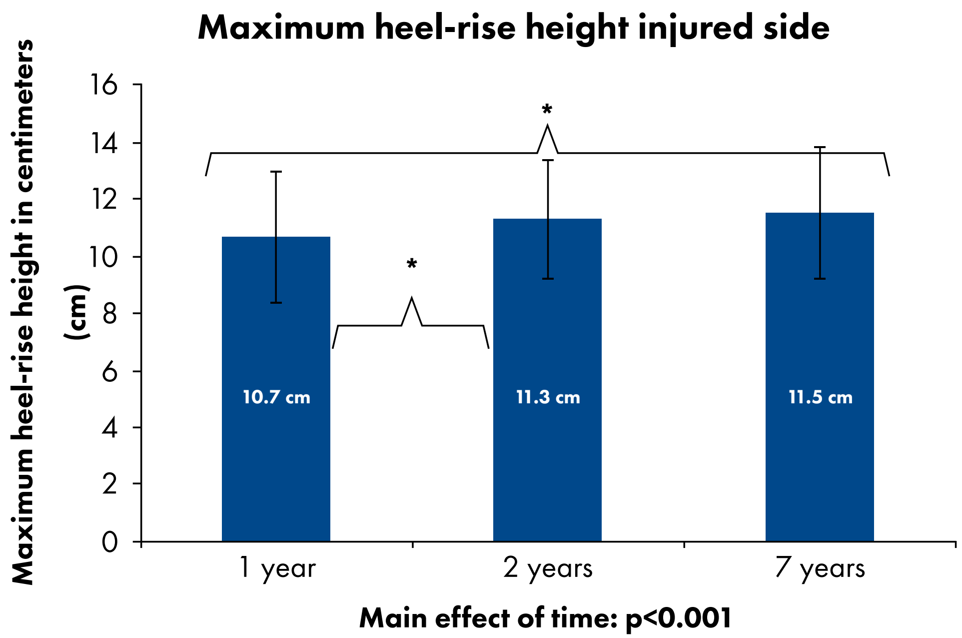


Figure 33. Change over time on the injured side in maximum heel-rise height (cm) in a single-leg standing heel-rise test. The bars correspond to mean values and the error bars to SD. Brackets indicate significance for pairwise comparison. * = p < 0.05

The median (range) ATRS score was 96/100 (0-100) and the median PAS score was 4/6 (2-6), indicating minor patient-reported symptoms and fairly high physical activity, despite the percentage of patients that reached LSI > 85% levels of success rate in the calf muscle performance tests 7 years after the injury *(Table 9)*.

Table 9. Percentage of patients reaching the different levels of success-rate in the calf muscle performance tests 7 years after the injury.

Variables	LSI <70%	LSI 70–85%	LSI >85%
LSI heel-rise height (n=65) (%)	8	38	54
LSI heel-rise repetitions (n=64) (%)	6	28	66
LSI heel-rise work (n=64) (%)	39	28	33
LSI conc power (n=65) (%)	40	31	29

Conclusion: Continued deficits in calf muscle endurance and strength remain 7 years after an Achilles tendon rupture. No continued improvement in calf muscle performance occurred after the 2-year follow-up, except for heel-rise height.

Study II

Recovery of calf muscle endurance 3 months after an Achilles tendon rupture

Introduction: The early stages of rehabilitation appear to be of great importance for the final outcome after an Achilles tendon rupture. It is a challenge to evaluate the patient's calf muscle endurance in this phase of the rehabilitation in a safe yet satisfactory manner.

Purpose: The purpose of this study was to evaluate calf muscle endurance in a seated position 3 months after an Achilles tendon rupture and to evaluate how the ability to perform standardized seated heel-rises correlated to the single-leg standing heel-rise test and to patient-reported symptoms evaluated with the Achilles tendon Total Rupture Score (ATRS) 3 and 6 months after the injury.

Methods: Ninety-three patients were included from a cohort of 101 patients participating in a prospective, randomized, controlled trial comparing surgical and non-surgical treatment after Achilles tendon rupture. Forty-seven patients were treated surgically and 46 non-surgically.

Results: Ninety-one patients of 93 (98%) were able to perform the standardized seated heel-rises. At the 3-month follow-up, there was a significant difference (p<0.001) between the injured and the healthy side in heel-rise height and numbers of repetitions when performing standardized seated heel-rises, but there were no significant differences between the treatment groups (surgery and non-surgery). Comparing the performance of the standardized seated heel-rises between the group which was able (heel-rise YES) and the group which was not able (heel-rise NO) to perform a single-leg standing heel-rise at the 3-month follow-up, the heel-rise YES group had a superior performance, together with superior results for symptoms and physical activity *(Table 10)*.

Table 10. Comparison between the injured and healthy sides in terms of the standardized seated heel-rises height and number of repetitions and patient-reported symptoms between the groups who could perform a single-leg standing heel-rise test (Heel-rise YES) and those who could not (Heel-rise NO) at the 3-month follow-up.

Variable	Heel-rise YES (n=46)			Heel-rise NO (n=47)			Comparison Heel-rise YES and Heel-rise NO	
	Injured side	Healthy side	*p-value*	Injured side	Healthy side	*p-value*	*Injured side p-value*	*Healthy side p-value*
Height (cm) Mean (SD) Min-max	6,8 (1.5) 4.1-10.2	8.8 (1.7) 6.4-13.8	*< 0.001*	5.4 (2.1) 0-10.1	9.1 (1.6) 6.4-15.1	*< 0.001*	*< 0.001*	*n.s.*
Reps Mean (SD) Min-max	67 (28) 20-100	92 (19) 26-100	*< 0.001*	49 (32) 0-100	87 (24) 23-100	*< 0.001*	*0.011*	*n.s.*
ATRS Mean (SD) Median (IQR) Min-max	45 (18) 43 (27.8) 9-86			34 (16) 32 (18) 6-73			*0.007*	
PAS Mean(SD) Median (IQR) Min-max	3.1 (0.96) 3 (0) 1-6			2.7 (0.98) 3 (1) 1-6			*0.04*	

There were also significant correlations (r=0.29-0.37, p<0.05) between the standardized seated heel-rises and the ATRS 3 and 6 months after injury in the group which was unable to perform single-leg standing heel-rises.

Specificity, sensitivity and positive predictive value were calculated and a positive result was being unable to perform a single-leg heel-rise. The specificity was defined as the proportion of individuals without the condition of interest who had a negative result (if they were able to perform a heel-rise, it was 98% certain that they would be able to perform more than 20 seated heel-rises as well). The sensitivity was defined as the proportion of individuals with the condition of interest who had a positive test result (if they did not manage to perform a heel-rise, it was only 21% certain that they would perform fewer than 20 seated heel-rises as well). The positive predictive value was defined as the proportion of patients with a positive test result who have the condition (if they did not manage more than 20 seated heel-rises, it was 91% certain that they would not be able to perform a single-leg standing heel-rise either) (*Table 11 and Table 12).*

Table 11. The specificity and sensitivity of the standardized seated heel-rises.

Seated heel-rise	Standing heel-rise NO (n)	Standing heel-rise YES (n)
Manage ≤ 20 repetitions	10 (true positive)	1 (false positive)
Manage > 20 repetitions	37 (false negative)	45 (true negative)
Specificity: 45/ (1+45) x 100 = 98%		
Sensitivity: 10/ (10+37) x 100 = 21%		

Table 12. The positive and negative predictive value of the standardized seated heel-rises.

Seated heel-rise	Standing heel-rise NO (n)	Standing heel-rise YES (n)
Manage ≤ 20 repetitions	10 (true positive)	1 (false positive)
Manage > 20 repetitions	37 (false negative)	45 (true negative)
Positive predictive value: 10 / (10+1) x 100 = 91%		
Negative predictive value: 45 / (37+45) x 100 = 55%		

Conclusion: The evaluation of standardized seated heel-rises appears to be a useful tool for quantifying progress and predicting future functional performance and patient-reported symptoms.

Study III

Sex differences in outcome after an acute Achilles tendon rupture

Introduction: Tendon healing differs between the sexes. Comparisons of outcome between men and women after an Achilles tendon rupture are often not possible because of the small female cohorts (<20%).

Purpose: To evaluate whether there are any differences in outcome between the sexes by combining the data from two large randomized, controlled trials that used identical outcome measurements

Methods: The evaluation included patients from two consecutive randomized, controlled trials comparing surgical and non-surgical treatment performed at our research laboratory. Patients who had a re-rupture were excluded from the analysis. A total of 182 patients (152 males, 30 females), with a mean (SD) age of 40 (11) years, were included; 94 (76 males, 18 females) were treated with surgery and 88 (76 males, 12 females) non-surgically. Patient-reported outcome was evaluated using the Achilles tendon Total Rupture Score (ATRS) and the functional outcome was measured with a heel-rise test (measurement of muscular endurance and heel-rise height) at 6 and 12 months after injury.

Results: Male patients experienced a greater improvement in heel-rise height at 12 months after the injury, regardless of surgical or non-surgical treatment (p=0.004). When each treatment group was analyzed separately, it was found that female patients had significantly (p<0.03) more symptoms after surgical treatment (mean (SD)) ATRS, 59 (24) compared with males at 6 (73 (19)) and 12 months (74 (27) vs 86.5 (17)). This sex difference was not found in the non-surgically treated group *(Table 13)*.

Table 13. Summary of the recovery after an Achilles tendon rupture in females compared to males.

Variables	Female versus Male	
	6 months	12 months
ATRS	Females < Males when surgically treated	Females < Males when surgically treated
LSI Heel-rise height	Females = Males	Females < Males
LSI Heel-rise work	Females =Males	Females = Males

For the entire group, there were no significant ATRS differences between treatments at either 6 or 12 months after the injury. The surgical group had significantly better results compared with the non-surgical group in terms of heel-rise endurance at 6 and 12 months and in heel-rise height recovery at 6 months *(Table 14)*.

Table 14. Results in ATRS and calf-muscle recovery between surgical and non-surgical treatments.

	6-month follow-up		*p-value*	12-month follow-up		*p-value*
Variables	Surgical	Non-surgical		Surgical	Non-surgical	
ATRS						
Patients, n	94	88		90	87	
Median (IQR)	75 (24)	75 (28)	*n.s.*	90 (16)	90 (20)	*n.s.*
Mean (SD), %	70 (21)	68 (22)		84 (20)	81 (23)	
Heel-rise height (LSI)						
Patients, n	94	88	0.005	88	87	*n.s.*
Mean (SD), %	72 (17)	64 (20)		79 (18)	77 (17)	
Heel-rise work (LSI)						
Patients, n	94	88	0.001	88	87	0.023
Mean (SD), %	64 (22)	52 (24)		75 (22)	68 (22)	

Conclusion: Sex differences were demonstrated and, at 12 months after the injury, female patients had a greater degree of deficit in heel-rise height as compared with males, irrespective of treatment. Females had more symptoms after surgical treatment at both 6 and 12 months, but this difference was not found for those treated non-surgically.

Study IV

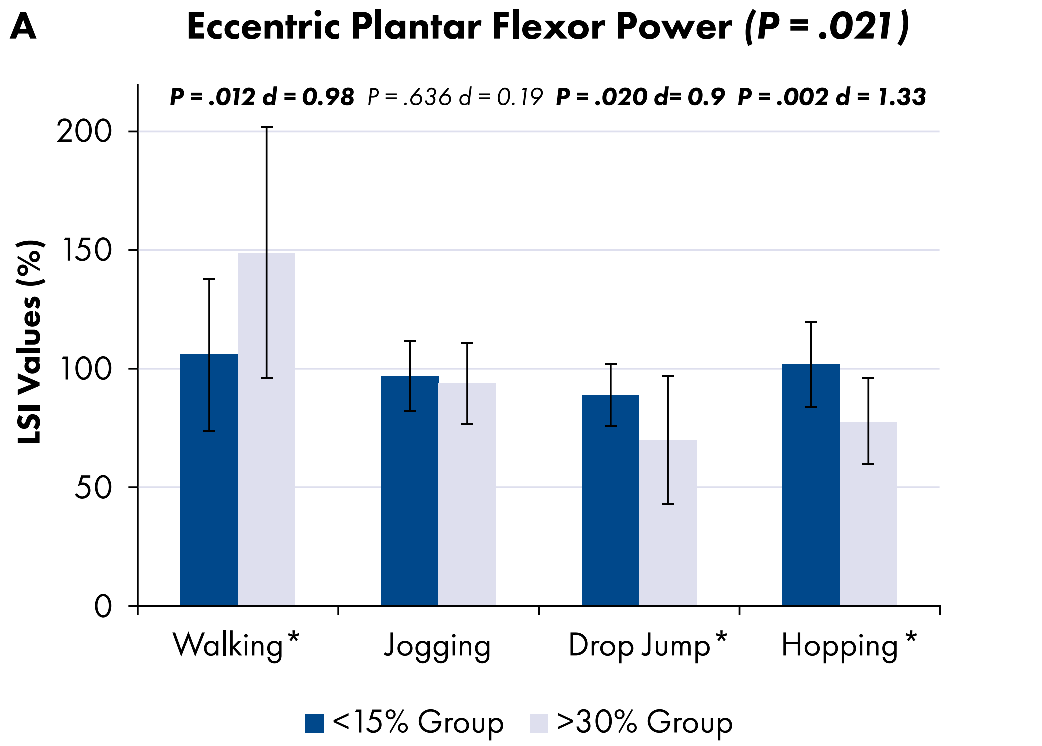
Heel-rise height deficit 1 year after Achilles tendon rupture relates to changes in ankle biomechanics 6 years after injury

Introduction: It is still unknown whether heel-rise height obtained in the single-leg standing heel-rise test 1 year after an Achilles tendon rupture correlates with ankle biomechanics during walking, jogging and jumping in the long term.

Purpose: The aim of this study was to explore the differences in ankle biomechanics, tendon length, calf muscle recovery and patient-reported outcome at a mean of 6 years after an Achilles tendon rupture between two groups that at the 1-year follow-up had < 15% versus > 30% differences in heel-rise height.

Methods: Seventeen patients with a < 15% (<15% group) and 17 patients with > 30% (>30% group) side-to-side difference in terms of heel-rise height 1 year post Achilles tendon rupture were evaluated at a mean of (SD) 6.1 (2.0) years after their Achilles tendon rupture. Ankle kinematics and kinetics were sampled via standard motion capture procedures during walking, jogging and jumping. Patient-reported outcome was evaluated with the Achilles tendon Total Rupture Score (ATRS), Physical Activity Scale (PAS) and Foot and Ankle Outcome Score (FAOS). Tendon length was evaluated by ultrasound assessment. The limb symmetry index (LSI=injured/healthy x 100) was calculated for side differences. In order to reduce the chance of a type 1-error, a multivariate analysis of variance (MANOVA) test was performed before calculating p-values for kinematics and kinetics during walking, jogging, drop CMJ and hopping between the <15% group and the > 30% group. When performing MANOVA, the differences between the injured and healthy side in degrees were used for the kinematic calculations and LSI values (%) were used for the kinetic calculations.

Results: The > 30% group had significantly more deficits in ankle kinetics during all activities compared with patients in the < 15% group a mean of 6 years post Achilles tendon rupture (*Figures 34 A-D*). During jumping, there were significant differences in all the kinetic variables (Table 15). There were no differences between groups in terms of ankle kinematics.



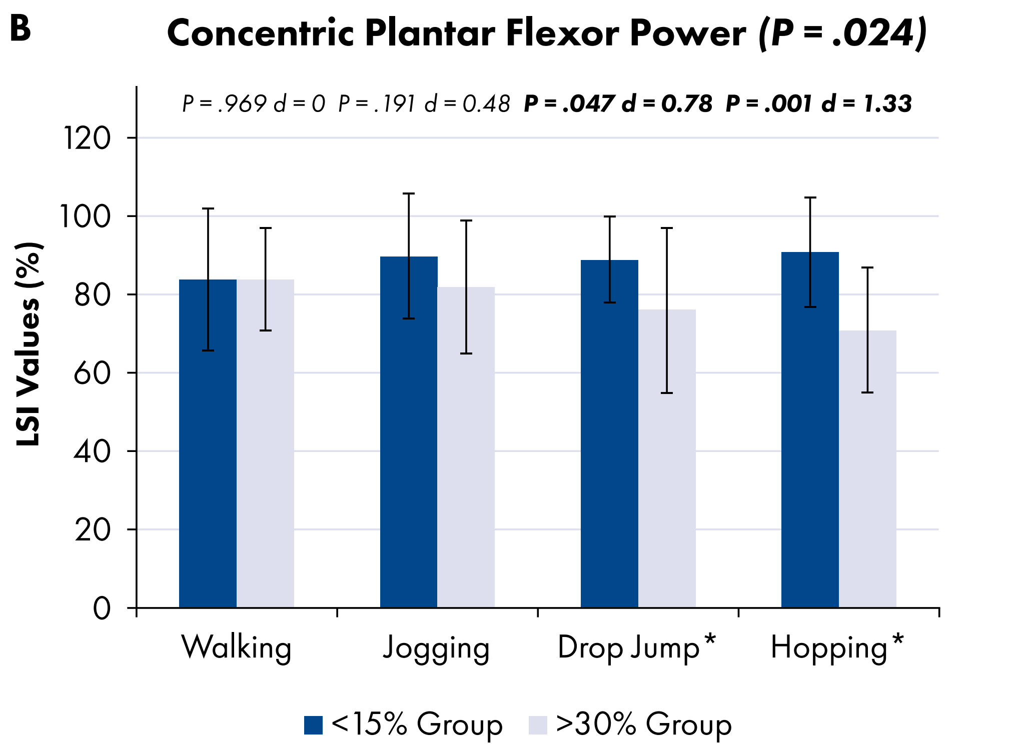
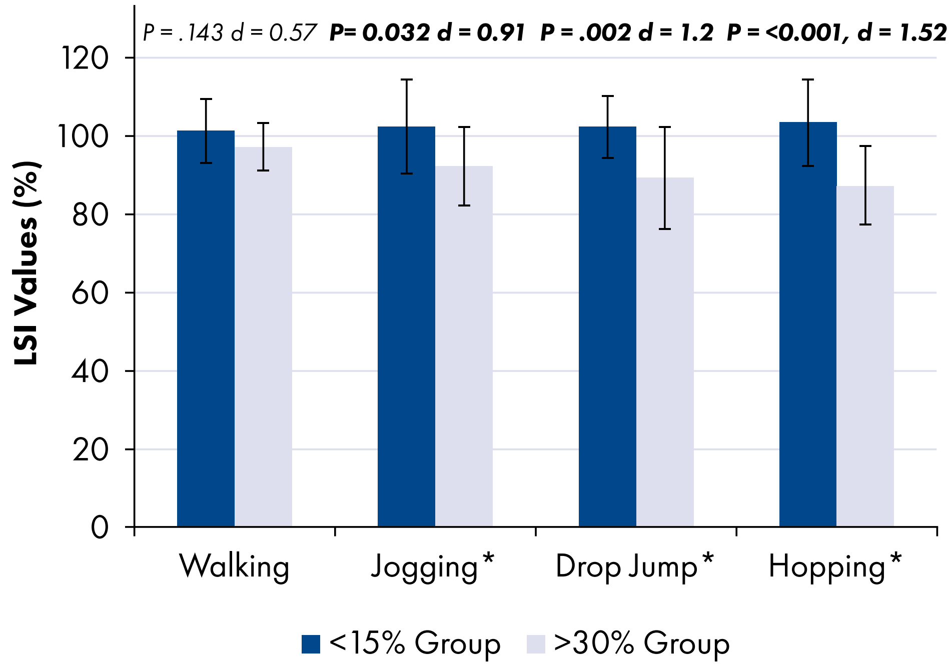


Figure 34 A-D (P 85-86). Differences between the group with < 15% side-to-side difference (< 15% group) and the group with > 30% side-to-side differences (> 30% group) in LSI heel-rise height at the 1-year follow-up in terms of eccentric plantar flexion power (A), concentric plantar flexion power (B), peak Achilles tendon force (C) and Achilles tendon impulse (D) during different activities a mean of 6 years after the Achilles tendon rupture. The bars correspond to mean values and the error bars to SD. An LSI value of < 100% indicates a poorer performance on the injured side compared with the healthy side. *=p<0.05, d=effect size, Cohen's d [23]

C **Peak Achilles Tendon Force *(P = 0.010)***



D **Achilles Tendon Impulse *(P = .024)***

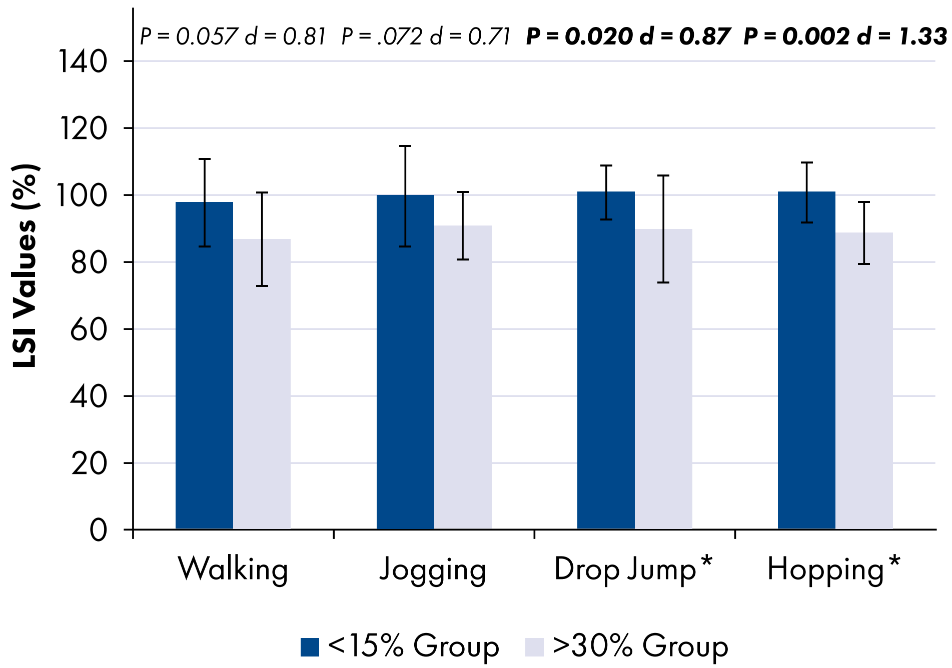


Table 15. Differences in ankle kinetics LSI values between the <15%-group and the >30%-group during different activities.

Variables	Group (<15% and >30%)	WALKING (LSI, %)	JOGGING (LSI, %)	DROP JUMP (LSI, %)	HOPPING (LSI, %)	*p-value (Pillai´s trace)*
Eccentric plantar flexion power	<15%	106(32)	97(15)	89(13)	102(18)	*0.021*
	>30%	149(53)	94(17)	70(27)	78(18)	
p-value (between group effects) at different activities		*0.012*	*n.s.*	*0.020*	*0.002*	
Concentric plantar flexion power	<15%	84(18)	90(16)	89(11)	91(14)	*0.024*
	>30%	84(13)	82(17)	76(21)	71(16)	
p-value (between group effects) at different activities		*n.s.*	*n.s.*	*0.047*	*0.001*	
Peak Achilles tendon force	<15%	101(8)	102(12)	102(8)	103(11)	*0.010*
	>30%	97(6)	92(10)	89(13)	87(10)	
p-value (between group effects) at different activities		*n.s.*	*0.032*	*0.002*	*<0.001*	
Achilles tendon impulse	<15%	98(13)	100(15)	101(8)	101(9)	*0.024*
	>30%	87(14)	91(10)	90(16)	89(8)	
p-value (between group effects) at different activities		*n.s.*	*n.s.*	*0.020*	*0.002*	

The > 30% group also had significantly lower values in terms of heel-rise height and heel-rise work and significantly larger side-to-side differences in tendon length compared with the < 15% group *(Table 16)*.

Table 16. Differences between the < 15%- group and the > 30%-group 6 years after the Achilles tendon rupture in LSI heel-rise-test and LSI tendon length.

Variables LSI (%)	< 15%-group (n=17)	>30% group (n=17)	*p-value*
Heel-rise height Mean (SD) Median Min-max	95 (12) 95 77 -123	72 (7) 72 59 – 84	*< 0.001*
Heel-rise reps Mean (SD) Median Min-max	98 (18) 97 70 – 137	85 (25) 81 29 – 133	*n.s.*
Heel-rise work Mean (SD) Median Min-max	91 (14) 96 67 – 110	58 (16) 62 18 – 79	*< 0.001*
Tendon length Mean (SD) Median Min-max	106 (6) 105 92 – 116	114 (9) 114 97 – 130	*0.012*

Achilles tendon length correlated to ankle kinematic variables (r=0.38-0.44, p=0.015-0.027), whereas heel-rise work correlated to kinetic variables (r=-0.57-0.56, p=0.001-0.047). LSI tendon length correlated negatively to LSI heel-rise height (r= -0.41, p=0.018). The were no differences between groups in patient-reported outcomes (p=0.143-0.852)

Conclusion: Maximum heel-rise height obtained during the single-leg standing heel-rise test, performed 1 year after an Achilles tendon rupture, is related to the long-term ability to regain normal ankle biomechanics.

08

DISCUSSION

The recovery of calf muscle function appears to be of great importance for the ability to participate in more demanding activities, as well as for self-perceived symptoms after an Achilles tendon rupture. For clinicians, evaluating heel-rises is a common way of both exercising the calf muscles and quantifying progress and optimizing the load during the rehabilitation process. Despite the long rehabilitation of 6 to 12 months, many patients are not able to achieve the same heel-rise height as in the healthy tendon. The reason for this may be strength and endurance deficits in the calf muscles, but another explanation could be that it is impossible to regain total calf muscle recovery when the Achilles tendon is elongated. To avoid this "Catch 22" situation, there is a need to expand our knowledge of ways of minimizing heel-rise height deficits, as well as optimizing calf muscle recovery during the rehabilitation after an Achilles tendon rupture.

A primary aim of this thesis was therefore to evaluate calf muscle recovery at different time points after an acute Achilles tendon rupture when treated with currently recommended treatment protocols. Both short-term and long-term calf muscle recovery have been investigated. In order to improve the evaluation of the patients' calf muscle performance at an early stage after the injury, standardized seated heel-rises were evaluated and found to be a safe and useful tool for quantifying progress and predicting future calf muscle performance and patient-reported symptoms. The development of calf muscle performance from 1 year to a mean of 7 years after the injury was evaluated in a long-term follow-up and it was concluded that no significant improvements in calf muscle performance occurred after a 2-year follow-up. Moreover, we demonstrated that there were sex differences in calf muscle recovery and symptoms. Female patients showed a greater degree of deficit in heel-rise height compared with males and they also experienced more symptoms 6 and 12 months after the injury when treated with surgery. Finally, it was shown that patients with large deficits, compared with patients with minor deficits, in heel-rise height at the 1-year follow-up still had lower values for ankle kinetics and calf muscle endurance and greater tendon elongation 5 years later. These deficits were most evident in more demanding activities such as jumping.

Short-term deficits in calf muscle recovery

A common way of evaluating calf muscle recovery after an Achilles tendon injury is to perform a single-leg standing heel-rise. The reason for using the single-leg standing heel-rise test in a clinical setting is that the test is easy and quick to perform and gives us knowledge of how to optimize and individualize the load for the patient. This test has also been shown to be reliable and responsive over time [106, 142, 143, 146]. Unfortunately, at the early stages, many patients have difficulty performing single-leg standing heel-rises at all and this may create an obstacle as the rehabilitation program progresses. The ability to perform at least one single-leg standing heel-rise on the injured leg just 3 months after the Achilles tendon injury has been shown to correlate with fewer symptoms and a higher physical activity level at the same time point [120]. Moreover, superior calf muscle endurance at 6 months after injury is linked to the same performance 1 year after the injury [13]. The mean time for being able to perform a single-leg standing heel-rise after an Achilles tendon rupture is between 10 and 14 weeks [70, 166, 185], while the range has been described to be between 7 and 25 weeks [166]. This is in line with Study II, where it was concluded that only 49% of the patients were able to perform a single-leg standing heel-rise 12 weeks after the injury.

However, performing the single-leg standing heel-rise test too soon after the injury can be more demanding and too difficult compared with a dynamometry strength test in a non-weight-bearing position [45]. Moreover, the risk of a re-rupture is greatest during the first 3 months after the injury [124, 130], which indicates that it is not advisable to push patients to perform maximum calf muscle strength tests in the controlled mobilization or early rehabilitation phase. In Study II, it was shown that the use of standardized seated heel-rises was a valid and reliable way to measure calf muscle performance at an early stage in the rehabilitation and that 98% of the patients were able to perform the test 12 weeks after the injury. A positive predictive value of 91% in the test was found (using ≤ 20 repetitions as a cut-off value), meaning that, if the patient was not able to perform more than 20 seated heel-rises with a load of 50% of body weight on the thigh, it was 91% certain that the patient would not be able to perform a single-leg standing heel-rise. Accordingly, one suggestion is that the first goal to achieve after weaning the patient off the boot could be to perform at least 20 repetitions in the standardized seated heel-rises on the injured foot with a load of 50% of body weight on the thigh. When this goal has been accomplished, the single-leg standing heel-rises could be introduced in the rehabilitation program.

TAKE-HOME MESSAGE:

One important goal to achieve in the early stages of rehabilitation is to perform a single-leg standing heel-rise on the injured foot. A first milestone during the early rehabilitation phase could be to perform at least 20 standardized seated heel-rises with a load of 50% of body weight.

Long-term deficits in calf muscle recovery

Heel-rise height

Studies I and IV have shown that a very common long-term deficit after an Achilles tendon rupture is decreased heel-rise height during a single-leg standing heel-rise in the injured limb. In both studies, patients with Achilles tendon rupture had remaining deficits in heel-rise height 6-7 years after the Achilles tendon rupture. This is in line with an earlier report [49]. However, in both Studies I and IV, it was found that continued improvement in heel-rise height occurred between the 1-year follow-up and the long-term follow-up at 6-7 years. In Study I, the heel-rise height in the injured limb increased significantly from the 1-year to the 7-year follow-up and the significant increase occurred during the first 2 years. In both studies, the difference in heel-rise height between the injured and healthy limb was 2 cm 6-7 years after the injury. However, the group in Study IV with the smallest side-to-side difference demonstrated no improvement between the 1-year follow-up and the long-term follow-up. However, 6 years after the injury, this group still had the best calf muscle recovery, measured in heel-rise height, compared with the group with the greatest side-to-side difference at the 1-year follow-up (LSI value of 95% compared with 72%). This may indicate that one important goal should be to improve heel-rise height as much as possible within the first year after an Achilles tendon rupture.

Calf muscle strength and endurance

As a result of the change in the muscle length-tension relationship in the injured calf muscle, it may be difficult to generate and fully regain calf muscle endurance and strength after an Achilles tendon rupture. A reduction in calf muscle strength and endurance after the injury has been reported in other long-term follow-up studies [46, 49, 82, 102]. However, the deficits in calf muscle strength and endurance after an Achilles tendon rupture are not comparable between studies due to different evaluation methods. Isokinetic calf muscle strength and endurance is often measured in a non-weight-bearing position that could not be compared with the evaluations of calf muscle strength and endurance performed in Studies I and IV. Fourteen years after an Achilles tendon rupture, Heikkinen et al. [46] reported 12.2-18% lower isokinetic calf muscle strength in the injured limb compared with the non-injured one. Similarly, Horstmann et al. [49] found a 14.9% decrease in calf muscle endurance during plantar flexion and a decrease in isokinetic calf muscle strength in ankle dorsi- and plantar flexion of between 3.2-6.7% 10 years after the injury. Another 10-year follow-up concluded that isokinetic ankle plantar flexion strength was up to 5.9% lower and calf muscle endurance was up to 8.9% less in the injured limb compared with the non-injured limb in patients with an Achilles tendon rupture [82]. Unfortunately, heel-rise height was not evaluated in these long-term follow-up studies. Deficits in heel-rise height after an Achilles tendon rupture may lead to, or may even be due to, decreased calf muscle strength and endurance. Regaining calf muscle strength and endurance after an Achilles tendon rupture is probably of great importance for returning safely to more demanding activities, such as running and jumping. It has previously been suggested that an LSI value of > 85% in different performance tests after an injury is an appropriate limit for return to sports [121, 161]. Only 6% of the patients in Study I managed to reach an LSI value of > 85% in all calf muscle performance tests a mean of 7 years after the Achilles tendon rupture. However, many patients appear to adapt to the changes in calf muscle performance after the injury and there is a lack of knowledge about whether the > 85% limit is a satisfactory value for a safe return to demanding activities in patients after an Achilles tendon rupture.

Tendon structure

Even if deficits in heel-rise height after an Achilles tendon rupture may be due to reduced calf muscle strength and endurance, it is not fully known why it is so difficult to recover heel-rise height in the injured limb. Other causes may be permanent changes that occur in the Achilles tendon structure after a rupture, such as tendon elongation and changes in mechanical properties. In Study IV, it was found that the side-to-side difference in tendon length correlated to the side-to-side difference in heel-rise height. Silbernagel et al [145] have previously come to the same conclusion. However, it is necessary to explore the degree to which the tendon can elongate before the lengthening affects the heel-rise height or whether the patients can develop compensatory mechanisms. Furthermore, it has also been suggested that the permanent changes in the tendon structure in the Achilles tendon after the injury are related to the recovery of heel-rise endurance [137]. Schepull et al.[137] concluded that early tensional loading was beneficial when it came to restoring the mechanical properties in the tendon, expressed as elasticity 1 year after the injury. Moreover, early weight-bearing has been shown to be advantageous for restoring mechanical properties in the tendon at the 6-month follow-up after an Achilles tendon rupture [103]. Nevertheless, both patients who were allowed early weight-bearing and patients who were not had significantly less stiffness (20-40%) in their injured leg compared with their healthy leg [103]. Geremia et al. [39], on the other hand, were not able to show that early mobilization was superior to traditional immobilization with a cast for 6 weeks, in terms of the force-elongation and stress-strain relationships of the injured tendon compared with the healthy tendon 2 years after an Achilles tendon rupture. It was shown that the mechanical properties of the injured tendon had not returned to the values of the uninjured tendon. The reason for this is thought to be multifactorial, but one explanation is that the content, quality and orientation of the collagen fibers have not managed to return to normal after an Achilles tendon rupture [64]. However, it is not known how the mechanical properties change over time after this injury and our knowledge of how we can optimize rehabilitation programs to improve the mechanical properties in the tendon is still limited.

TAKE-HOME MESSAGE:

Tendon elongation after an Achilles tendon rupture affects heel-rise height during a single-leg standing heel-rise. With the currently recommended treatment protocols, calf muscle performance is not restored completely in most patients. There is some evidence that regaining calf muscle performance within the first year after the injury is beneficial. Further studies exploring how different rehabilitation protocols can improve the restoration of calf muscle strength, endurance and heel-rise height are needed. However, calf muscle recovery takes a long time and improvements in heel-rise height in the injured limb are found up to 7 years after the injury.

Symptoms and physical activity

Three different patient-reported outcome measurements (PROMs) were used in this thesis; the ATRS [112], PAS [42, 134] and FAOS [132]. Of these, the ATRS is the only patient-reported outcome measurement that is designed exclusively for patients with an Achilles tendon rupture and it has been shown to be reliable and valid and to have high responsiveness [112].

It has previously been reported that, 2 years after an injury, the ATRS median (range) is high; 95 (12-100), indicating that, as a group, the patients were satisfied with the outcome after the Achilles tendon rupture, even if some individuals reported very low values [121]. This is in line with Studies I and IV in this thesis, as they both reported a high median on the ATRS; 91 and 92 respectively. In Study I, a significant increase in the ATRS was found between the 1-year follow-up and the 2-year follow-up, but not after 2 years. In Study IV, no significant improvement in the ATRS was found between the 1-year follow-up and the 6-year follow-up and this may be due to high scores at both the 1- and 6-year follow-ups. The PAS scores in Studies I and IV did not change at all after the 1-year follow-up. In both studies, the median PAS value was 4 on all occasions after the 1-year follow-up. The reasons for these high scores on the ATRS and PAS have not been fully clarified, but it is possible to speculate that the patients adapt to the new circumstances after the injury or that the PROMs do not fully capture the impact of the Achilles tendon rupture in terms of sport performance. The ATRS has been reported to have higher responsiveness between 3 and 6 months after injury (effect size 2.21) compared with between 6 and 12 months (effect size 0.87) [112] and it is not known whether the responsiveness continues to decrease as the time after the injury increases. Twenty-six percent of the patients obtained the highest possible score at the 7-year follow-up compared with 22% at the 2-year follow up and 14% at the 1-year follow-up in Study I. This could perhaps mean that the ATRS reached a ceiling effect 2 years after the injury. Another issue which is important to consider is the somewhat high mean age in Studies I and IV (50 and 48), which could reflect the fact that these patients do not participate to any great extent in highly demanding physical activities but are instead more frequently physically active for recreation. Since the injury often occurs during sporting activities, there are reasons to believe that patients who suffer an Achilles tendon rupture are generally more physically active than age-matched controls [131] and may also be more motivated to stay physically active even after the injury.

The mean scores on the FAOS in Study IV were also high; 88-100 in all subscales, which may indicate that there is a ceiling effect on the FAOS a mean of 6 years after the injury.

> **TAKE-HOME MESSAGE:**
> Patient-reported outcome measurements are important tools for improving our knowledge of the patients' experiences after an Achilles tendon rupture. However, it has to be remembered that some questionnaires may have reached a ceiling effect when used many years after the injury. There is a need to further investigate whether the patient-reported outcome measurements that are used today are able to capture the remaining deficits which patients experience in the long term.

The impact of sex on calf muscle recovery

There is conflicting evidence about the impact of sex on calf muscle recovery after an Achilles tendon rupture. The reason for this can be partly explained by the fact that only approximately 20-25% of the injured patients are female [27, 38, 50, 52]. In Study III, with 20% women, the difference in outcome between men and women after an Achilles tendon rupture was evaluated. It was found that men had recovered their heel-rise height to a greater degree than women 12 months after the injury, regardless of the treatment. Leppilahti et al. [86] also showed that women had greater calf muscle weakness, measured as isokinetic strength, compared with men 0.7-6.7 years after the injury, but, on the other hand, Bostick et al. [13] found that women had better calf muscle endurance 1 year after an Achilles tendon rupture. Being able to perform a single-leg standing heel-rise 3 months after an Achilles tendon rupture has also been found to correlate to being of male sex [120]. The reasons for these differences are not fully known, but it has been suggested that women have decreased collagen synthesis compared with men, as well as a poorer ability to adapt body tendons to loading [94, 105, 177]. It has also been demonstrated that estrogen changes the strain behavior in the Achilles tendon in women [17], as well as having an inhibitory effect on collagen synthesis [105], but the question of whether this is correlated with an increased risk of trauma or poorer tendon healing ability needs to be further explored.

In Study III, it was also found that women who were treated surgically, but not those treated non-surgically, reported a greater degree of symptoms evaluated with the ATRS compared with men at both the 6- and 12-month follow-ups. Further studies are needed to investigate whether and when women should be treated surgically. It has previously been reported that women experience wound complications to a greater extent than men [15] and also have more comorbidities that could predispose them to an Achilles tendon injury [175]. No comorbidities, such as the use of fluoroquinolone antibiotics or systemic steroids, or wound complications were noted in Study III.

> **TAKE-HOME MESSAGE:**
> There is some evidence that women and men react differently when treated with the same treatment protocols. Differences are found in heel-rise height and symptoms between men and women after an Achilles tendon rupture, but they are not consistent. Further studies are needed to conclude whether men and women should be treated with the same treatment protocols and whether the assumed differences remain over time.

The impact of tendon elongation on calf muscle recovery

The fact that tendon elongation occurs after Achilles tendon rupture has been known for decades [115]. Information on how much the tendon elongates during the healing process varies; an elongation of 0.02-4.1 cm has been reported in different studies, measured as the side-to side difference [61, 115, 133, 145, 147, 187]. However, it must be noted that the methods for evaluating tendon elongation are not consistent and tendon elongation is not comparable between different methods. In Study IV, it was shown that the tendon elongated a mean of 2.1 cm, with a range of 1.5-5.9 cm in the injured limb, measured as the side-to side difference. There were no differences between the group treated with surgery and the group treated non-surgically. Moreover, it was shown that the tendon elongation correlated with the side-to-side difference in maximum heel-rise height 6 years after the injury. Silbernagel et al. [145] also reported the correlation between the two variables 6 and 12 months after the injury, while Schepull et al. [138] were unable to find any correlation between tendon elongation and the heel-rise index 18 months after injury. One explanation for these conflicting findings is that different, not comparable, evaluation methods were used in the two studies. Moreover, in most patients, the calf muscle complex slowly rebuilds to match the new biomechanical situation in the ankle and the heel-rise height therefore continues to increase, even if the tendon elongation stays the same. It is also possible that other plantar flexors in the foot, such as the flexor hallucis longus and tibialis posterior, change their recruitment pattern in order better to assist the triceps surae complex in plantar flexion. In Study IV, half the patients already had the greatest side-to-side differences in heel-rise height at the 1-year follow-up and this could possibly be due to greater tendon elongation. A greater degree of tendon elongation has also been found to correlate with a poorer clinical outcome evaluated with a scoring assessment (Leppilahti et al. [84], including both an evaluation of subjective symptoms, as well as objective measurements) 5 years after the injury [61]. Moreover, a relationship has been found between greater side-to-side differences in tendon length and increased activation in the calf muscles, evaluated with electromyography (EMG), during a gait cycle [155].

In Study IV, it was also shown that side-to-side difference in tendon length correlated to side-to-side difference in the kinematic variable of ankle abduction while walking and jogging but not during jumping activities. No correlations were found between tendon elongation and kinetic variables, which was similar to the findings of Agres et al. [2].

TAKE-HOME MESSAGE:

Regardless of treatment with or without surgery, the Achilles tendon elongates during the healing process. Tendon elongation has an impact on heel-rise height during a single-leg standing heel-rise, as well as the activity of the calf muscles. Moreover, kinematic variables are influenced by tendon elongation, while kinetic variables appear to remain unaffected to a greater extent. Minimizing tendon elongation during rehabilitation appears to be of major importance for calf muscle recovery.

The impact of age on calf muscle recovery

After an Achilles tendon rupture, older age has been shown to be a predictor of lower maximum heel-rise height expressed as a 10-year increment in age resulting in an 8% decrease in height [122]. However, increasing age was a low predictor of symptoms [122]. Age has also been found to be a predictor in relation to a subjective assessment of symptoms, together with ankle range of motion and isokinetic ankle strength evaluated 3 years after the injury [84]. Moreover, it has been suggested that increasing age, but also disuse, influence reductions in tendon stiffness in healthy tendons, even if this decrease can be counteracted to some extent by resistance exercises [95]. Even at older ages (over 66 years), it appears that strength training can prevent tendon stiffness decreasing [129]. A recent study concluded that, after 45 years of age, a decrease in muscle strength and calf muscle mass occurs due to normal aging [80]. The median age in Study I was 48.5 years and 68% were 45 or older, while, in Study IV, the median age was 46 years and 53% of the patients were 45 or older. This may explain some of the remaining deficits in calf muscle recovery demonstrated in these long-term follow-ups. In Study IV, it was shown that the patients with the greatest side-to-side differences in heel-rise height at the 1-year follow-up were a mean of 16 years older than the group with the smallest side-to-side differences in terms of heel-rise height. This was not known when the study was designed, but it may explain the poorer heel-rise height in this group already at the 1-year follow-up.

TAKE-HOME MESSAGE:

Older age appears to be related to reduced calf muscle recovery, but individual differences are common. The reasons for the deficits in calf muscle recovery in older subjects are not fully known, but they could be linked to the decrease in the ability for tendon remodeling due to normal aging. However, it has to be remembered that, if small positive changes occur in long-term follow-ups, this might be of significance, since the patients are getting older.

The impact of calf muscle recovery on walking, jogging and jumping

Our knowledge of the way calf muscle recovery after an Achilles tendon rupture affects the movement pattern and the joint loads in the lower limbs is limited. Deficits in the eccentric strength of the calf muscles have been found to be related to changes in gait pattern 2 years after an Achilles tendon rupture [32]. In Study IV, a significant negative correlation was found between side-to-side differences in terms of calf muscle endurance and side-to-side differences in eccentric plantar flexion power during walking. It has also been suggested that patients with an Achilles tendon rupture present changes in ankle biomechanics during walking compared with healthy controls [157]. A case study evaluating running biomechanics before and 1 year after an Achilles tendon rupture showed changes in kinematics in the injured ankle [147] in terms of greater ankle dorsiflexion, eversion and rear foot abduction. Moreover, the patients in Study IV also demonstrated decreased ankle joint kinetics, together with increased knee joint kinetics in the injured limb during jogging and hopping [181]. One clinical impact of this knowledge may be that, after an Achilles tendon rupture, patients compensate, without being aware of it, by overloading the knee in their injured limb and the ankle in the healthy limb and will therefore run a greater risk of other injuries. In Study IV, it was shown that a > 30% decrease in heel-rise height compared with the healthy limb 1 year after an Achilles tendon rupture led to greater deficits in ankle kinetics during walking, jogging and jumping than if the deficit in heel-rise height at 1 year was < 15%. This difference was most evident during jumps, particularly hopping. During hopping, the mechanical work performed by the calf muscles is twice that during counter-movement jumps [36]. Additionally, during bilateral hopping, an injured tendon has shown higher stretching amplitudes, but lower stiffness and peak Achilles force values compared with a healthy tendon [119]. One clinical implication of these results may be that, for patients returning to sports that include jumping activities, it appears to be crucial to regain heel-rise height in the injured limb within the first year. Satisfactory ankle function is required during more demanding activities, since the biomechanical asymmetries in the lower leg appear to increase during running and jumping but not to the same extent during walking. The differences in ankle biomechanics between the two groups in Study IV were only present for kinetic variables but not for kinematic variables. The reason for this is not fully understood, but one suggestion is that clinical gait analyses may not be sensitive enough to detect the kinematic diversities in patients with an Achilles tendon rupture. Taken together, in order to avoid new injuries, it appears to be important to include evaluations and exercises not only for the injured foot and ankle but also for other muscles in the lower limb and trunk.

TAKE-HOME MESSAGE:

Deficits in heel-rise height after an Achilles tendon rupture appear to influence ankle biomechanics during walking, jogging and jumping. The impact appears to be greatest during jumping tasks, particularly during hopping. The early recovery of heel-rise height is expected to be of great importance for the restoration of ankle biomechanics during demanding activities.

Predictors of function and symptoms

There is no support in the literature for the hypothesis that either surgical or non-surgical treatment is a predictor of calf muscle recovery in the long term. Patients with an Achilles tendon rupture exhibit a wide range of residual deficits in calf muscle recovery of differing severity. Additionally, the way each patient experiences these deficits is very individual. It may therefore be difficult to recognize the important predictors of reduced calf muscle function and increased symptoms in the individual patient. However, it has been shown that high-level physical function and favorable calf muscle endurance at 6 months after the injury are predictors of upgraded calf muscle endurance 1 year after the injury [13]. As mentioned earlier, increasing age is a strong predictor of reduced heel-rise height in the injured leg and a high BMI is a strong predictor of more symptoms [122]. The results in Study IV give reasons to believe that high side-to-side differences in heel-rise height 1 year after the injury can lead to a greater degree of deficits in ankle biomechanics during demanding activities in the long term, but older age may also be a reason for lower heel-rise height.

TAKE-HOME MESSAGE:

The early recovery of calf muscle endurance and an early high physical function level, together with younger age, are strong predictors of good calf muscle recovery, while a high BMI is a predictor of more symptoms after an Achilles tendon rupture.

Return to sports after an Achilles tendon rupture

For most patients, the goal of rehabilitation is to be able to return to sports to some extent. Historically, the criterion for returning to sports has been the time that has passed since the injury [186]. Since no consideration is taken of individual differences in calf muscle recovery, this is not an appropriate criterion in the clinical setting. It has been reported that approximately 20% of the patients with an Achilles tendon rupture are unable to return to their previous level of physical activity [186]. For professional athletes, returning to sports as soon as possible may be considered to be even more important. Trofa et al. [163] showed that athletes had a decreased performance level 1 year after their Achilles tendon rupture but not 2 years after their injury. There is also a need to explore the criteria that should apply to a return to sports. Saxena et al. [136] suggested that patients who had undergone surgery for different Achilles tendon disorders (including acute Achilles tendon rupture) should be able to perform 5 x 25 single-leg standing heel-rises and have side-to-side symmetry of calf circumference and ankle range of motion before returning to physical activity. The patients who were unable to meet all three criteria also experienced a delay in returning to physical activity and, for the 27 patients with an Achilles tendon rupture, the time before returning to physical activity was 21.8 ± 4 weeks. An often-used criterion for a safe return to sports is the LSI ≥ 85% limit, indicating that the injured side has reached ≥ 85% of the value in the functional variable compared with the healthy side [121, 161]. A test battery containing different tests of lower leg function has been used in several studies to evaluate patients with Achilles tendon disorders [111, 121, 123, 142] and a modified version of this test battery was used in Study I. As mentioned earlier, it may be impossible for patients with an Achilles tendon rupture to reach the LSI limit of ≥ 85% in heel-rise height due to tendon elongation. In Study I, only 6% of the patients were able to reach the LSI ≥ 85% limit in all calf muscle performance tests. On the other hand, it is not known whether this limit is appropriate for a safe return to sports in patients with an Achilles tendon rupture. Moreover, reduced values for ankle kinetics in the injured limb were found in Study IV and elevated values for knee joint kinetics in the healthy limb after an Achilles tendon rupture have also been discovered a mean of 6 years after the injury [181]. Further research is needed to explore the impact these findings should have on future rehabilitation programs and evaluations after an Achilles tendon rupture. It is very likely that the criteria for returning to sports need to be individualized, since the demands for calf muscle recovery differ tremendously between different sports, as well as different age groups. In this thesis, the mean age was between 40 and 50 years, indicating that the majority of the patients were not aiming to return to highly demanding activities. On the other hand, the median scores on the PAS in the long-term follow-ups were fairly high; 4 on a six-level scale, which means "Moderate exercise 1-2 hours a week, e.g. jogging, swimming, gymnastics, heavy gardening, home repairs or easy physical activities more than 4 hours a week". In Study II (3-month follow-up) the median score on the PAS was 3. One explanation of the somewhat high PAS scores could be that patients adapt to the new circumstances in calf muscle function and return to physical activity in an adjusted form. It may also be that patients return to sports, even if their calf muscle function is not completely restored and this may lead to other injuries in the long run.

TAKE-HOME MESSAGE:

There is a need for individualized criteria for returning safely to sports after an Achilles tendon rupture, together with an understanding that other joints, apart from the ankle joint, may bear an increasing load to compensate for the decreased load on the injured ankle. The impact of permanent deficits in calf muscle recovery in the long term needs to be further explored.

09

LIMITATIONS

Study I

Eighteen patients from the original cohort of 84 patients (79%) were not evaluated in this long-term follow-up for different reasons (1 deceased, 4 declined to attend, 2 living abroad, 7 missed their appointments, 4 could not be reached). The results at the 1-year follow-up were therefore compared between the included patients and the missing patients in terms of age, weight, height, calf muscle recovery measured with a single-leg standing heel-rise test, the ATRS, PAS, sex, initial treatment and the side of injury. No differences were found between the two groups, apart from the fact that the missing patients were significantly younger (38 versus 44 years respectively). Moreover, in Study I, the one-leg hop for distance was used to evaluate hop performance in the test battery instead of the drop counter-movement jump and the hopping that was used at the 1- and 2-year follow-ups. It was assumed that the one-leg hop for distance would better mirror the situations experienced in daily life, such as jumping ashore from a boat, compared with hopping and the drop counter-movement jump.

Even if it was concluded that very few (6%) of the patients reached the limit of LSI values of ≥ 85% in all calf muscle function tests 7 years after the Achilles tendon rupture, the extent to which these deficits have an impact on the patients' risk of overload injuries when returning to physical activity is not known.

The question of whether new and individualized treatment protocols for patients with Achilles tendon ruptures can improve calf muscle recovery in the long term needs to be explored.

Study II

When designing the standardized seated heel-rises, it was postulated that a load of 50% of body weight placed just posterior to the patients' knee joints would be a proper challenge without putting the injured Achilles tendon at risk. Moreover, a limit of a maximum of 100 repetitions was set in order to avoid any increased risk of re-injury. It was found that 23% of the patients actually managed to reach the limit of 100 repetitions on the injured leg and 74% of the patients crossed the limit in their healthy leg. There is therefore reason to believe that the LSI value in the standardized seated heel-rises would probably have been lower if the limit of 100 repetitions had not been set. Moreover, it is not known whether a load of 50% of body weight is the optimal load during the performance of standardized seated heel-rises 3 months after an Achilles tendon rupture. The standardized seated heel-rises were shown to be reliable, with an ICC value of 0.606 in heel-rise height and 0.701 in repetitions in healthy subjects, but this has not been evaluated in patients with an Achilles tendon rupture. A positive predictive value of 91% was found when using a cut-off value of ≤ 20 repetitions as a positive result. It has to be evaluated whether ≤ 20 repetitions with 50% of body weight as a load is the optimal value for repetitions before single-leg standing heel-rises are introduced.

There is also a need for further investigation of the way the different muscles in the calf are recruited during seated heel-rises and the positions that are superior for recruiting the different calf muscles at different stages after an Achilles tendon rupture.

Study III

Data from two randomized, controlled studies were combined in order to increase the power for comparisons between the sexes. Even if significant differences were found between men and women, the cohort of women in Study II was still limited, which affects the ability to draw definitive conclusions. Additionally, the rehabilitation protocols (Appendix) were not exactly identical in the two studies, even if the number of patients who had surgery was equal to the number of patients who were treated non-surgically.

Since the number of women with an Achilles tendon rupture is increasing, future studies need to investigate whether the differences in outcome after an Achilles tendon rupture should lead to different treatment protocols for men and women.

Study IV

The two groups in Study IV were created according to the LSI heel-rise height the patients achieved at the 1-year follow-up. When analyzing the demographics in the groups, it was found that the patients who had > 30% side-to-side differences in terms of heel-rise height at the 1-year follow-up were a mean of 16 years older than the patients with <15% side-to-side differences in heel-rise height. Despite this, the calf muscle performance in the healthy limb was equal, at both at the 1-year and the 6-year follow-ups and the impact the age difference between the groups had on the biomechanical results in this study is therefore not known. In addition, no comparison with healthy controls was performed in this study. Since the patients in the study came from two different randomized, controlled trials, a risk of biased inclusion due to self-selection may be present. Only patients with > 30% or <15% side-to-side differences in heel-rise height at the 1-year follow-up were, however, asked to participate.

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CONCLUSION

When treated with the currently recommended rehabilitation protocols, deficits in calf muscle recovery persist many years after an Achilles tendon rupture, regardless of the initial treatment, i.e. surgical or non-surgical.

Seven years after the injury, significant losses of calf muscle strength and endurance were found on the injured side, even if the patients reported minor symptoms and had returned to physical activity at a fairly large rate. There was no further improvement in calf muscle recovery, apart from heel-rise height, after the 2-year follow-up.

A standardized seated heel-rise test is a safe tool to use early in the rehabilitation process in patients with an Achilles tendon rupture; both for progress assessment and to predict forthcoming calf muscle performance and patient-reported symptoms.

A significant difference in regaining heel-rise height in the injured limb was found in women compared with men, regardless of surgical or non-surgical treatment, but women treated with surgery reported more symptoms in contrast to men both 6 and 12 months after the injury.

The recovery in heel-rise height in the injured limb at 1 year after the injury is related to the long-term ability to achieve normal ankle biomechanics during different physical activities, mainly demanding activities such as jumping. As tendon elongation and side-to-side differences in heel-rise height correlate, an early goal for the patient with an Achilles tendon rupture is to minimize tendon elongation and maximize heel-rise height during the first year after the injury.

These results could possibly form part of the groundwork for developing more effective, individualized rehabilitation protocols for patients with an Achilles tendon rupture.

11

FUTURE PERSPECTIVES

In order to be able to develop efficient, individualized rehabilitation protocols for patients with an Achilles tendon rupture, there is a need for reliable, valid methods for evaluating all the aspects involved in rehabilitation; lower leg function, mechanical properties, tendon structure, physical activity level, symptoms, participation and environmental factors. These studies, together with additional studies of tendon healing within the field of biomedicine, can give us extended knowledge of how and when the tendon should be loaded in an optimal way for healing.

Moreover, studies with a sufficient sample size, including multi-center studies, are required to give the results enough power to explore whether there are differences between the sexes in terms of tendon healing or reaction in the load response of the tendons. The answers would then have an impact when it comes to deciding whether women should be treated with the same rehabilitation protocols as men after an Achilles tendon injury. A national register for patients with Achilles tendon ruptures might have a large impact on the opportunity to design new studies with the capability of evaluating important predictors of outcome.

There is a discrepancy between the outcome in terms of calf muscle recovery and patient-reported outcome measurements in patients with an Achilles tendon rupture at later stages after the injury. Functional deficits may exist without having any impact on lighter, less demanding activities, but there is also a risk that some individuals will adapt to a lower activity level due to fear of re-injury. It is also possible that the available patient-reported outcome measurements have a lower responsiveness or a ceiling effect after a few years. The further development of patient-reported outcome measurements designed for later stages in the rehabilitation process is therefore needed in order to capture the deficits in calf muscle recovery or fear of re-injury at these stages. Qualitative research may also be a possible way to further explore the patients' experience of an Achilles tendon rupture in the long term.

Ankle biomechanics during different sporting activities after sustaining an Achilles tendon rupture need to be further explored, together with studies of the way the injury affects muscle recruitment in the lower leg, in order to investigate how various deficits influence functional performance. Another important area for investigation is to examine calf muscle performance and lower leg biomechanics after an Achilles tendon rupture at different stages before and after fatigue, in order to explore the calf muscles and see whether the results differ from those of age-matched healthy controls.

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ATRS Swedish [112]

Lundberglaboratoriet för Ortopedisk Forskning

ATRS

(Achilles tendon Total Rupture Score)

Alla frågor avser hur du upplever eventuella besvär på grund av din skadade hälsena

Markera med ett kryss i den ruta som bäst motsvarar din uppfattning!

1. Är du begränsad av minskad kraft i vaden/hälsenan/foten?

mycket begränsad	0	1	2	3	4	5	6	7	8	9	10	**inte alls begränsad**	Poäng

2. Är du begränsad av att du blir trött i vaden/hälsenan/foten?

mycket begränsad	0	1	2	3	4	5	6	7	8	9	10	**inte alls begränsad**	Poäng

3. Är du begränsad av stelhet i vaden/hälsenan/foten?

mycket begränsad	0	1	2	3	4	5	6	7	8	9	10	**inte alls begränsad**	Poäng

4. Är du begränsad av smärta i vaden/hälsenan/foten?

mycket begränsad	0	1	2	3	4	5	6	7	8	9	10	**inte alls begränsad**	Poäng

5. Är du begränsad i ditt dagliga liv?

mycket begränsad	0	1	2	3	4	5	6	7	8	9	10	**inte alls begränsad**	Poäng

Achilles Tendon Rupture Score (ATRS)
Version 6, Katarina Nilsson-Helander 2006-03-07

Lundberglaboratoriet för Ortopedisk Forskning

Alla frågor avser hur du upplever eventuella besvär på grund av din skadade hälsena

Markera med ett kryss i den ruta som bäst motsvarar din uppfattning!

6. Är du begränsad när du går på ojämnt underlag?

mycket begränsad	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	**inte alls begränsad**	Poäng
	0	1	2	3	4	5	6	7	8	9	10		

7. Är du begränsad när du går raskt uppför en trappa/backe?

mycket begränsad	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	**inte alls begränsad**	Poäng
	0	1	2	3	4	5	6	7	8	9	10		

8. Är du begränsad vid aktiviteter som innebär att springa?

mycket begränsad	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	**inte alls begränsad**	Poäng
	0	1	2	3	4	5	6	7	8	9	10		

9. Är du begränsad vid aktiviteter som innebär att hoppa?

mycket begränsad	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	**inte alls begränsad**	Poäng
	0	1	2	3	4	5	6	7	8	9	10		

10. Är du begränsad att utföra hårt fysiskt arbete?

mycket begränsad	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	**inte alls begränsad**	Poäng
	0	1	2	3	4	5	6	7	8	9	10		

Achilles Tendon Rupture Score (ATRS)
Version 6, Katarina Nilsson-Helander 2006-03-07

ATRS English [19]

Achilles tendon Total Rupture Score (ATRS)

Hospital Number: **Date:**

Date of rupture: **Injured Side:**

Date of repair/reconstruction:

Please rate your current limitations; 0 is no limitation, 10 is severe limitation, circle your answer to the following questions.

1. Are you limited due to decreased strength in the calf/Achilles tendon/foot?

0 1 2 3 4 5 6 7 8 9 10

2. Are you limited due to progressive tiredness in the calf/Achilles tendon/foot?

0 1 2 3 4 5 6 7 8 9 10

3. Are you limited due to stiffness in the calf/Achilles tendon/foot?

0 1 2 3 4 5 6 7 8 9 10

4. Are you limited due to pain in the calf/Achilles tendon/foot?

0 1 2 3 4 5 6 7 8 9 10

5. Are you limited during activities of daily living?

0 1 2 3 4 5 6 7 8 9 10

6. Are you limited when walking on uneven ground?

0 1 2 3 4 5 6 7 8 9 10

7. Are you limited when walking quickly up stairs or up a hill?

0 1 2 3 4 5 6 7 8 9 10

8. Are you limited during activities that include running?

0 1 2 3 4 5 6 7 8 9 10

9. Are you limited during activities that include jumping?

0 1 2 3 4 5 6 7 8 9 10

10. Are you limited in performing heavy physical work?

0 1 2 3 4 5 6 7 8 9 10

PAS Swedish [42, 134]

ndberglaboratoriet för Ortopedisk Forskning
Laboratoriet för muskelfunktion och rörelseanalys

Ringa in det alternativ som bäst överensstämmer med din nivå just nu.

Fysisk aktivitetsnivå JUST NU

Ta hänsyn till vad du arbetar med, samt din fritid, motion och idrott

1 **Knappast någon fysisk aktivitet alls.**

2 **Mest stillasittande, ibland promenad, lättare trädgårdsarbete, eller liknande.**

3 **Lättare fysisk ansträngning omkring 2-4 timmar per vecka, t.ex. promenader, cykling, dans, ordinärt trädgårdsarbete, eller liknande.**

4 **Mer ansträngande motion 1-2 timmar per vecka t.ex. tennis, simning, löpning, motionsgymnastik, cykling (spinning), dans, fotboll, innebandy, tyngre trädgårdsarbete, byggarbete, eller liknande**
***ELLER* lättare fysisk aktivitet (enligt nivå 3) mer än 4 timmar per vecka**

5 **Mer ansträngande motion minst 3 timmar per vecka t.ex. tennis, simning, löpning, motionsgymnastik, cykling (spinning), dans, fotboll, innebandy, tyngre trädgårdsarbete, byggarbete, eller liknande**

6 **Hård träning regelbundet och flera gånger i veckan, där den fysiska ansträngningen är stor**

PAS English

1	Hardly any physical activity
2	Mostly sitting, sometimes a walk, easy gardening or similar tasks
3	Light physical exercise around 2-4 hours a week, e.g. walks, fishing, dancing, normal gardening, including walks to and from shops
4	Moderate exercise 1-2 hours a week, e.g. jogging, swimming, gymnastics, heavy gardening, home repairs or easy physical activities more than 4 hours a week
5	Moderate exercise at least 3 hours a week, e.g. tennis, swimming, jogging etc.
6	Hard or very hard exercise regularly and several times a week, where the physical exertion is great, e.g. jogging, skiing

FAOS [132]

FAOS
Frågeformulär för patienter med fot- och fotledsbesvär

DATUM: ________________ PERSONNUMMER: _________________

NAMN: ____

INSTRUKTIONER: Detta formulär innehåller frågor om hur Du ser på din fot / fotled. Informationen ska hjälpa till att följa hur Du mår och fungerar i ditt dagliga liv. Besvara frågorna genom att kryssa för det alternativ Du tycker stämmer bäst in på dig (ett alternativ för varje fråga). Om Du är osäker, kryssa ändå för det alternativ som känns riktigast.

Symptom
Tänk på de **symptom** Du haft från din fot / fotled under den **senaste veckan** när Du besvarar dessa frågor.

S1. Har foten / fotleden varit svullen?

Aldrig	Sällan	Ibland	Ofta	Alltid
☐	☐	☐	☐	☐

S2. Har Du känt att det maler i foten / fotleden eller hör Du klickande eller andra ljud från foten / fotleden?

Aldrig	Sällan	Ibland	Ofta	Alltid
☐	☐	☐	☐	☐

S3. Har foten / fotleden hakat upp sig eller låst sig?

Aldrig	Sällan	Ibland	Ofta	Alltid
☐	☐	☐	☐	☐

S4. Har Du kunnat sträcka vristen / fotleden helt?

Alltid	Ofta	Ibland	Sällan	Aldrig
☐	☐	☐	☐	☐

S5. Har Du kunnat böja vristen / fotleden helt?

Alltid	Ofta	Ibland	Sällan	Aldrig
☐	☐	☐	☐	☐

Stelhet
Följande frågor rör **stelhet**. Stelhet innebär svårighet att komma igång eller ökat motstånd. Markera graden av stelhet Du har upplevt i din fot / fotled den **senaste veckan**.

S6. Hur stel har din fot / fotled varit när Du just har vaknat på morgonen?

Inte alls	Något	Måttligt	Mycket	Extremt
☐	☐	☐	☐	☐

S7. Hur stelt har din fot / fotled varit efter att Du har suttit eller legat och vilat **senare under dagen**?

Inte alls	Något	Måttligt	Mycket	Extremt
☐	☐	☐	☐	☐

Smärta

P1. Hur ofta har Du ont i foten / fotleden?

Aldrig	Varje månad	Varje vecka	Varje dag	Alltid
☐	☐	☐	☐	☐

Vilken grad av smärta har Du känt i din fot / fotled den **senaste veckan** under följande aktiviteter?

P2. Snurra/vrida på belastad fot

Ingen	Lätt	Måttlig	Svår	Mycket svår
☐	☐	☐	☐	☐

P3. Sträcka vristen / fotleden helt

Ingen	Lätt	Måttlig	Svår	Mycket svår
☐	☐	☐	☐	☐

P4. Böja vristen / fotleden helt

Ingen	Lätt	Måttlig	Svår	Mycket svår
☐	☐	☐	☐	☐

P5.Gå på jämnt underlag

Ingen	Lätt	Måttlig	Svår	Mycket svår
☐	☐	☐	☐	☐

P6. Gå upp eller ner för trappor

Ingen	Lätt	Måttlig	Svår	Mycket svår
☐	☐	☐	☐	☐

P7. Under natten i sängläge (smärta som stör sömnen)

Ingen	Lätt	Måttlig	Svår	Mycket svår
☐	☐	☐	☐	☐

P8. Sittande eller liggande

Ingen	Lätt	Måttlig	Svår	Mycket svår
☐	☐	☐	☐	☐

P9. Stående

Ingen	Lätt	Måttlig	Svår	Mycket svår
☐	☐	☐	☐	☐

Funktion, dagliga livet

Följande frågor rör Din fysiska förmåga. **Ange graden av svårighet Du upplevt den senaste veckan vid följande aktiviteter på grund av dina fot / fotledsbesvär.**

A1. Gå nerför trappor

Ingen	Lätt	Måttlig	Stor	Mycket stor
☐	☐	☐	☐	☐

A2. Gå uppför trappor

Ingen	Lätt	Måttlig	Stor	Mycket stor
☐	☐	☐	☐	☐

A3. Resa dig upp från sittande

Ingen	Lätt	Måttlig	Stor	Mycket stor
☐	☐	☐	☐	☐

Ange graden av **svårighet** Du upplevt med varje aktivitet den **senaste veckan**.

A4. Stå stilla

Ingen	Lätt	Måttlig	Stor	Mycket stor
☐	☐	☐	☐	☐

A5. Böja Dig, t ex för att plocka upp ett föremål från golvet

Ingen	Lätt	Måttlig	Stor	Mycket stor
☐	☐	☐	☐	☐

A6. Gå på jämnt underlag

Ingen	Lätt	Måttlig	Stor	Mycket stor
☐	☐	☐	☐	☐

A7. Stiga i/ur bil

Ingen	Lätt	Måttlig	Stor	Mycket stor
☐	☐	☐	☐	☐

A8. Handla/göra inköp

Ingen	Lätt	Måttlig	Stor	Mycket stor
☐	☐	☐	☐	☐

A9. Ta på strumpor

Ingen	Lätt	Måttlig	Stor	Mycket stor
☐	☐	☐	☐	☐

A10. Stiga ur sängen

Ingen	Lätt	Måttlig	Stor	Mycket stor
☐	☐	☐	☐	☐

A11. Ta av strumpor

Ingen	Lätt	Måttlig	Stor	Mycket stor
☐	☐	☐	☐	☐

A12. Ligga i sängen (vända dig, hålla foten i samma läge under lång tid)

Ingen	Lätt	Måttlig	Stor	Mycket stor
☐	☐	☐	☐	☐

A13. Stiga i och ur badkar/dusch

Ingen	Lätt	Måttlig	Stor	Mycket stor
☐	☐	☐	☐	☐

A14. Sitta

Ingen	Lätt	Måttlig	Stor	Mycket stor
☐	☐	☐	☐	☐

A15. Sätta dig och resa dig från toalettstol

Ingen	Lätt	Måttlig	Stor	Mycket stor
☐	☐	☐	☐	☐

A16. Utföra tungt hushållsarbete (snöskottning, golvtvätt, dammsugning etc)

Ingen	Lätt	Måttlig	Stor	Mycket stor
☐	☐	☐	☐	☐

A17. Utföra lätt hushållsarbete (matlagning, damning etc)

Ingen	Lätt	Måttlig	Stor	Mycket stor
☐	☐	☐	☐	☐

Funktion, fritid och idrott

Följande frågor rör Din fysiska förmåga. **Ange graden av svårighet Du upplevt den senaste veckan vid följande aktiviteter på grund av dina fot / fotledsbesvär.**

SP1. Sitta på huk

Ingen	Lätt	Måttlig	Stor	Mycket stor
☐	☐	☐	☐	☐

SP2. Springa

Ingen	Lätt	Måttlig	Stor	Mycket stor
☐	☐	☐	☐	☐

SP3. Hoppa

Ingen	Lätt	Måttlig	Stor	Mycket stor
☐	☐	☐	☐	☐

SP4. Vrida/snurra på belastad fot / fotled

Ingen	Lätt	Måttlig	Stor	Mycket stor
☐	☐	☐	☐	☐

SP5.Ligga på knä

Ingen	Lätt	Måttlig	Stor	Mycket stor
☐	☐	☐	☐	☐

Livskvalité

Q1. Hur ofta gör sig Din fot / fotled påmind?

Aldrig	Varje månad	Varje vecka	Varje dag	Alltid
☐	☐	☐	☐	☐

Q2. Har Du förändrat Ditt sätt att leva för att undvika att påfresta foten / fotleden?

Inte alls	Något	Måttligt	I stor utsträckning	Totalt
☐	☐	☐	☐	☐

Q3. I hur stor utsträckning kan Du lita på Din fot / fotled?

Helt och hållet	I stor utsträckning	Måttligt	Till viss del	Inte alls
☐	☐	☐	☐	☐

Q4. Hur stora problem har Du med foten / fotleden generellt sett?

Inga	Små	Måttliga	Stora	Mycket stora
☐	☐	☐	☐	☐

Tack för att Du tagit dig tid att besvara samtliga frågor!

Frågeformulär och användarguide kan hämtas från: www.koos.nu

Rehabilitation protocol used for patients in Study I, III and IV [111]

Rehabilitation Protocol

Weeks 8-11

Treatment: Shoe with a heel-lift (1.5 cm), crutches as needed for another 1-3 weeks

Exercise program: Visit to physical therapist 2-3 times/wk and home exercises daily

Exercise bike
Ankle range of motion
Sitting heel-rise
Standing heel-rise (2 legs)
Gait training
Balance exercises
Leg press
Leg extension and leg curl

Weeks 11-16

Treatment: Shoe with a heel-lift (1.5 cm) until week 16

Exercise program: Visit to physical therapist 2-3 times/wk and home exercises daily

Exercises as above with increased weight
Standing heel-rise increase to hold at end range of plantar flexion on 1 leg
Step
Walking on mattress

Weeks 16-20

Exercise program: Visit to physical therapist 2-3 times/wk and home exercises

Exercises as above with increase in weights and intensity as tolerated
Slide
Quick rebounding heel-rises

From week 18

Heel-rise in stairs
Side jumps
2-legged jumps

Week 20-24

Exercise program: Visit to physical therapist as needed

Exercises as above with increase in weights and intensity as tolerated
Jog
Side jumps forward

Week 24 and onward

Exercise program: Continued physical therapy if needed

Start group exercise class (similar to aerobics)
Gradual return to sports (dependent on patient ability)

Rehabilitation protocol for patients used in Study II, III and IV [123]

TREATMENT PROTOCOL – ACHILLES TENDON RUPTURE SURGICALLY TREATED

Week 0-2: Visit orthopaedic surgeon
Treatment: Walker brace with 3 heel pads, 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 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 pads (take off the upper pad), full weight-bearing, use of 2 crutches if needed. Allowed to take off the walker brace for washing and aerating the foot. When the walker brace is removed, no weight-bearing or dorsal extension 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 pad (take off the upper pad), 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 pad, 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

TREATMENT PROTOCOL – ACHILLES TENDON RUPTURE SURGICALLY TREATED

After 6 weeks: Visit orthopaedic surgeon
Treatment: Wean off walker brace. Use of shoes with heel-lift (bilateral) for 4 weeks, compression stocking to prevent swelling.
Exercise program: ***Important that all exercises are performed slowly and carefully***
Home exercises:

- Active ankle exercises for ROM, ankle exercises (DE, 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, compression stocking 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 Lundberg Lab
Treatment: Use of regular shoes after 10 weeks, barefoot after 12 weeks, compression stocking 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 Lundberg 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 Lundberg 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 pads, 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 aerating the foot. When the walker brace is removed, no weight-bearing or dorsal extension of the foot is allowed. Wearing the walker brace while sleeping.

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

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After 2 weeks:

Treatment: Walker brace with 2 heel pads (take off the upper pad), 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 pad, full weight-bearing

Exercise program: home exercises daily as described above

After 6 weeks:
Treatment: Walker brace without heel pad, 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), compression stocking to prevent swelling.

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

Home exercises:
- Active ankle exercises for ROM, ankle exercises (DE, 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

TREATMENT PROTOCOL – ACHILLES TENDON RUPTURE NON-SURGICALLY TREATED

After 10 weeks:

Treatment: Use of shoes with heel-lift until 14 weeks after injury, compression stocking 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 - transcend 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 Lundberg Lab

Treatment: Use of shoes with heel-lift until 14 weeks after injury, compression stocking 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, compression stocking 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
- Start with gentle jog (thick mattress, in 8´s, zig-zag)
- Start with two-legged jumps and increase gradually

After 18 weeks: Evaluation at Lundberg 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.

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