ACUTE ACHILLES TENDON RUPTURE:

THE IMPACT OF PHYSIOLOGICAL AND PSYCHOLOGICAL FACTORS ON FUNCTION AND RETURN TO ACTIVITY

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Acute Achilles tendon rupture: The impact of physiological and psychological factors on function and return to activity

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“Student: Dr. Einstein, aren’t these the same questions as last year’s final exam?

Dr. Einstein: Yes; but this year the answers are different.”

ALBERT EINSTEIN

ABSTRACT

Unfortunately, there is no guarantee of a full return to physical activity after an Achilles tendon rupture. About 20% of those who sustain the injury do not return to their previous level of physical activity. Although the reasons for this have been examined, no definitive conclusion has been reached. The main aim of this thesis was to gain knowledge of what can cause an incomplete recovery, which might negatively influence the return to physical activity. In this thesis, we try to identify interventions to eliminate the causes of incomplete recovery after an Achilles tendon rupture.

In **Study I** foot structure was evaluated. We compared the uninjured and the injured sides 6 years after an Achilles tendon rupture. Two treatment groups (surgical and non-surgical) were also compared. Lower values for navicular drop and drift were found in the foot structure of the injured side in all participants, meaning that the translation of the navicular bone was less on the injured side compared with the uninjured side. The foot structure values (longitudinal arch angle and navicular drop and drift) were lower on the uninjured side in the surgically treated group compared with the non-surgical group, while there were no differences between the groups on the injured side.

The effect of fatigue on the kinetics of the lower extremities was evaluated in **Study II**, two years after an Achilles tendon rupture. The peak power values of the ankle, knee and hip during landing and push-off for a drop countermovement jump were used for evaluation before and after a fatigue protocol. The results showed greater effect on the ankle joint after the fatigue protocol on the uninjured side compared with the injured side. However, there were no differences before and after the fatigue protocol in the knee and hip joints.

In **Study III,** the impact of fear of reinjury on the kinetics in the lower extremities during a drop countermovement jump was evaluated 2 years after an Achilles tendon rupture. The participants were divided into two groups (Fear group and No-Fear group) depending on their answer to the question: "*Do you ever refrain from any activity due to fear of reinjuring your Achilles tendon?*". The peak power values of the ankle, knee and hip joints during a drop countermovement jump were compared between the two groups. The results demonstrated increased asymmetry of the lower leg kinetics in the injured side in the Fear group, with less power in the ankle joint and increased compensatory power in the knee joint compared with the injured side in the No-Fear group.

A qualitative content analysis was performed in **Study IV**, aimed at identifying factors that affect return to activity after an Achilles tendon rupture. Twenty participants were interviewed 4-6 years after an Achilles tendon rupture. The interviews were analysed and coded in order to categorize factors that collectively determine the thread/theme of the interviews. The overarching theme of the study was "Help me and then I can fix this". This theme can be interpreted to the prerequisite that if the support one needs is in order, one can handle the next step.

In summary, it is obvious that various physiological and psychological factors affect the return to activity. However, none of the factors examined in this thesis pointed the way towards a clear strategy. The effect of these factors appears to vary between individuals. It can thus be concluded that individualized treatment and rehabilitation are important, with frequent updates and evaluation of progress.

Keywords: Achilles tendon rupture; Return to activity; Biomechanics; Kinetics; Qualitative study; Rehabilitation.

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SAMMANFATTNING PÅ SVENSKA

Att återhämta sig helt och hållet efter en hälseneruptur kan tyvärr inte garanteras. Omkring 20% (eller fler) av de som skadar sig, återgår inte till sin tidigare fysiska aktivitetsnivå. Orsaken till detta har tidigare studerats utan att någon specifik förklaring kunnat anges. Huvudsyftet med avhandlingen var att fördjupa kunskapen om vad som kan orsaka otillfredsställande återhämtning efter en hälseneruptur.

I **Studie I**, utvärderades fotstruktur och jämfördes mellan skadad och frisk fot 6 år efter akut hälseneruptur. Behandlingsgrupperna (opererad och icke-opererad) jämfördes också. Hos samtliga deltagare uppvisade den skadade foten lägre värden i navicular drop och drift, vilket betyder att os naviculare förflyttades i mindre utsträckning i den skadade foten jämfört med den friska foten. Fotstrukturvärdena (longitudinal arch angle och navicular drop och drift) var lägre i den friska foten i den opererade jämfört med den icke-opererade gruppen. Det var ingen skillnad mellan grupperna vid jämförelse av den skadade foten.

Hur muskulär uttröttning påverkar kinetiken i nedre extremiteten utvärderades i **Studie II**, två år efter akut hälseneruptur. Kraftutvecklingen före och efter uttröttning i fot-, knä- och höftled under landningsfas samt ned-/upphopp (drop countermovement jump) under upphoppsfas från en 20 cm hög låda användes för utvärdering. Resultatet visade en större påverkan i fotleden efter trötthetsprotokollet i det friska jämfört med det skadade benet. Det var ingen skillnad i kraftutveckling före uttröttningen jämfört med efter, varken i knä- eller höftled.

I **Studie III** utvärderades hur rädsla för att skada sig igen påverkade kinetiken i nedre extremiteten, 2 år efter akut hälseneruptur. Deltagarna delades upp i två grupper (”Rädsla” respektive ”Icke Rädsla”) beroende på deras svar på frågan om de någon gång avstod från någon fysisk aktivitet på grund av rädsla för att skada sig igen. Kraftutvecklingen i fot-, knä- och höftled under landningsfas och upphoppsfas vid nedhopp/upphopp (*drop countermovement jump*) från en 20 cm hög låda användes för utvärdering. De maximala värdena i fot-, knä- och höftleder jämfördes mellan grupperna. Resultatet visade att ”Rädsla”- gruppen hade minskad kraftutveckling i fotleden men ökad kraftutveckling i knäleden i sitt skadade ben jämfört med ”Icke Rädsla”-gruppen under hoppet.

Metoden kvalitativ innehållsanalys användes i **Studie IV** med syfte att belysa faktorer som påverkar återgång till fysisk aktivitet efter en akut hälseneruptur. Tjugo deltagare intervjuades 4–6 år efter skadan. Intervjuerna analyserades, kodades och kategoriserades för att kunna sammanställa ett tema utifrån intervjuerna. Temat från analysen var

”Hjälp mig, så kan jag fixa detta”. Temat kan översättas till att om förutsättningar finns för den support som man behöver, då kan man fixa nästa steg själv.

Sammanfattningsvis är det uppenbart att det är flera olika faktorer som påverkar förmågan till återgång till fysisk aktivitetsnivå. Ingen av de faktorer som studerats i denna avhandling är så framträdande att en enkel lösning är i sikte. Faktorerna är både fysiologiska och psykologiska och påverkar inte alla individer på samma sätt. Avhandlingens konklusion är att det är viktigt att anpassa behandling och rehabilitering till varje patient samt att frekvent uppdatera och utvärdera framstegen.

Nyckelord: Hälseneruptur; Återgång till aktivitet; Biomekanik; Kinetik; Kvalitativ forskning; Rehabilitering.

ÁGRIP Á ÍSLENSKU

Endurkomu til virkni eftir hásinaslit er því miður ekki hægt að ábyrgjast. Um það bil 20% þeirra sem slíta hásin, komast ekki til fyrri virkni á sama stigi og fyrir slys. Ástæður þess hafa verið rannsakaðar, en án ákveðinnar niðurstöðu. Aðalmarkmið þessarar ritgerðar var að auka við þekkingu á hvað getur valdið ófullnægjandi bata eftir hásinaslit, sem gæti haft áhrif á endurkomu til virkni. Í framhaldi af því verður reynt að finna leiðir til að leiðrétta það sem hefur misfarist í bataferlinu.

Í **Rannsókn I**, var staða fótanna metin og borin saman milli sköðuðu og frísku hliðarinnar, 6 árum eftir hásinaslit. Meðferðarhóparnir (aðgerð eða ekki aðgerð) voru einnig bornir saman. Hjá öllum þátttakendunum voru gildi sköðuðu hliðarinnar lægri þar sem navicular fall og færsla voru metin. Það þýðir að hreyfing navicular beinsins var minn á sköðuðu hliðinni borið saman við frísku hliðina. Gildin fyrir stöðu fótarins (iljarboga horn og navicular fall og færsla) voru lægri á frísku hlið hópsins sem var meðhöndlaður með aðgerð borið saman við hópinn sem var ekki gerð aðgerð á. Aftur á móti var enginn munur á milli hópa á sköðuðu hliðinni.

Áhrif þreytu á kraftvægi neðri útlima voru metin 2 árum eftir hásinaslit, í **Rannsókn II**. Hámarks kraftgildi við lendingu og fráspyrnu ökkla, hnjáa og mjaðma, við fallhopp voru metin fyrir og eftir fyrirfram ákveðið þreytuferli. Niðurstöðurnar sýndu meiri áhrif á ökklaliðinn á frísku hliðinni borið saman við hliðina sem skaðaðist. Það var enginn munur á milli hliða í hné- og mjaðmaliðum.

Í **Rannsókn III** voru áhrif hræðslu við endurmeiðsli metin, þar sem kraftvægi neðri útlima var skoðuð, 2 árum eftir hásinslit. Þátttakendum var deilt upp í tvo hópa (þá hræddu og þá óhræddu) byggt á svari þeirra um hræðslu við endurmeiðsli. Hámarks kraftgildi ökkla-, hnjá- og mjaðmaliða voru borin saman milli hópanna. Niðurstöðurnar sýndu fram á aukið ójafnvægi í kraftvægi neðri útlima á sköðuðu hlið þeirra sem hræddir voru um endurmeiðsli. Minni kraftur var í ökklaliðnum og uppbótarkraftur var notaður í hnéliðnum þegar það var borið saman við sköðuðu hlið þeirra sem voru óhræddir við endurslit.

Eigindleg efnisgreining var notuð í **Rannsókn IV** þar sem markmiðið var að greina þætti sem hafa áhrif á endurkomu til virkni eftir hásinaslit. Tuttugu þátttakendur mættu í viðtöl 4-6 árum eftir hásinaslit. Viðtölin voru greind og kóðar voru skapaðir til að flokka þá þætti sem að sameiginlega ákvarða rauðan þráð/þema viðtalanna. Yfirgrípandi þema rannsóknarinnar var "Hjálpið mér og þá get ég hjálpað mér sjálfur/sjálf/sjálft". Þetta þema er hægt að yfirfæra á þann veg að ef suðningurinn sem viðkomandi þarf, er til staðar, þá getur viðkomandi klárað málið sjálfur.

Tekið saman, þá er það ljóst að þeir þættir sem hafa áhrif á endurkomu til virkni

eru mismunandi og enginn þeirra sem skoðaðir voru voru svo afgerandi að auðveld lausn sé í sjónmáli. Þessir þættir eru bæði líkamlegir og andlegir og virðast hafa mismunandi áhrif á einstaklingana. Það er hægt að álykta að það sé mikilvægt að veita hverjum sjúklingi einstaklingsmiðaða meðferð og endurhæfingu, þar sem gerðar eru reglubundnar uppfærslur á endurhæfingaráætlun og ferlið endurmetið.

Lykilorð: Hásinaslit; Endurkoma til virkni; Lífaflfræði; Kraftvægi; Eigindleg rannsókn; Endurhæfing.

LIST OF PAPERS

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

I. Brorsson A, Jónsdóttir US, Nygren D, Larsson N, Tranberg R.
The Injured Limb Presents Lower Values in Foot Structure Measurements 6 Years After an Achilles Tendon Rupture.
Muscles, Ligaments & Tendons Journal (MLTJ). 2021;11(4) DOI: 10.32098/mltj.04.2021.12

II. Jónsdóttir US, Briem K, Grävare Silbernagel K, Tranberg R, Brorsson A.
Dissimilar effect of fatigue on lower limb kinetics during single-leg drop countermovement jump two years after an Achilles tendon rupture.
In manuscript.

III. Jónsdóttir US, Briem K, Tranberg R, Brorsson A.
The effect of fear of reinjury on joint power distribution during a drop countermovement jump two years after an Achilles tendon rupture.
Translational Sports Medicine. 2021;4(5):667-674. DOI: 10.1002/tsm2.261

IV. Jónsdóttir US, Brorsson A, Nilsson Helander K, Tranberg R, Larsson MEH.
Factors That Affect Return to Sports After an Achilles Tendon Rupture: A Qualitative Content Analysis.
Orthopaedic Journal of Sports Medicine. 2023;11(2): DOI:10.1177/23259671221145199

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ABBREVIATIONS

3D	3-dimensional
ACL	Anterior cruciate ligament
ANOVA	Analysis of Variance
AOFAS	American Orthopaedic Foot and Ankle Society
ATR	Achilles tendon rupture
ATRA	Achilles tendon resting angle
ATRS	Achilles tendon Total Rupture Score
BMI	Body mass index
CMJ	Countermovement jump
GRF	Ground reaction force
Hz	Hertz (1/s)
ICC	Intraclass correlation coefficient
IPDAS	International Patient Decision Aid Standards
J	Joule = Newton*meter
Kg	Kilogram
LSI	Limb symmetry index = (injured side/healthy side) *100
m	Meter
Max	Maximum
mm	Millimeter
Min	Minimum
MRI	Magnetic resonance imaging
N	Newton
n	Number of participants
p	p-value, probability
PAS	Physical activity scale
PFPS	Patellofemoral pain syndrome
PHQ-9	The Patient Health Questionnaire 9
PROM	Patient reported outcome measure
PTOA	Post-traumatic osteoarthritis
RCT	Randomized controlled trial
ROM	Range of Motion
RTS	Return to Sports
s	Seconds
sEMG	Surface electromyography
SD	Standard deviation
SIBAS	Swedish Icelandic Biomechanical Achilles tendon Study
SMART	The Swansea Morriston Achilles Rupture Treatment
TSK	Tampa Scale of Kinesiophobia
W	Watt = Joules/second

DEFINITIONS IN SHORT

Biomechanics	Measurements of the movements of the living body.
Body mass index (BMI)	An index calculating body size using weight (kg) and height (m) as reference. *BMI=kg/m*^{2}
Borg scale	A rating of intensity level during activity.
Categories	A concept that represents a group of codes. Categories are then grouped into an overarching theme.
Codes	The label of a meaning unit found in a transcribed text. Recurring similar codes are grouped into categories.
Force (N)	The push or a pull of an object that results in a movement of another object. Expressed in Newtons *N=Mass (kg)*acceleration (meter/seconds*^{2}*)*
Gravity	The earth's pull on every object on its surface. *9.81 N/kg*
Ground reaction force	Every weight placed on the ground results in a reaction force from the ground.
Kinematic	The study of the geometry of body segments
Kinetic	The study of the forces causing the movement of body segments.
Limb symmetry index (LSI)	An index presenting the difference between opposite limbs. *LSI= (injured limb/uninjured limb) *100*
Meaning unit	A word, phrase or a sentence that represents a specific phenomenon. A meaning unit is given a name by the researcher and then be referred to as a code.
p-value	A measurement of the likelihood that an observed difference between two groups is due to chance. The p stands for probability.
Pes cavus (high arch foot)	A deformity of the foot, where the longitudinal arch is abnormally high.
Pes planus (flat foot)	A deformity of the foot where the longitudinal arch is abnormally low.
Power (Watt, W)	Any rate of generated or consumed energy *W=Work (joules)/time (s)*
Reliability	Evaluation of how reliably a method measures what it is supposed to measure.
Tendon elongation	Difference in length between a healthy tendon and one that is healed after rupture.
Theme	An overarching concept that collectively represents a group of categories.
Validity	How results represent a true finding and are representative of the study population.
Work (J)	The result of the force and distance through which the body moves presented *in Joules(J). J=Force (N)*distance (m)*

CHAPTER 1

INTRODUCTION

INTRODUCTION

The Achilles tendon is one of the strongest and largest tendons in the human body, so large that Hippocrates named it "tendo magnus" [9,78,91]. The name has been used to indicate the point of vulnerability, as in the story of the god Achilles by the Greek poet Homer (Figure 1) [78]. Achilles was a warrior, whose mother dipped him into the river Styx to make him invulnerable, but held him by the heel (to prevent him from drowning) and therefore the heel was the only part of his body that was vulnerable to injury [40,78]. The end of this story is well known and Achilles was killed in the Trojan war when his opponent Paris shot a poisoned arrow into his heel [40,74].

The Achilles tendon is crucial for running and jumping in bipedal man, but does not exist in our close ancestor, the great ape [78].

Even in the time of Hippocrates, it was recognised that an Achilles tendon rupture had a major influence on patients' lives. Hippocrates wrote "This tendon, if bruised or cut, causes the most acute fevers, induces choking, deranges the mind and at length brings death" [24]. In more recent days, an article published in 1929 by two French surgeons, Qenu and Stoianovitch, described the results of both surgical and non-surgical treatments, and even then, the difference in terms of outcome was inconclusive [78].

Today, the prognosis after an Achilles tendon rupture is not as dramatically bad as in the time of Hippocrates and can in fact be considered quite good. Nevertheless, there are still several factors that need to be studied and resolved more fully, which will be attempted in this thesis.

FIGURE 1: The Greek God Achilles.

ANATOMY

The inserts of the Achilles tendon are on the middle part of the posterior surface of the calcaneus from the calf muscles, that are termed the triceps surae [74,116]. The triceps surae is the name of the conjoint junction of the gastrocnemius medialis, gastrocnemius lateralis and soleus muscles. Combined with the plantaris muscle, they form the posterior compartment of the lower leg known as the common calf muscle (Figure 2) [74,116].

The gastrocnemius muscles, medial and lateral heads, stretch over the knee and their insertions are proximal on the medial and the lateral condyles of the femur, respectively [116]. The soleus muscle insert is on the dorsal aspect of the fibula. These three muscles form the Achilles tendon and insert on the calcaneal bone [74,116]. The proximal part of the Achilles tendon is rounder, while it becomes flatter closer to the insertion on the calcaneus bone [91]. As the tendon flattens out, it rotates approximately 90° and medially located fibres at proximal level will be in a posterior position at the insertion (Figure 2) [40,91].

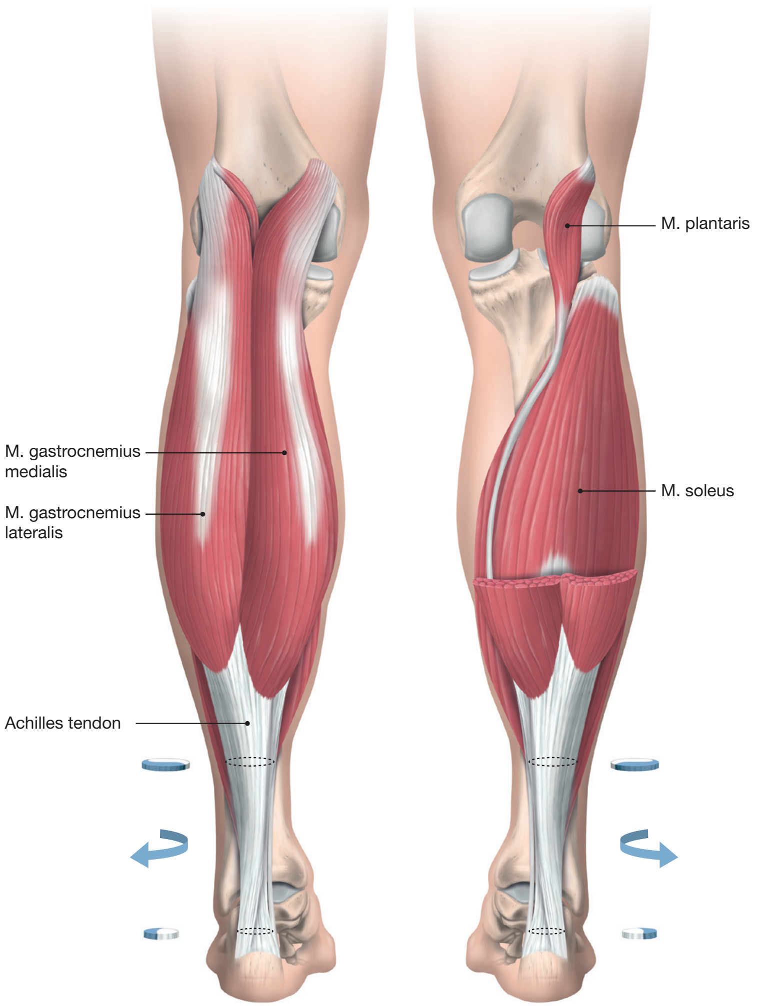

FIGURE 2: Triceps surae, the Achilles tendon and its rotation.

In a study of 22 cadavers (14 men and 8 women), it was found that the average length of the Achilles tendon is 18.2 cm (range 14.0-24.5 cm) with a mean width at the calcaneal insertion of 3.4 cm (range 2.0-4.8 cm) and the narrowest part being 1.8 cm (range 1.2-2.6 cm) at approximately 3-4 cm from the calcaneal insertion [6].

The Achilles tendon is constructed microscopically from collagen fibrils and macroscopically as the tendon (Figure 3). A large number of collagen fibrils collectively form the collagen fibres that become the primary fibre bundle (also called the subfascicle). Many primary fibre bundles form the secondary fibre bundle, or the fascicle, which combine to form the tertiary fibre bundle. Taken together, these parts constitute the strongest tendon in the human body, the Achilles tendon [73,105]. The tendon's dry weight mainly consists of collagen type I (65-80%) but also elastin (1-2%), collagen type III (0-10%), collagen type IV (about 2%) and various proteins (approximately 4.5%) [77]. When the tendon is injured, the ratio of collagen type III increases [77]. The Achilles tendon is covered by a paratenon, which is not attached to the tendon, and surrounded by fluid that prevents friction [105].

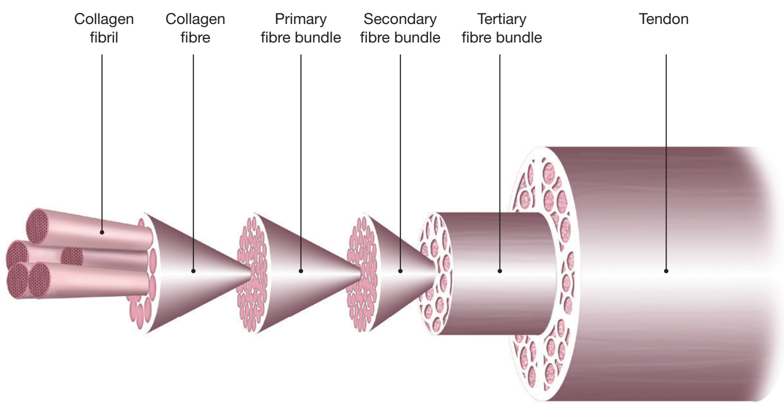

FIGURE 3: The construction of a tendon.

Compared with muscles, tendons have a poor vascularization and are therefore white while the muscles are red [1]. Vascularization facilitates regeneration of the tendon and tendon cell's function. The posterior tibial artery vascularizes the Achilles tendon through the paratenon. In the proximal part of the Achilles tendon, the vessels originate from the calf muscles, but closer to the insertion the vessels pass the periosteum of the calcaneus bone. The midportion of the tendon is more poorly vascularized, which could be a reason for the high incidence of Achilles tendon rupture in that area [1].

The innervation of tendons is mainly on the tendon surface with nerve endings crossing to the epitenon septa but not entering the tendon itself [1]. The triceps surae is innervated by the tibial nerve (S1-S2), while the surrounding skin on the posterior side is innervated by the sural nerve [40,116].

Tendons are protected from bony structures by bursae to reduce friction that can damage them [73]. The retrocalcaneal bursa is located anterior to the Achilles tendon and prevents friction against the calcaneal bone during dorsiflexion [23]. Between the Achilles tendon and the bony structures anterior to it, i.e. the tibia and calcaneus, there is a fat pad called Kager's fat pad [74] and this area is often called Kager's triangle. The fat pad is assumed to lubricate and reduce friction at the anterior aspect of the tendon as well as relieving pressure on the tendon [74].

FUNCTIONAL ANATOMY

During muscle contraction the force runs through a tendon and causes a rotational movement of the joint it crosses [91]. The triceps surae with the Achilles tendon, plantar flexes the ankle joint, which consists of the talocrural joint, the subtalar and talocalcaneonavicular joint and in mammals is well suited for running, jumping and hopping [4]. Another role of the triceps surae is stabilization of the ankle joint as it is the strongest supinator of the subtalar and talocalcaneonavicular joints [116]. The role of the triceps surae has been studied and it was shown that it does not push the centre of mass forward during walking, but rather keeps the body stable [66]. On the other hand, while jumping and running, the role of the triceps surae is that of a pusher [66].

The foot consists of three arches; the transverse arch and the medial and lateral longitudinal arches (Figure 4) [87]. The support of the medial longitudinal arch mainly comes from the plantar aponeurosis, but also from the three plantar ligaments; the spring ligament, the short plantar ligament, and the long plantar ligament. When loaded, the plantar aponeurosis holds the anterior and posterior parts of the foot together, with its origin on the calcaneus and extending to each of the phalanges [16]. This structure supports the medial longitudinal arch, both as a rigid stability structure and a dampening mobility one [87]. The biomechanical factors outlined here have been termed as the windlass mechanism, with the loaded plantar fascia compared to a tightening of a rope during the dorsiflexion of the big toe [16].

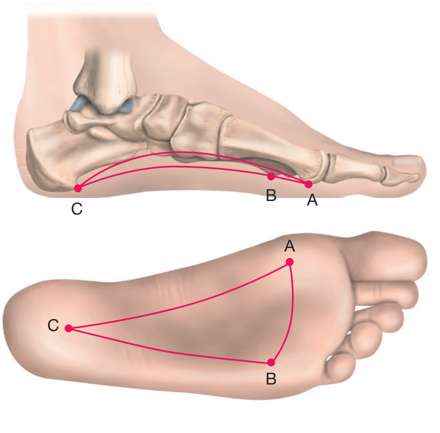

FIGURE 4: The planes of the foot. A-C medial longitudinal arch, B-C lateral longitudinal arch, A-B transverse arch.

When evaluating the foot, abnormal shapes are described as pes cavus (high arch foot) or pes planus (flat foot) depending on the structure of the medial longitudinal arch (Figure 5). Pes planus, in association with the pronated foot during gait, is one of the most common disorders of the foot [45]. When simulating the flat foot deformity, it has been shown that the plantar aponeurosis is the main inhibitor of arch elongation, while the spring ligament prevents pronation. These two structures complement each other, and prevent a deficiency when one of them fails [31].

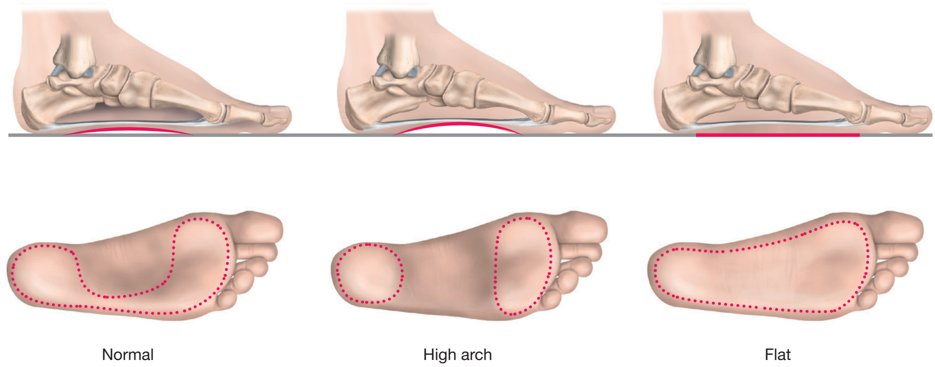

FIGURE 5: Different foot and footprint shapes.

When evaluating foot structure, some measurements that are more common than others, such as longitudinal arch angle, arch height, navicular drop and drift, along with radiographic evaluations measured either during static or dynamic conditions [14,33,43,97,121].

BIOMECHANICS

The word "mechanics" refers to the science of structure and movement, but when the prefix "bio" is added, it is limited to the structure and movement of living organisms [3]. Mechanics can be divided into two different categories, static and dynamic [80]. The static category concerns systems that do not move, while dynamics is related to moving systems. Dynamics is then further subdivided into kinematics and kinetics. Kinematics is the study of the system's time and space in the movement, while kinetics studies the influence of bodily movement, i.e. which forces drive the motion [80].

When describing movement, the use of x, y and z coordinates indicates the three dimensional motions of the joint [86]. In biomechanics the coordinates are usually transcribed to the planes, i.e., the sagittal (anterior posterior, x), the frontal (coronal, y), and the transverse (horizontal, z) plane (Figure 6). These planes are evaluated from an anatomic position in which a person stands with the face and palms in a forward position [86].

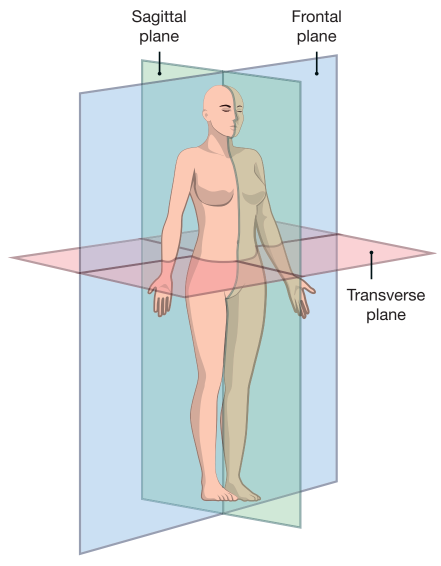

FIGURE 6: Biomechanical planes.

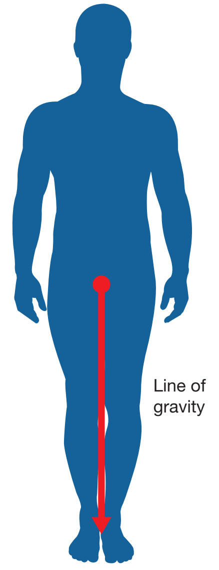

FIGURE 7: Centre of gravity.

To explain why motion occurs, it is vital to take account of the forces affecting the moving object. To simplify body movement, it can be divided into a force that either pushes or pulls. Moreover, the forces can be categorized as internal, such as muscles, ligaments and bones, or external, such as gravity, water, wind and other moving objects (people, vehicle) or as static objects (briefcase, backpack) [86]. Force is presented in Newton (N) using this formula:

Force (N) =mass (kg) *acceleration (meter /seconds²).

The force of gravity is the pull of the earth on any mass (kg) [80,86]. Gravity pulls on every point of every object on earth, but to simplify the calculations, objects are given a centre of gravity, a point in the centre of the mass to which the force is applicable. This point is located in front of the second sacral vertebra in a completely symmetrical human body, standing in an anatomical position (Figure 7) [86]. The strength of gravity is 9.81 N/kg i.e., 1 kg of the force due to the pull of the earth is 9.81 N.

Work is calculated as the force over a distance and the unit for work is Nm,

Work (Nm) =Force (N)*distance (m).

Work is expressed in joules (1 Nm = 1 joule) in the literature. To calculate the power used at a given moment, work is divided by time,

Power (joules/s) = work (joules) / time (s).

The unit for power is Watt [86].

The definition of force of friction is the force produced by two surfaces that contact and slide against each other. As a result, the relative motion of two components causes friction at every joint in a machine and therefore energy is spent on overcoming the friction. When a person walks and places her/his foot on the ground it causes a counter force from the ground. This force is called ground reaction force (GRF). For example, when a person jumps there is a specific amount of force from the body to the ground in a downward direction, creating the same amount of force from the ground in an upward direction [86]. The GRF vector is 3-demensional and its three components can be expressed using the Cartesian coordinate system. Force plates are employed to calculate GRF and its origin [86].

RECOVERY AFTER INJURY

Injury is damage to the body, usually caused by an accident. As indicated by the word accident, it is unexpected. Because the victim is unprepared for the injury, it also affects her/his mental state. A study by Lindahl et al. [89] revealed that people who suffer from a musculoskeletal injury often have little knowledge of what awaits them and the outcome is usually not as expected [89]. Patients involved in an accident who suffered bone fractures, often have unrealistic expectations about the recovery duration. The results showed that up to 44% predicted they would be fully recovered within 3 months but at 6 months, only 8% reported being fully recovered, while an additional 33.5% had recovered reasonably well [89].

However, overall, it appears that the lower the expectations, the less likely patients are to achieve the desired outcome compared to those with higher expectations [42]. Full recovery, or as close to full recovery as possible, is vital for athletes who are recovering and returning to sport after injury, as previous injury is one of the best predictors of subsequent injury [100].

RETURN TO ACTIVITY AFTER INJURY

There are many factors that need to be taken into consideration when the patient makes the decision to return to activity after an injury. A consensus statement pertaining to return to sports (RTS) was published after a meeting held at the first World Congress in Sports Physical Therapy in 2016 [7]. In that meeting, 17 experts defined and discussed four main sections of RTS:

1) When defining RTS it is important to be aware that rehabilitation, recovery and return to sports is a continuum, not a separate decision taken in isolation. Therefore, there are three levels of RTS:

   a. Return to participation – the athlete is still in rehabilitation, but takes part in some training or even in their sport at a lower level. Activity has begun, but the athlete is not ready to RTS.

   b. Return to sport – the athlete is back in his/her sport, but has not reached the desired performance level.

   c. Return to performance – the

athlete is back in his/her sport and performing at a preinjury level or even higher.

2) A model to help understand and guide the RTS process is based on biological, psychological, and social factors, which influence the RTS decision. The roles of the team members who make the RTS decision must be predefined, and information should be shared regularly within the team. The athlete's progress should be assessed and reviewed regularly.

3) The evidence available for RTS varies between injuries, which makes it more challenging to predict the injury prognosis and timeline. The decision should be based on information derived from tests imitating the individuals sport situation. In addition, the psychological aspect should be taken into consideration before RTS. Common injuries should have their own RTS criteria, but that requires a consensus.

4) A priority for future RTS research should be standardised injury definitions in relation to the injury, its severity and recurrence. The level of sport should also be reported and standardised. Moreover, RTS outcomes and follow-up should be standardised. Factors affecting the outcomes should be identified and tools to measure RTS must be designed and validated.

The conclusion of the consensus stated that "combining information from a biological, psychological and social standpoint, while considering the risks can help all RTS decision-makers – whether they be clinicians, athletes, coaches or other stakeholders – make optimal decisions" [7].

ACUTE ACHILLES TENDON RUPTURE

The typical individual who suffers an Achilles tendon rupture is the so-called "weekend warrior"; male, between 30 and 50 years old, playing a sport that requires a rapid change of direction such as basketball and tennis [85,111,119,135]. In older individuals, Achilles tendon rupture is instead connected to nonsporting activities [85,119].

The most common location of the Achilles tendon rupture is the midportion of the tendon, 2-6 cm above the calcaneus bone [9]. When studying histological samples from the rupture, degenerative and necrobiotic changes can be seen in the tendons of most – if not all – patients suffering from an acute Achilles tendon rupture [9].

The stress-strain curve for tendons is commonly used to describe the Achilles tendon rupture [91,105]. In a relaxed position the collagen fibres are wavy and flexible. The normal 1-3% stretch is produced during activities such as walking, but if there is more than a 3% stretch on the tendon, the fibrils start to slide past each other leading to micro-ruptures in the tendon. At this point the tendon cannot regain its original position. If the tendon stretches more than 8%, it ruptures [105].

Healing of the Achilles tendon usually takes place by means of vascular ingrowth from the surrounding tissue, because when the tendon ruptures, this tissue is also damaged, which leads to bleeding [51]. Following an injury, there is vascular ingrowth from the tissue around the tendon, which causes the fibroblasts to proliferate. After two weeks the fibroblasts have secreted collagen molecules, which become fibrils arranged into thicker bundles than the original ones, thus providing strength to the tissue. At this point, movement is allowed, which realigns the collagen fibrils with the direction of force. These collagen fibres are mainly type III, V and VI, which result in scar tissue that is larger and weaker. Other differences in the scar tissue are an elevated quantity of glycosaminoglycans and a lower number of collagen crosslinks [51].

EPIDEMIOLOGY

Acute Achilles tendon rupture is a common injury and its incidence is increasing, as demonstrated by records from Finland, Denmark and Sweden [47,69,82,83,85]. A recent study examining Achilles tendon rupture in Finland from 1997 to 2019 presented an increase from 17.3 to 32.3 per 100,000 person years during that period [83]. The incidence increased steadily until 2011 but reached a plateau at that point in time. Nonoperative treatment increased from 3.7 to 27.5 (per 100,000 person years), while operative treatment decreased from 13.6 to 4.9 (per 100,000 person years). This trend started around 2008 [83]. The increase in Achilles tendon rupture is more prominent in older individuals [47,83] and the incidence is higher in males (75-79%) compared with females (21-25%) [69,83].

INJURY MECHANISM

Approximately one third of patients who rupture their Achilles tendon are not active in playing sports although they are physically active. However, for those who play sports, the injury is most common in racket sports, such as badminton and tennis, but also in football and activities involving jumping [2,74]. The Achilles tendon rupture mechanisms have been classified by means of four categories related to physical activity (Figure 8) [9,13]:

1) A forceful plantar flexion with the knee extended on the weightbearing limb, for example a real sprint push-off.

2) An unexpected dorsiflexion of the ankle joint, where the calf muscles are initially not fully contracted but do so as a reaction to the unexpected movement. An example of this is the heel moving downwards unexpectedly when slipping into a hole.

3) A strong change from plantar flexion to dorsiflexion. This can happen when landing from a jump for example, when the whole foot makes contact with the ground, the calf muscles contract for stability, but pull hard on the tendon [9].

The fourth way to rupture the Achilles tendon is during an oblique traction of the calcaneus, which can happen during an ankle sprain (Figure 8) [13]. It was put forward that in addition to the oblique traction of the calcaneus, if there was maximal contraction of the calf muscle, the muscle was tired and the initial length of the tendon was short, that would be optimal circumstances for an Achilles tendon rupture [13].

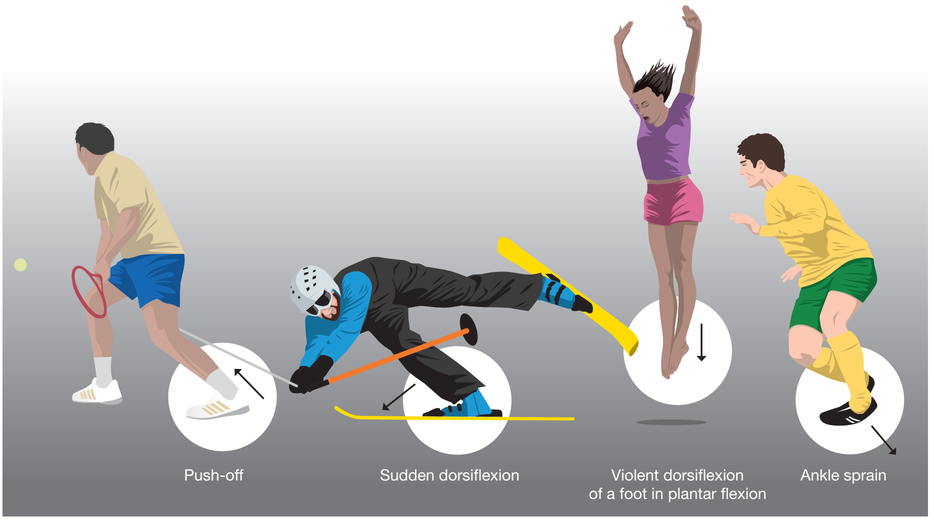

FIGURE 8: The 4 categories of Achilles tendon ruptures during activity.

DIAGNOSIS

The patient's description of the injury is a sudden pain as if someone had kicked them in the heel. Sometimes they also hear a snap as the tendon ruptures [9].

A thorough clinical examination together with the patients history is vital when diagnosing acute Achilles tendon rupture [90]. Palpation and visualization soon after the injury can reveal a gap in the tendon that can be felt and/or seen. Generally, this indicates a total rupture of the tendon. Over time, oedema, hematoma and scar tissue will fill the gap making palpation more unreliable. Other factors that might confuse the issue are that in some cases the patient can walk immediately after the injury and perform a standing plantar flexion, where muscles other than the triceps surae are responsible for the movement [90].

A few tests such as calf squeeze test and Matles test are commonly used to establish a diagnosis of Achilles tendon rupture (Figure 9) [90].

Calf squeeze test: this test is also known as the Simmond's or Thompson's test [74]. The patient lies prone or on his/her knees on a treatment table with the foot hanging from the edge of the table. The examiner uses one hand to gently squeeze the calf muscle of the limb in question. If the Achilles tendon is intact the foot will reflexively plantar flex. If it is ruptured there is only a minimal or no plantar flexion with an obvious difference compared to the unaffected side [11,74,90].

The Matles test: the patient lies prone on the treatment table and is asked to actively flex both knees. In this posture the difference in position of both ankles is evaluated. If the Achilles tendon is intact the ankle joint will remain in a neutral position, i.e.in plantar flexion. If the tendon is ruptured, the ankle joint on the affected side will show an increased dorsiflexion when compared with the unaffected side [74,90]. This test can be connected to the Achilles tendon resting angle (ATRA), which is the angle measured from the fibula's long axis representing one arm, while the other arm is from the tip of the distal end of the fibula (malleolus lateralis) to the middle of the head of the metatarsal 5 (Figure 10) [25,26]. ATRA measures the passive dorsiflexion of the ankle joint and is used to compare the sides. If the Achilles tendon is ruptured and untreated, dorsiflexion and the measured value increase. After a rupture, a study showed that mean difference between the sides was 12° ($p<0.001$), where the mean dorsiflexion on the affected side was 55° compared with 43° on the unaffected side [25].

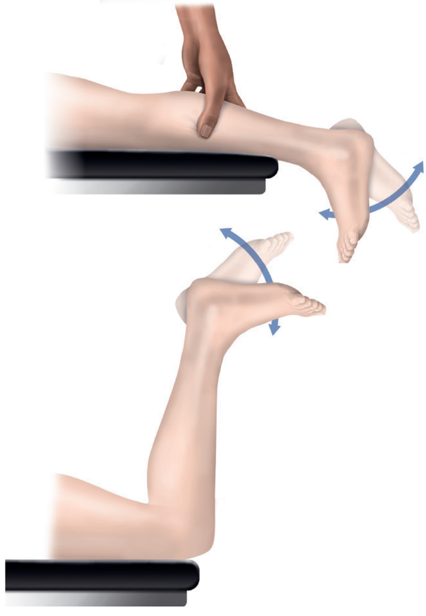

FIGURE 9: Calf squeeze test (above) and The Matles test (below).

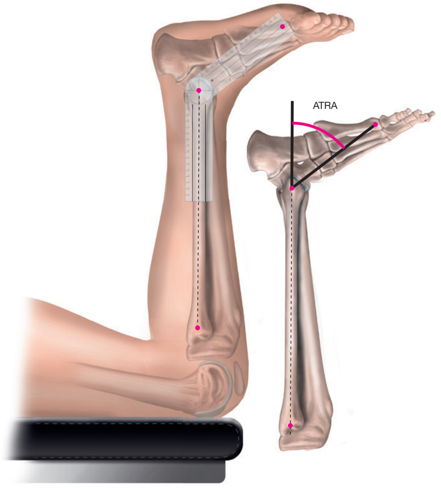

FIGURE 10: ATRA.

Imaging can be used as a secondary diagnostic tool, but this is usually not needed. The most common forms of imaging are ultra-sonography and magnetic resonance imaging (MRI), which are employed after clinical examination as imaging alone could lead to Achilles tendon rupture being underdiagnose [36,48,90]. The calf squeeze test has a sensitivity of 96% [90] while that of ultrasonography is 79-100% [36]. Both ultrasonography and MRI can be used to establish a chronic Achilles tendon ruptures diagnosis, with ultrasonography being more accessible and less expensive than MRI [36,74,90]. However, the disadvantage of ultrasonography is that the imaging protocol is not standardised and therefore, when looking at the images afterwards, it can be difficult to determine the exact angle from which they were taken. This fact can be a disadvantage when an orthopaedic surgeon interprets the images made by a radiologist. On the other hand, ultrasonography is easy to use and the person doing the imaging (radiologist/doctor) can follow the results in immediately, which is a great advantage.

TREATMENT

Several studies and systematic reviews have been published on whether surgical or non-surgical treatment is optimal for Achilles tendon rupture [38,65,106,120,144] as both forms of treatment have positive and negative aspects. Surgical treatment has been recommended for athletes and those who are young and highly active, because it enables a shorter lay-off time and is safer than non-surgical treatment when returning to activity [74]. It has been shown in three recent systematic reviews and a meta-analysis that surgical treatment reduces the risk of re-rupture (surgical: 2-4% vs. conservative: 10-12%; $p<0.001$ [38]) but increases the wound complication rate [38,65,120]. No significant differences have been reported between the two treatment groups in terms of deep venous thrombosis, return to sports, Achilles tendon total rupture score (ATRS), the Physical activity scale (PAS) or range of motion (ROM) [38,65,120].

Several different types of surgical repair have been described, which can generally be divided into minimally-invasive, percutaneous and open repair [146]. The complications usually examined are re-rupture, sural nerve damage, wound complications, functional outcome scores as well as patient reported outcome measures (PROMs) [120,146]. According to a meta-analysis from 2017, there is no difference in re-rupture rate or functional outcome between the percutaneous repair and open repair techniques, while there is a reduced risk of sural nerve damage using open repair. On the other hand, there is less risk of wound complications using minimally-invasive and percutaneous repair [146]. A recent systematic review and a meta-analysis demonstrated that operation time, deep infection and the American Orthopaedic Foot and Ankle Society (AOFAS) score all favoured the minimally-invasive technique, while the risk of sural nerve damage was increased [120]. Both studies recommend the minimally-invasive surgery technique despite the increased risk of sural nerve damage [120,146].

REHABILITATION

The treatment post-surgery and during non-surgical treatment has not been formally described, as the optimal strategy has yet to be explored. A common treatment today is described in a recently published Norwegian study, where the patient wears a plaster cast for 2 weeks [101]. The cast is below the knee, with the ankle in plantar flexion (Figure 11). After the 2 weeks the patient receives a brace for the following 6 weeks and is then allowed to put his/her full weight on the injured limb (Figure 12). The brace has three to five heel-wedges that are removed one by one every other week until at 8 weeks post injury all have been removed [101].

FIGURE 11: A patient with a cast, with the ankle in plantar flexion.

FIGURE 12: A patient with an ankle brace; here in neutral position.

When it comes to the optimal rehabilitation strategy in terms of function and activity, there is a noticeable knowledge gap. In a systematic review, Zellers et al.[150] defined early functional rehabilitation, concluding that it should start as early as the first two weeks after the initiated of treatment and comprise weightbearing and exercises. Unfortunately, the included studies varied both in terms of outcome measures and interventions and a further limitation was the lack of standardised definitions. Therefore, the results cannot be generalised [150].

More recent systematic reviews and a meta-analyses examined different studies of rehabilitation in the weeks following Achilles tendon rupture repair [52,93]. The rehabilitation protocols were divided into four groups:

- weightbearing and mobilization,
- weightbearing and immobilization,
- non-weightbearing and mobilization,
- non-weightbearing and immobilization.

The outcome factors were re-ruptures, return to work, return to sports and complications. The results revealed no significant differences between the groups in terms of the outcome parameters. However, the most favourable results of the previously mentioned outcome factors were found for weightbearing and mobilisation during the period when a brace was used [93].

A scoping review from 2020 [29] analysed rehabilitation in the first 8 weeks after diagnosis. Thirty-eight studies were included. They were divided into surgical treatment (19 studies), non-surgical treatment (8 studies) and both treatments (11 studies). The exercises extracted from the studies were categorised into isometric exercises, heel-rises, strength training with external resistance and unspecified. Unfortunately, most of the studies provided incomplete information about the exercises, making difficult to determine which programme was the most effective [29].

Further rehabilitation is always required when the brace is removed. In 2015, Hutchison et al. [68] published the outcome of The Swansea Morriston Achilles Rupture Treatment (SMART) programme. The decision to perform surgical or non-surgical treatment was mainly based on the ultrasound image results (gap between tendon ends >1cm), but also on the age of the patient and rupture being in the mid-substance of the tendon [68]. All patients used a brace, with weightbearing for the first 10 weeks and exercises starting at week 5-7 using a TheraBand™. When the brace was removed, the focus was on range of motion and plantar flexion strength training. The aim was to achieve a single-leg standing heel-rise as well as 2 feet jumps and jogging while leaning on table or on a trampette within 5 months. At 5-6 months post injury, jogging on a flat surface, eccentric step exercises and sport specific exercises were introduced. After 6 months, horizontal and vertical hopping and a return to sports were added if the patient was able to cope with them. The re-rupture rate was 1.1% (surgical treatment: 1/62; non-surgical treatment: 2/211) and ATRS at 9 months was 72.4 (n=43) [68].

Another study on rehabilitation was performed by Lim et al. [88], in which the rehabilitation started at week 4 after the injury with the introduction of active ROM exercises, guidance for walking, isometric calf exercises, manual therapy and pool exercises. At week 8 the brace was removed and strength exercises were introduced along with proprioception exercises and stretching. By week 12, single-leg standing heel-rises and jogging were introduced while running started a month later. The results showed no differences in re-rupture related to the form of treatment (surgical treatment: 2/99; non-surgical treatment: 6/101) nor between treatment groups or gender in ATRS (whole group: mean 85.1; median 91.0) [88].

PHYSICAL RECOVERY

Achilles tendon rupture is a serious injury requiring a long period of rehabilitation, during which several changes in daily living are necessary. These changes involve social life, work and new footwear, as well as the “do ́s and don’ts” that are important to adhere to for optimal recovery., Intrinsic factors, such as deficits in muscle power and agility, tendon elongation and difference in foot structure, can also be apparent. Some of those factors have already been evaluated, while others have not. Various changes involving intrinsic factors and foot structure can affect lower leg function and biomechanics.

Tendon elongation

Tendon elongation is common after an Achilles tendon rupture and in a systematic review from 2020 the range of average elongation is reported to be between 0.15 and 3.1 cm using different imaging techniques [39]. The effects of tendon elongation has on PROMs, biomechanics and functional strength were also evaluated, but the results were not as conclusive as expected. There is a fair amount of evidence of the effect of Achilles tendon elongation on lower leg biomechanics. However, the evidence for the impact of Achilles tendon elongation on PROMs and functional strength are either poor or controversial. The impact on lower leg biomechanics may have negative consequences in highly active individuals [39].

The reason for the differences in Achilles tendon elongation between individuals after injury is not well understood. The effect of treatment (surgical or non-surgical) on tendon length has been evaluated with varying results [62,124]. Eighteen months after injury there was a significant difference in Achilles tendon length between the surgical and non-surgical groups measured with MRI. Patients who were surgically treated had 1.9 cm shorter Achilles tendons compared with those in the non-surgical group [62]. On the other hand, when using MRI, Rosso et al. [124] did not detect a significant differences between surgical (open repair and percutaneous) and non-surgical treatments. The difference between the non-surgical group and the two surgical treatment groups (open repair and percutaneous) was 4.5 mm and 1.5 mm, respectively [124]. Therefore, it remains difficult to conclude which treatment has the most positive effect in terms of tendon elongation. On the other hand, tendon elongation is clearly a negative factor when it comes to physical function after injury and treatment [22,131].

Another factor that could affect Achilles tendon elongation after an injury is the initial form of immobilisation. The wearing of a brace or a cast for the first 3 weeks after an injury was examined by means of the Danish registry for data collection [63]. Patients treated both surgically and non-surgically were included in the study. The results showed no significant differences in terms of functional outcomes evaluated with ATRS or when assessing tendon length based on heel-rise height and ATRA [63]. Other studies have evaluated the differences between various forms of braces and/or a cast, but without Achilles tendon length as an outcome measure [34,44,75]. The overall outcome measures reveal no significant difference between the use of a brace or a cast or are inconclusive, in the above references.

Okoroha et al. [107] evaluated the difference in Achilles tendon length between accelerated rehabilitation and a more traditional approach. No significant differences was between the groups at the 6-month follow-up, in either tendon length or the other parameters examined (ROM and ATRS) [107].

Foot structure

Injuries related to foot structure have been evaluated in several studies, especially in runners [122,143]. In 2001, a survey was conducted, in which two groups ("high arch group" and "low arch group") were evaluated with respect to their injury patterns [143]. The survey was performed by measuring the arch of 40 runners, 20 in the high arch group and 20 in the low arch group, and recording their running-related injury history.

The predominant injuries in the high-arched runners were in the ankle, with lateral and bone injuries in the lower extremities, while the low-arched runners mainly exhibited injuries to the knee, medial ankle and soft tissue, such as posterior tibial tendinitis and patellar tendinitis. The researchers suggested that the injuries of the high-arched runners might be associated with more lateral loading of the foot, such as during the stance phase in running, when the centre of pressure is more lateral. In contrast, the low-arch caused a more pronated foot structure, which intensified the load on structures on the medial side of the lower extremity, thus increasing the risk of injury [143]. Another study evaluating lower limb disorders and foot structure connected pes planus (flat foot) and a pronated foot posture to patellofemoral pain syndrome (PFPS) [14]. The pronated foot posture was described by the Foot structure index and the longitudinal arch angle but without specifying the criteria for pronation (the cut-off was not stated). The participants with PFPS were matched with a control group and their feet were evaluated by means of the foot posture index, vertical navicular height, navicular drop and drift as well as the longitudinal arch angle. The group with PFPS had significantly greater foot pronation compared with the control group [14].

Plantar fasciitis is another overuse injury that appears to be connected to foot structure [122]. When comparing a group presenting of plantar fasciitis pain, a group with history of plantar fasciitis pain and a control group, the plantar fasciitis groups had a significantly lower plantar medial longitudinal arch index, which can be interpreted as having more elevated plantar arches. Rearfoot alignments were also evaluated and no differences between any of the groups were found [122].

A recent randomised controlled trial (RCT) of the flexible flat foot evaluated the effect of a six week exercise programme on foot alignment [19]. The outcome measure were the longitudinal arch angle and navicular drop height. The results revealed a much larger improvement of both measures in the experimental group (longitudinal arch angle +20°, navicular drop height -0.5cm) compared to the control group (longitudinal arch angle +4°, navicular drop height -0.1cm). The researchers concluded that exercises including gluteal exercises, foot shortening exercises, mobility exercises in dorsi and plantar flexion as well as stretching can improve foot structure in cases of flat foot structure [19].

Calf muscle recovery

After an Achilles tendon rupture, the endurance of the lower leg muscles is often impaired both in the short [21] and the long term [20,62,136]. In the short term (3 months after injury) there is a significant difference in the standardized seated heel-rise test in terms of both height and repetitions, between the uninjured and the injured sides. Around half of the study group could perform a standing heel-rise [21].

In the longer term, a study evaluating calf muscle performance seven years after an

Achilles tendon rupture revealed that when heel-rise repetitions and heel-rise work were assessed, the injured side was significantly impaired compared to the uninjured side [20]. Moreover, it has been reported that isokinetic plantar flexion strength 14 years after an Achilles tendon rupture indicates a deficit of 12% in the soleus muscle and 18% in the gastrocnemius muscle on the injured side compared with the healthy side [62]. When muscle fatigue was evaluated with surface electromyography (sEMG) on the gastrocnemius muscles during heel-rises 2.0 – 6.7 years after the injury, the results were the same, i.e., increased fatigue on the injured side when compared with the healthy side [136]. Flexor hallucis longus hypertrophy has been observed as a possible compensation mechanism for calf muscle deficits [62,76].

Gait, run and jump performance

Movement, such as walking, running and jumping after an Achilles tendon rupture has been widely evaluated [22,103,109,110,118,145]. In a study by Willy et al. [145] published in 2017, it was reported that there were no differences in biomechanics during walking, jogging or jumping, between surgical and non-surgical groups six years after the injury, while the differences between the injured and the uninjured side were significant [145]. The differences were reported in ankle kinematic values during walking, jogging and jumping [145].

The drop countermovement jump (drop CMJ) test is commonly used to measure the functional difference between the injured and the uninjured side in dynamic activities after an Achilles tendon rupture [22,103,109,110,118]. A study by Powell et al. [118], reported significantly lower values in jump height for the injured side during drop CMJ up to six years after an acute Achilles tendon rupture. The same study also evaluated the consequences of Achilles tendon rupture on the kinetics of the knee and ankle, reporting lower values of both eccentric and concentric ankle joint power in the injured side compared to the uninjured side. The opposite was observed in the knee, where the results showed higher values in eccentric power on the injured side, while there was no difference in concentric power [118].

Differences in kinematics have also been detected during running after an Achilles tendon rupture [70]. At initial contact the knee is overextended and the range of motion in the ankle joint is reduced in the second half of the stance phase. Therefore, the range of motion of the knee was increased at the beginning of the stance phase when compared with healthy controls. The differences between sides are also apparent in the joint moment of the hip on the contralateral side, which increased by 22% compared to healthy controls. This suggests a compensational change in movement during running after an Achilles tendon rupture [70]. Similar compensational results have been found in the above-mentioned study by Willy et al. [145].

PSYCHOLOGICAL RECOVERY

Although it is widely accepted that participation in sports and activity is important for physical and psychological health, musculoskeletal injuries are always a risk [141]. The short-term consequences of such an injury can be pain and functional disability, as well as loss of social identity, changes in mood and withdrawal from sports. In the long term, the consequences can give rise to further musculoskeletal disorders, which can develop into psychological disorders and a poorer quality of life [141].

Psychological recovery after injury is as important for an athlete as reaching milestones in terms of strength, ROM or endurance [30]. To increase the likelihood of an athlete returning to preinjury activity, it is essential to build confidence and set goals [8]. Fear of reinjury is a major barrier for the athlete to overcome when returning to sports and therefore a sense of autonomy is crucial along with the feeling of competence to perform the task ahead [8]. Unfortunately, high scores in stability or strength tests are no guarantee that the athlete is ready to return to previous activity [30]. Various approaches can be used to help athletes achieve the emotional state that they need to recover after injuries [49]. Effective interventions include goal setting, counselling, relaxation/guided imagery, positive self-talk, modelling videos and emotional/written disclosures [49].

A study focusing on lower leg injury that required surgery (Achilles tendon rupture and ankle fracture) tested the correlation between those injuries and subsequent depression [37]. During a period of one year, the patients were asked to complete The Patient Health Questionnaire 9 (PHQ-9) [10], both before and after the operation (in week 1, 2, 4, 8, 16, 24, 32, 40 and 52). This was in order to evaluate whether there was a risk of developing depression when having to undergo surgery, being non-weightbearing, immobilised and undergoing rehabilitation. The results showed that in the week following the operation, about half of the patients had some level of depression, but within the year, it returned to the preinjury state [37].

In combination, the awareness of possible mental health problems appears to be greater than previously anticipated and the focus has shifted towards psychological health in connection with recovery after injury. This might increase the number of individuals returning to preinjury level or at least to some form of activity.

Fear of reinjury

Fear of reinjury in athletes was evaluated in a clinical review in 2017 [67]. The objective was to “provide an overview of the implications of fear of reinjury on the rehabilitation of athletes, including clinical methods to measure fear of reinjury; the impact of fear of reinjury on rehabilitation outcomes, including physical impairments, function and return to sports rate; and potential interventions to address fear of reinjury during rehabilitation“ [67]. Taken together, it was concluded that fear of reinjury can have a negative impact on rehabilitation outcomes and prevent a successful return to activity/sport/play. It is important to evaluate fear of injury in order to deal with it, but ones should be aware that the fear might not appear until the athlete starts more intensive exercises or during the return to activity/sport/play [67].

The Tampa Scale of Kinesiophobia (TSK) [98] is often used to measure kinesiophobia (or fear of movement) after an injury [108,128,137], where a higher score indicates greater kinesiophobia.

The Swedish version of the TSK (TSK-SV) was used when evaluating kinesiophobia 12 weeks after an Achilles tendon rupture as well as the ability to perform a single-leg standing heel-rise test [108]. A significant negative correlation was found between the TSK-SV and other PROMs evaluated. The factors evaluated were; physical activity (PAS) [55,56], symptoms and function (ATRS) [104], activities of daily living, function in sports and recreation and quality of life using the foot and ankle outcome score (FAOS) [123] and general health based on the EuroQol Group (EQ-5D) [58]. On the other hand, there were no significant differences in terms of TSK between those who were able to perform a single-leg standing heel-rise test and those who could not [108].

The TSK has also been used for patients with anterior cruciate ligament (ACL) injuries where the relationship between kinesiophobia and kinematic and muscle activation has been evaluated during jump-landing tasks [137]. Results showed a correlation between increased kinesiophobia and decreased knee and trunk flexion as well as increased hip adduction and gluteus maximus preparatory activation, which was interpreted as greater guarding of the movement. These results indicate that a stiffer movement pattern, such as decreased knee and trunk flexion during landing in the sagittal plane and increased motion in the frontal plane, were prominent in those who have a higher TSK score. The stiffer movement pattern has been linked to an increased risk of ACL injury [137].

Silbernagel et al. [128] applied the TSK-SV to evaluate the 5-year outcome after Achilles tendinopathy when using exercise alone, examining whether there was any correlation between function and kinesiophobia. The results revealed a significant negative correlation, as those with a higher TSK score were less recovered when muscular endurance was evaluated by means of the single-leg standing heel-rise test [128].

RETURN TO SPORT

Definitions of return to activity/sport/play vary in the literature. Nevertheless, Habets et al. [59] performed a qualitative systematic review related to return to sport definitions and criteria in athletes with midportion Achilles tendinopathy.

In their study, the Habets et al. [59] presented three main content categories to define return to activity/sport/play:

- Reaching preinjury activity/sports level, with the ability to perform training and matches without limitations
- Absence of pain
- Recovery

For return to play, the criteria were divided into eight categories:

- Level of pain
- Level of functional recovery
- Recovery of muscle strength
- Recovery of range of motion
- Level of endurance of the injured side
- Medical advice
- Psychosocial factors
- Anatomical/physiological properties of the musculotendinous complex

This can be interpreted to mean that the formal return to activity/sport/play is achieved when training/playing at preinjury level is reached, but pain in relation to activity/sport/play should also be considered [59]. Another qualitative systematic review was performed on return to activity/sport/play after hamstring injuries, where the results were comparable with the above-mentioned study [138]. Reaching the preinjury level and being able to perform the required activities was used as a definition for return to activity/sport/play [138].

As mentioned above, the definition of return to activity/sport/play is sometimes vague and differs between studies. A systematic review and a meta-analysis were published in 2016, where the rate of return to activity/sport/play after an Achilles tendon rupture was evaluated [148]. Eighty-five studies were included. The range of return to activity/sport/play varied between 18.6% and 100%, with an average of 80%. This means that approximately 20% of patients who rupture their Achilles tendon did not return to activity/sport/play. What should be noted is that the most common definition is return to preinjury level of activity/sport/play, but not all the studies included in the systematic review used this definition [148]. Therefore, it can be assumed that the percentage of return to activity/sport/play might be even lower than 80%, especially when the level is not defined. This has also been reported in several studies [57,79,127,140].

THE IMPORTANCE OF RETURNING TO PHYSICAL ACTIVITY AFTER INJURY

An evaluation of both short- and long-term consequences of sport injuries affecting the athlete concluded that musculoskeletal injuries in the lower extremity can affect individuals later in life [142]. In the short-term, most consequences are negative with feelings such as isolation, fear of reinjury, physical inactivity, less social identity and withdrawal from physical activities. There is an association between sport-related injuries and obesity, reduced quality of life and post-traumatic osteoarthritis (PTOA) in cases where the individual does not manage to return to the preferred activity. The potential risk profile of suffering from PTOA was outlined. It includes 10 factors; "intra-articular injury/reinjury; early return to sport; obesity/adiposity; physical inactivity/sedentary behaviour; muscle weakness/altered neuromuscular control; fear of movement; poor diet; inaccurate beliefs/unrealistic expectations; insufficient and ill-timed exercise-therapy; joint dysplasia" [142]. Other diseases or symptoms often evolve from these factors, such as mental disorders, heart disease and diabetes [142]. Even though this study is mainly based on intra-articular injuries, the consequences can be just as relevant for individuals who have sustained an Achilles tendon rupture, as it has been suggested that asymmetrical biomechanics after an Achilles tendon rupture may lead to other overload injuries, for instance knee injuries [70]. Therefore, it is easy to argue the importance of an optimised, individualised rehabilitation after an Achilles tendon rupture (and other injuries).

CHAPTER 2

KNOWLEDGE GAPS

KNOWLEDGE GAPS

The knowledge gaps that I will attempt to bridge in this thesis concern the factors that affect a return to activity after an acute Achilles tendon rupture. Acute Achilles tendon rupture has been widely studied, in an attempt to determine the optimal treatment and rehabilitation. Although the protocols have improved greatly, there are aspects that need to be addressed to ensure a recovery that is as complete as possible for most patients.

Let us first consider what affects everyone ́s movement pattern. The feet constitute the foundation for most of our movement. If a step does not follow the normal pattern, its impact on the ankle, knee, hip and trunk is apparent. Therefore, the changes, if any, in the foot structure of those who have ruptured their Achilles tendon need to be identified (Study I).

The difference in kinetics of the ankle and knee between the uninjured and the injured side after an Achilles tendon rupture has been examined. However, the effect of Achilles tendon rupture on the kinetics of the ankle and knee during a few jumps or heel-rises might differ compared to when the individual is tired. Therefore, it is important to try to analyse how fatigue can lead to changes in the kinetics of the lower extremities after Achilles tendon rupture (Study II).

The lower extremity movement pattern and differences between the sides after Achilles tendon rupture can be due to various factors with one of them possibly being fear of reinjury. Fear of reinjury has been shown to have an effect on movement patterns after ligament injuries such as ACL ruptures and reconstruction. Therefore, after Achilles tendon rupture, the movement pattern of the lower extremities needs to be examined in those who are afraid of reinjury and compared with that of those who do not have such a fear (Study III).

As mentioned above, many factors can influence the changes in movement pattern and overall recovery after an Achilles tendon rupture. Some factors might not be obvious to healthcare professionals and only known to those who have sustained an Achilles tendon rupture. Questionnaires might not be sufficient for gaining a deeper understanding of what affects recovery and return to activity after Achilles tendon rupture. Therefore, detailed interviews need to be conducted and analysed (Study IV).

CHAPTER 3

AIM

AIM

The overall aim of this thesis was to evaluate different factors that may influence patients' return to physical activity after an Achilles tendon rupture.

Both physiological and psychological factors affect the rehabilitation and recovery process, some of which are possible to control, while others are not. Greater knowledge of these factors will enable healthcare professionals to decide what should be prioritized during the initial treatment, as well as in the ongoing rehabilitation. Overall, this may reduce the risk of permanent interlimb difference, thus increasing the individual's chance of a safe return to the desired activity/sport/play.

A safe return to activity is important for preventing other symptoms and illnesses that can develop over time due to lack of physical activity.

OBJECTIVES

Study I:

The primary aim was to evaluate the difference in foot structure between the uninjured and the injured side six years after an acute Achilles tendon rupture. A secondary aim was to assess the correlation between the foot structure on each side as well as functional and clinical outcomes. The differences between treatment groups were also assessed.

Study II:

The aim was to determine the effect of fatigue on lower limb kinetics after an Achilles tendon rupture. This was achieved by evaluating whether the effect of fatigue on the ankle, knee or hip differed between the uninjured and the injured side during a single-leg drop countermovement jump (CMJ) test.

Study III:

The aim was to evaluate interlimb differences during a single-leg drop CMJ between those who refrained from activity due to fear of re-injury and those who did not, at an average of two years after injury. This was achieved by evaluating the differences in peak negative and positive joint power values during landing and push-off, respectively. The ankles, knees and hips were compared.

Study IV:

The aim was to deepen the understanding of what influences the patient to return to activity/sport/play after an acute Achilles tendon rupture, using a qualitative content analysis approach.

CHAPTER 4

METHODS

METHODS

Several different research methods were employed in this thesis. An overview of the methods used in each studies is presented in Table 1. A detailed description of each of them can be found in the following chapters.

TABLE 1: Overview of the methods used in each study.

	Study I	Study II	Study III	Study IV
Patient Reported Outcome Measures (PROMs)	x	x	x	
Quantitative research Foot structure evaluation	x			
Quantitative research Tendon length evaluation	x			
Quantitative research Functional evaluation	x	x	x	
Quantitative research Biomechanical evaluation		x	x	
Qualitative research Content analysis				x

PATIENT REPORTED OUTCOME MEASURES

Patient reported outcome measures (PROMs) are widely used in research to evaluate patients' experiences. In this thesis, three different PROMs were used in each of the three studies (Table 2).

TABLE 2: Patient reported outcome measures used in the studies.

	Study I	Study II	Study III	Study IV
ATRS	x	x	x	
PAS	x	x	x	
Fear of reinjury			x	

Achilles tendon total rupture score (ATRS)

The ATRS was developed in Sweden and is used to evaluate physical activity and function after an acute Achilles tendon rupture [104]. The instrument consists of ten questions about limitations caused by symptoms such as pain and decreased strength when performing certain activities e.g., walking uphill, running and jumping. It is graded on a scale from 0-10, where 10 is the best possible outcome. The highest possible final score is 100, which indicates no functional deficits due to an Achilles tendon rupture.

The ATRS validation was found to be high, when compared with other scores. Reliability testing showed an internal consistency of 0.96 and an intraclass correlation coefficient (ICC) of 0.98 [104]. The ATRS is frequently used all over the world and has been translated, cross-culturally adapted, validated and reliability tested in thirteen languages, including Chinese [35], Polish [12] and English [27].

Physical activity scale (PAS)

The PAS was first introduced in 1968 by Saltin and Grimby [126] to evaluate "middle-aged and old former athletes" and designed as a four-level scale where occupational activity and spare-time physical activity were evaluated. A modified scale from 1986 for measuring physical activity in older individuals was used in the present thesis [55]. It comprises six levels, 1-6, where one indicates barely any physical activity and six indicates heavy physical exercise several times a week. The scale has been modified several times over the years to fit various studies, thus making comparison between studies difficult [56].

Fear of reinjury

To evaluate fear of reinjury in Study III, one question was asked two years after the injury: *"Do you ever refrain from any activity due to fear of reinjuring your Achilles tendon?".* The response alternatives were yes/no and determined whether patients were afraid of reinjury. This question has not previously been validated or reliability tested for patients with an Achilles tendon rupture.

QUANTITATIVE RESEARCH METHOD

General quantitative research methods are objective measurements, which require mechanical equipment to perform as opposed to the researcher's judgement [139]. A measurement involves establishing a value and comparing it to a standard. The measurements obtained for research purposes are called data and statistics are used to organize and interpret them to achieve a result. Further evaluation of the results is necessary to determine their relevance and whether they add anything to existing research.

In order to use the collected data, they must be obtained by means of objective, validated and reliable methods. Objective methods are free from bias and the investigators' own feelings cannot influence the measurements. To be properly validated, methods must be evaluated to determine how appropriately they measure what they are supposed to measure. The reliability of the data is based on the consistency of the values, evaluated by means of test-retest methods. The results should be identical when doing the same measurement multiple times, under the same circumstances [139].

FOOT STRUCTURE EVALUATION

In Study I, the foot structure was evaluated at a mean of six years after an Achilles tendon rupture as described by Barton et al. [14]. The measurements used for foot structure evaluation were navicular drop and drift, longitudinal arch angle and standing dorsiflexion with the knee straight and bent. Foot structure evaluations have been tested with good to excellent intra- and inter-rater reliability and were found to be sensitive to group differences in patients with patellofemoral pain syndrome [14]. Foot structure has also been evaluated in healthy patients with varying results. An excellent intra-rater reliability has been reported (ICC: 0.928-0.937) but inter-rater reliability was reported as moderate (ICC: 0.525-0.655) [33]. It is therefore, important that the same evaluator performs all measurements, as was the case in the present study. Foot structure has not been reliability tested in patients with Achilles tendon rupture. Further information about foot structure measurement is presented below.

Navicular drop and drift [14]

To measure navicular drop (Figure 13) and drift (Figure 14), vertical navicular height is assessed, which was measured from the navicular tuberosity to the base of the foot. This measurement was performed with the participant standing on both feet, with all his/her weight on one leg while the other leg was measured. The researcher adjusted the unloaded foot into a neutral position. To evaluate the navicular drop and drift, the translation of the vertical and horizontal navicular tuberosity was measured from an unloaded standing neutral position to equal weight on both feet.

Intra-rater reliability tests have been reported moderate to excellent reliability (ICC: 0.73-0.95) and inter-rater reliability as moderate to excellent (ICC: 0.67-0.93) [14].

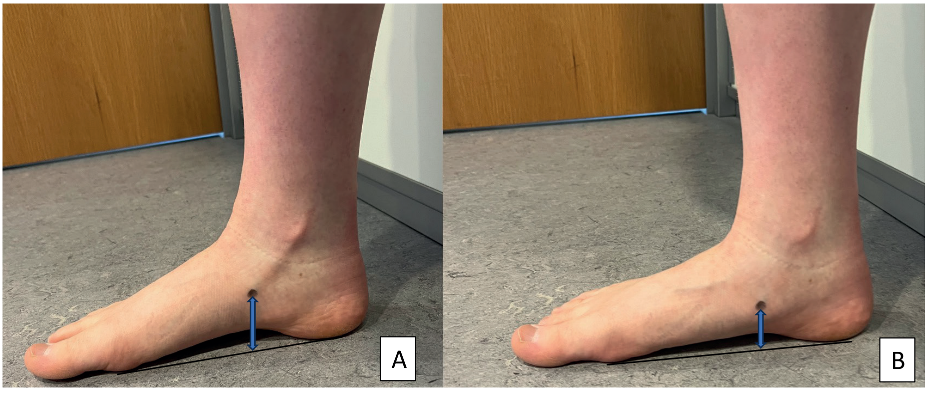

FIGURE 13: Navicular drop, the change in height of the navicular tuberosity is the navicular drop. A: the foot is unloaded and in neutral position. B: the foot is loaded.

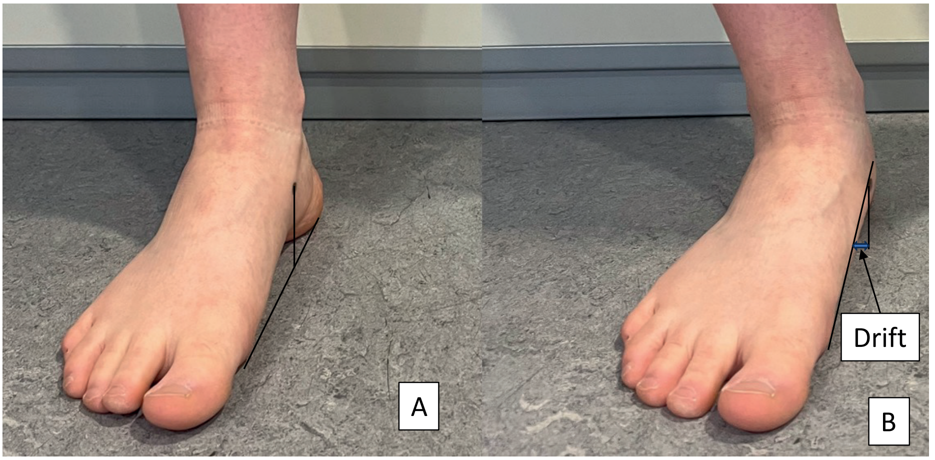

FIGURE 14: Navicular drift, the horizontal translation of the navicular tuberosity is the navicular drift. A: the foot is unloaded and in neutral position. B: the foot is loaded.

Longitudinal arch angle [96]

The longitudinal arch angle (Figure 15) is the angle formed with the head of the navicular tuberosity as the middle point and the arms directed towards the tip of the medial malleolus and the head of the first metatarsal head, respectively. A (small) goniometer was used to measure the angle with an equal weight on both feet.

A reliability test has shown that intra-rater reliability was high (ICC:0.95-0.96) while inter-rater reliability was moderate (ICC:0.67) [95].

Standing ankle dorsiflexion with knee straight and bent [99]

Ankle dorsiflexion was measured in a standing position with the knee both straight and bent. A digital inclinometer (Mitutoyo, Digital Protractor, Pro 360) was positioned on the anterior border of the tibia as the patient performed a full ankle ROM with the knee both straight (Figure 16) and bent (Figure 17).

A reliability test has been performed for the measurement with the knee straight [99]. The results revealed good intra- and inter-rater reliability (ICC: 0.77-0.91 and ICC: 0.92-0.95, respectively).

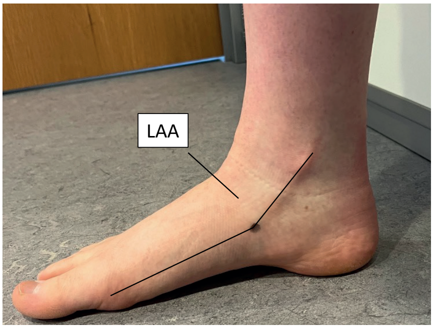

FIGURE 15: The longitudinal arch angle.

FIGURE 16: Dorsiflexion measured with knee straight.

FIGURE 17: Dorsiflexion measured with knee bent.

TENDON LENGTH EVALUATION

Tendon length measured by means of ultrasonography

When measuring the length of the Achilles tendon with ultrasonography, the musculotendinous junction (MTJ) of the soleus and gastrocnemius muscles as well as the calcaneal osteotendinous junction (OTJ) were included in the same image (Figure 18) [130]. The length measurement was performed with an extended field of view included in the ultrasound machine (Logiq E Ultrasound; GE Healthcare Sweden AB). The entire tendon was determined to extend between the calcaneal notch and the muscle-tendon junction between the gastrocnemius muscle heads [125,130].

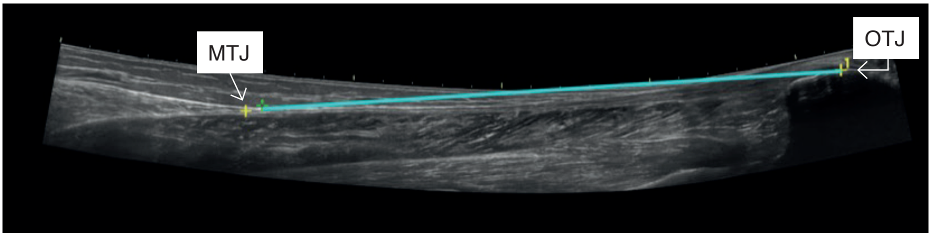

FIGURE 18: An ultrasonographic image of an Achilles tendon. MTJ=musculotendinous junction; OTJ=calcaneal osteotendinous junction.

The use of ultrasonography with an extended field of view has been found to be reliable and valid for measuring Achilles tendon length. When compared to measuring cadavers with a tape measure, ultrasonography measurement from the calcaneus to the gastrocnemius muscle (ICC=0.895) and from the calcaneus to the soleus muscle (ICC=0.744) in healthy subjects has shown good correlation [130].

FUNCTIONAL EVALUATION

Drop countermovement jump (drop CMJ)

The drop CMJ is a commonly used test when evaluating jumping mechanisms after Achilles tendon rupture (Figure 19) [103,110,118]. The instructions are to stand on one foot on a 20 cm high box and thereafter drop from the box to the floor, land with the same leg on a force plate embedded in the floor (Kistler AG, Winterthur, Switzerland) and jump as high as possible with the countermovement time being as short as possible [118]. In the present studies, 5-10 jumps were recorded. The participants all wore the same brand of shoes (Omega; Bagheera).

Biomechanical analysis of the drop CMJ

To evaluate the kinematics and kinetics during the drop CMJ, a 12-camera motion-capture system with a sampling frequency of 250 Hz was used (Oqus 4; Qualisys AB, Gothenburg, Sweden). For acquisition of kinetic data, a force plate was synchronized to the camera system (Kistler AG, Winterthur, Switzerland). In total, 54 markers were attached to define and track the following body segments: the feet, shins, thighs, pelvis and trunk (Figure 20). The tracing of body segments makes it possible to calculate kinematic and kinetic values, such as joint angles, rotary motion, linear speed and angular momentum.

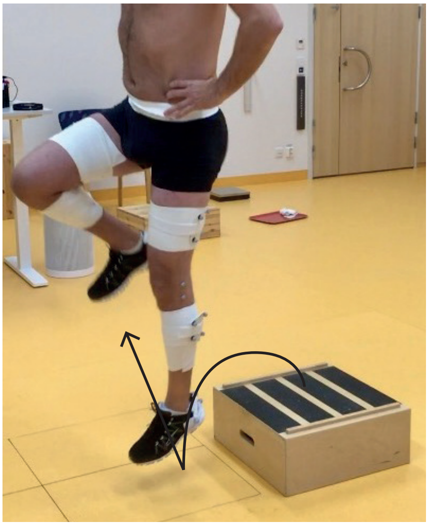

FIGURE 19: Drop countermovement jump.

FIGURE 20: Markers.

This is a well-known method for evaluating biomechanics of the lower extremities during movement [5,70,118,145]. The variables used in the present study were peak power, i.e., the lowest/highest value for eccentric/concentric power during landing/push-off calculated for the ankle, knee and hip joint.

Fatigue protocol

Single-leg standing heel-rise test

The single-leg standing heel-rise test is frequently employed to evaluate calf muscle endurance (Figure 21) [20,103,110,129]. In addition, the test was used as part of the fatigue protocol in Study II. Hébert-Losier et al. [61] tested it and found that it had excellent reliability (ICC=0.96) when evaluating calf muscle endurance. In the same study, these researchers used the outcome of repetitions as representative of a normative population, with a median of 24 and 21 repetitions for males and females, respectively [61]. The validity of the heel-rise test has also been tested; the calculations resulted in good validity [129]. The authors recommended it as a heel-rise work test, as it combines muscle endurance and heel-rise height [129].

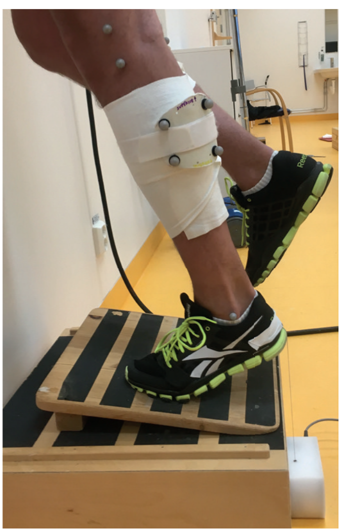

FIGURE 21: Single-leg standing heel-rise test.

The instructions for the test are to perform as many heel-rises as possible at the rate of 30 per minute, on a 10° incline on top of a box and to go as high as possible during each heel-rise. Balance support with the fingertips on the wall at shoulder height is permitted. A metronome is used to guide the tempo during the heel-rises. To measure the height and frequency of the heel-rise, a linear encoder unit connected to the MuscleLab™ (Ergotest Technology, Oslo, Norway) measurement system is attached to the heel cap of the patient's shoe (see white unit on the bottom right in Figure 21). The measurement stops when the heel-rise height is below 2 cm, or the patient is unable to maintain the required tempo. If the patient's body weight is known, it is possible to calculate the work expended during the test*. In the studies included in this thesis, the patients always wore standardized shoes (Omega; Bagheera) to minimize the effect of different shoe designs. The measurement started on the uninjured side, followed by the injured side.

Sliding on a slide board

To implement a more global fatigue, a standardised fatigue protocol for healthy participants performing drop CMJ was implemented [18]. A slide board was adjusted to 1.5x the lower extremity length and the participant slides sideways for 5 minutes with increased intensity (Figure 22). Before

* *Work (Nm) =Force (N, mass (kg)*acceleration (metre/seconds^2)) *distance (m)*

starting the protocol the participant was introduced to the Borg scale [28], an instrument that is used to evaluate the physical activity intensity level. The version used has a scale of 6-20 and the aim was for the participants to reach levels 15-20 by the end of the fatigue protocol.

FIGURE 22: Sliding on a slide board.

BIOMECHANICAL EVALUATION

In Studies II and III the biomechanical data were processed using commercial biomechanical software (Visual 3D™; C-Motion, Inc, Germantown, USA). After examination of the data, the faulty trials were removed. A low-pass Butterworth filter (20 Hz cut-off) was used to filter noise from the raw Ground Reaction Force (GRF). For the marker data a low-pass Butterworth filter (8 Hz cut-off) was employed.

A Microsoft Excel file with all the data was extracted from the Visual 3D and the trials were labelled according to the data they presented. In Study II, the labels indicated before and after fatigue (pre/post fatigue), landing and push-off phases, and the uninjured and injured side. In Study III, the labels denoted Fear and No-fear depending on the answer to the question about fear of reinjury, landing and push-off phases, and uninjured and injured side. Later in the process the data for the landing and push-off phases were labelled as eccentric and concentric phases.

The power of the hip, knee and ankle joints were calculated. The peak power of the lower extremity joints in the sagittal plane was used as well as the peak power in the frontal plane for the hips. Body weight enabled normalization of the kinetic data.

STATISTICAL METHODS

Study I: Evaluation of the data using the Shapiro-Wilks test revealed that not all variables were normally distributed. Therefore, it was decided to employ non-parametric statistics. The Wilcoxon signed rank test was applied for comparison between sides and the Mann-Whitney U test was used to compare treatment groups. Spearman's correlation coefficient was applied to examine whether the difference between sides in terms of foot structure correlated with functional and clinical outcome in the lower extremities. The p-value for the level of significance was set at 0.05 ($p \leq 0.05$).

To compare the difference between sides, the Limb Symmetry Index (LSI) was calculated between the injured side and the uninjured side, expressed in percent:

(LSI= (injured side/uninjured side) *100)

To our knowledge no foot structure research has been conducted on patients who have injured their Achilles tendon and therefore, no power calculation was performed. However, in our study all the patients were randomized to surgical or non-surgical treatment groups and all measurements were executed by the same experienced physiotherapist.

Studies II and III: The same data collection method was used for Studies II and III, but the factors evaluated differed.

When calculating group demographics, the difference was that in Study II Microsoft Excel was used for group demographics (mean, standard deviation, median, minimum value and maximum value), while IBM SPSS statistics version 25 for Mac was employed in Study III for the statistical analysis of demographics. In Study III, non-parametric tests were applied when calculating demographics due to low number of participants in both groups. For between-group measurements, the Mann-Whitney test was used for age, time since rupture, height, weight, Body Mass Index (BMI), ATRS and PAS. However, Fisher's exact test was applied for the nominal data of treatment type and gender.

Jamovi (version 1.2.17.0) for Mac for Analysis of Variance (ANOVA) as well as post hoc tests of the biomechanical data were used in both studies. The biomechanical data were normally distributed and therefore evaluated using parametric statistics in both studies. To calculate effect size and analyse kinetic variables, a mixed-model full-factorial ANOVA ($\alpha = 0.05$) was employed.

The difference in biomechanical analysis between Studies II and III was the evaluation of the "fatigue" variables (before and after fatigue protocol) and the "Fear/No-fear group" variables, respectively. Both studies compared variables between sides (injured and uninjured side) and phases (landing and push-off). In Study III, Bonferroni correction was used for post-hoc testing where appropriate.

Calculations of statistical power (95% power and $\alpha = 0.05$) for side-to-side difference between ankle eccentric power and concentric power indicated that a sample size of 25 and 28 participants, respectively, were required.

Study IV: No statistical methods were used in this qualitative study.

QUALITATIVE RESEARCH

According to Graneheim and Lundman [54] trustworthiness is the aim of all research, both quantitative and qualitative. For quantitative research, validity and reliability are calculated for the tests to ensure trustworthiness.

The five main concepts in qualitative research are credibility, dependability, confirmability, transferability and authenticity [53]. To ensure credibility it is important to be certain that the participants have first-hand experience of the phenomenon under study and that there is a variation in experiences between the participants in the group. To establish that significant distribution is achieved, it is important to capture as much variation as possible. It can therefore be difficult to decide how many participants are required for the interviews. However, at some point their experiences will overlap and there are no further meaningful quotes added (called meaning units) even though increased number of new interviews are conducted. Meaning units are concepts, words, phrases or sentences, which are highlighted in a transcribed text and support the emerging thread.

A good description of the participants is important for transferability to enable comparison with similar groups and contexts. Qualitative research cannot be compared with a general population but only with a group very similar to that in the interviews. Dependability is the assurance that the meaning units, codes and categories are correctly created and that the qualitative research rules have been adhered to. Therefore, it is recommended that more than one person should analyse the text, especially as one's own experience can influence what is considered a meaning unit. Analysis of the text by more than one person is termed consensus or confirmability. To ensure that the core message reaches the reader it is important that quotations from the interviews are included in the paper as a means of confirming the authenticity and credibility of the study and that the interviewees' voices are heard [53].

QUALITATIVE CONTENT ANALYSIS

Qualitative content analysis is a form of research, where data are analysed "within a specific context in view of the meanings someone – group or a culture – attributes to them" [81]. A text can have different meanings for the writer and the reader that are related to the context in which it was written. The findings of a content analysis cannot be observed immediately but have to be interpreted before reaching a conclusion and there is never one right answer as is often the case in quantitative studies [81].

When evaluating the reasons patients return to their previous activity by means of qualitative content analysis, the aim is to study something that cannot be identified with PROMs but affects the patients ´road to recovery.

The semi-structured interviews were audio recorded with a digital voice recorder (Olympus DM-770,) and then transcribed by a secretary. The transcripts were uploaded to the NVivo 12 (QSR International Pty Ltd, Doncaster, Victoria, Australia) software in order to analyse the data based on the method described by Graneheim and Lundman [54].

The first step is to derive meaning units from the text. Meaning units are units that the researcher identifies as important for fulfilling the study aim. Meaning units can consist of words, concepts, phrases, sentences or even paragraphs, which are extracted and coded. Codes are usually concepts or sentences that summarize different meaning units. The codes are then sorted into categories or sub-categories, depending on the researcher interpretation. The final step is to formulate themes to provide an overview of the categories (Figure 23) [54].

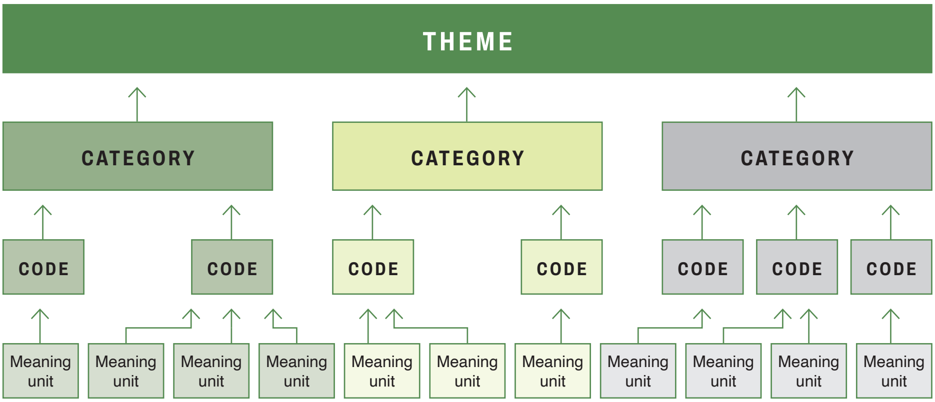

FIGURE 23: Flowchart explaining the levels in qualitative content analysis.

CHAPTER 5

PARTICIPANTS

PARTICIPANTS

The studies from which the participants were drawn are presented in the flowchart (Figure 24).

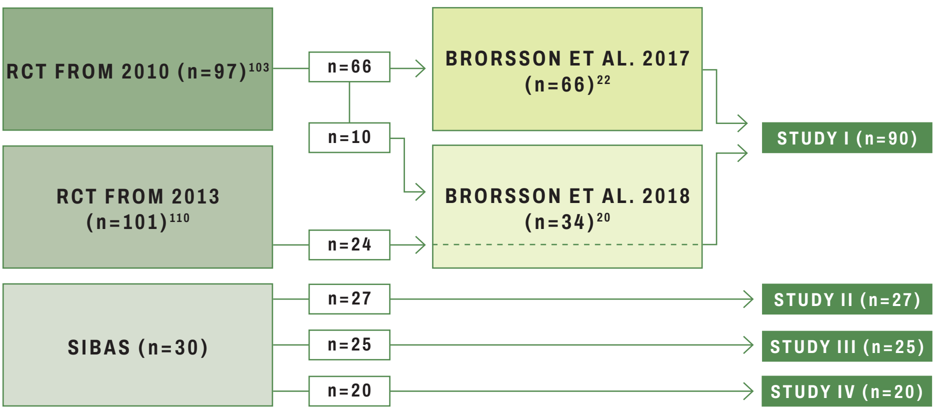

FIGURE 24: Flowchart of the studies from which the participants were drawn. SIBAS: Swedish Icelandic Biomechanical Achilles tendon Study.

Study I: The participants in Study I were recruited from a previously studied population in two randomized controlled trials (RCT ́s) in which the difference between surgical and non-surgical treatment was evaluated. In the 2010 study by Nilsson-Helander et al. [103] 97 patients were randomized into treatment groups and followed for one year [103]. After a year evaluations were performed, which included inter alia clinical examination, functional tests and ATRS. All the participants had sought medical treatment because of acute Achilles tendon rupture from 2004 to 2007 at Sahlgrenska University Hospital in Gothenburg, Sweden. These participants were also evaluated in two different studies at two years [109] and seven years [20] post injury. During the seven-years follow-up, the 66 participants had their foot structure evaluated, which data were used in the present study. Therefore, out of the 97 patients in the original RCT, 66 were enrolled to the present study. The RCT from 2013 by Olsson et al. [110] included 100 patients recruited from 2009 to 2010 at Sahlgrenska University Hospital in Gothenburg. The patients were randomized to surgical treatment with an accelerated rehabilitation protocol or non-surgical treatment [110]. Out of the original 100 participants, 24 were included in the present study. Twenty-four participants from Olsson et al. (2013) [110] and 10 participants from Nilsson-Helander et al. (2010) [103] made up the sample of 34 participants in a 2017 study conducted by Brorsson et al. [22].

Of the 90 participants in our study, 45 had undergone surgery while 45 had not. Demographics of the participants are presented in Table 3.

Studies II-IV: Participants in all three studies came from a collaboration between the laboratory at the Department of Orthopaedics at Sahlgrenska Academy in Gothenburg and the Department of Physical Therapy, Research Center of Movement Science, Faculty of Medicine at the University of Iceland. Therefore, the data were labelled the Swedish Icelandic Biomechanical Achilles Tendon Study (SIBAS). All participants sought medical assistance at Sahlgrenska University Hospital in Gothenburg because of an acute Achilles tendon rupture and the data collection was performed in 2016.

Data were collected from 30 participants. The demographics of the study participants are presented in Table 3.

TABLE 3: Demographics of the participants in all studies.

	Study I	Study II	Study III	Study IV
Patients included (n)	90	27	25	20
Age				
mean, years (SD),	49 (9)	43 (8.9)	43.5 (9.3)	46.2 (9.76)
median,	48	44	45	47
min-max	30-69	24-59	24-59	27-62
BMI				
mean (SD),	27.0 (3.5)	26.0 (2.4)	26.2 (2.6)	26.0 (2.7)
median,	26.3	26.4	26.5	26.4
min-max	21.8-44.9	21.4-30.6	21.4-30.6	21.4-30.6
Time since injury				
mean, years (SD),	6.3 (1.5)	2.0 (0.70)	2.0 (0.68)	5.0 (0.7)
median,	7	2.25	1.75	5.25
min-max	4-9	1-2.9	1.1-2.9	4.1-5.9
Gender (male/female)	75/15	24/6	20/5	14/6

CHAPTER 6

ETHICAL CONSIDERATIONS

ETHICAL CONSIDERATIONS

Study I: Ethical approval for the original studies was obtained from the Regional Ethical Review Board in Gothenburg, Sweden (DNR: S617-03, 307-07 and 032-09) and additional approval was obtained for the present study (DNR: T426-12 and 058-14). The participants gave their oral and written consent before inclusion in the study and offered their time for the measurements and for answering PROMs. There was no risk of injury to the participants.
The data obtained were stored in a locked cabinet at the Department of Orthopaedics, Institute of Clinical Sciences at Sahlgrenska Academy, University of Gothenburg.

Studies II and III: Ethical approval was obtained from the Regional Ethical Review Board in Gothenburg, Sweden (DNR: 803-15). Oral and written information was provided to all the participants before recruitment and they gave their oral and written consent. The preparation for and execution of the tests required time and patience. There was a small risk of injury and minor muscle fatigue after the tests.
The data obtained were stored in a locked cabinet at the Institute of Clinical Sciences at Sahlgrenska Academy, University of Gothenburg.

Study IV: Ethical approval for the study was obtained from the Regional Ethical Review Board in Gothenburg, Sweden (DNR: 876-18). The participants gave their oral consent before being included in the study. Prior to the interviews, the participants were provided with an information document to read, allowed to ask questions about the study and given a consent form to sign. There was no risk of injury when performing this study, but the interviews took time and, although unlikely, some might experience psychological discomfort after the interview.
The data obtained were stored in a locked cabinet at the Institute of Clinical Sciences, Sahlgrenska Academy, University of Gothenburg.

CHAPTER 7

RESULTS AND SUMMARY OF PAPERS

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STUDY I

The injured limb presents lower values in foot structure measurements 6 years after an Achilles tendon rupture

Aim: The primary aim of the study was to evaluate the difference in foot structure between the uninjured and the injured sides as well as between the two treatment groups 6 years after an Achilles tendon rupture. A secondary aim was to evaluate whether there was a correlation between the difference in foot structure and clinical and functional outcome in the lower limb. The differences between treatment groups were also evaluated.

Method: Foot structure measurements were performed on 90 patients (75 males and 15 females) who were randomized to surgical (n=45) and non-surgical (n=45) treatment. The group members' mean age was 49 years (SD: 9). The measurements comprised navicular drop and drift, longitudinal arch angle and ankle dorsiflexion, standing with the knee straight and bent. The single-leg standing heel-rise test was used to examine calf muscle performance and tendon length was examined by means of ultrasound. The Achilles tendon total rupture score and the Physical activity scale were employed for patient-reported outcome measures. Both sides were evaluated and compared using the limb symmetry index (LSI (%) =injured/uninjured*100).

Results: Firstly, there were significant differences between the uninjured and the injured sides, where the latter had lower values for ankle dorsiflexion with knee bent and navicular drop and drift (Table 4). When comparing treatment groups, there were no differences in terms of the injured side, but there were higher values in the longitudinal arch angle and navicular drop and drift in the uninjured side.

Secondly, there was a correlation between the LSI navicular drop and LSI heel-rise height as well as the LSI dorsiflexion with the knee straight. The LSI navicular drift also correlated with the LSI heel-rise height.

Conclusion: Achilles tendon rupture affects the foot structure 6 years after injury but there is no difference between treatment groups on the injured side. The uninjured side had significantly higher foot structure values in the non-surgically treated group, meaning that the longitudinal arch angle is larger (higher arch) than in the surgically treated group. There was also increased navicular drop and drift on the uninjured side of the non-surgically treated group compared with the surgically treated one.

TABLE 4: Interlimb foot structure difference and difference between treatment groups. The difference between the injured side and the uninjured side in both groups is also presented.

VARIABLES	INJURED SIDE	UNINJURED SIDE	P-VALUE	INJURED SIDE	UNINJURED SIDE	P-VALUE	INJURED SIDE	UNINJURED SIDE	P-VALUE	P-VALUE INJURED SIDES	P-VALUE UNINJURED SIDES
	Total			Surgery			Non-surgery				
LAA	n=90	n=90		n=45	n=45		n=45	n=45			
Mean (SD)	142.6 (13.4)	143.7 (12.5)	n.s.	138.8 (16.6)	139.6 (14.2)	n.s.	146.4 (7.7)	147.9 (8.9)	n.s.	n.s.	0.016
Median	144	145.5		142	144		146	148			
Min Max	100 168	98 168		100 162	98 160		136 168	128 168			
NAV_{DRIFT} (mm)	n=90	n=90		n=45	n=45		n=45	n=45			
Mean (SD)	6.0 (3.2)	6.7 (3.4)	0.034	6 (3.3)	6 (3.7)	n.s.	6.0 (3.2)	7.4 (3)	0.005	n.s.	0.044
Median	5	6		5	5		6	8			
Min Max	0 17	0 14		1 17	0 14		0 14	2 14			
Nav_{DROP} (mm)	n=90	n=90		n=45	n=45		n=45	n=45			
Mean (SD)	6.6 (3.4)	7.4 (3.6)	0.032	6.4 (3.9)	6.6 (3.9)	n.s.	6.9 (3.4)	8.2 (3.2)	0.005	n.s.	0.019
Median	6	7.5		6	6		6	9			
Min Max	0 17	0 17		1 17	0 17		0 17	2 15			

n.s.: non significant
LAA: longitudinal arch angle
NAV_{DRIFT}: navicular drift
NAV_{DROP}: navicular drop
mm: millimeter

STUDY II

Dissimilar effect of fatigue on lower limb kinetics during single-leg drop countermovement jump two years after an Achilles tendon rupture

Aim: To explore lower extremity kinetics and the difference before and after a fatigue protocol during a drop countermovement jump (drop CMJ), 2 years after an Achilles tendon rupture.

Method: Twenty-seven patients were biomechanically evaluated two years after an Achilles tendon rupture. The drop CMJ functional test was used to evaluate peak power values before and after a fatigue protocol for the ankle, knee and hip joints. A mixed model ANOVA was applied to calculate the differences between sides before and after the fatigue protocol during peak eccentric power (landing) and peak concentric power (push-off).

Results: The fatigue protocol had a greater effect on the ankle of the uninjured side than the injured one i.e., the power of the uninjured ankle decreased significantly more than on the injured ankle. The fatigue protocol had no effect on the knee or the hip.

Conclusion: The decrease in power during landing and push-off after the fatigue protocol on the uninjured side is significantly higher than on the injured side.

STUDY III

The effect of fear of reinjury on joint power distribution during a drop countermovement jump two years after an Achilles tendon rupture

Aim: The aim of the study was to evaluate biomechanical differences in the lower extremities, between those assigned to a Fear group and a No-Fear group based on self-reported fear of reinjury during activity after an Achilles tendon rupture. This was explored by evaluating the landing and push-off in a drop countermovement jump (drop CMJ).

Method: A total of 25 participants were evaluated two years after an Achilles tendon rupture by asking them whether they refrained from movement due to fear of injuring their Achilles tendon again. Based on their answer (yes/no), they were appointed to the Fear/No-fear group. Peak power values both for landing and push-off in the ankle, knee and hip joints were calculated during a drop CMJ. The between group peak power evaluations were performed by means of a mixed model ANOVA.

Results: Thirteen participants answered "yes" and twelve answered "no" to the question: "Do you ever refrain from physical activity because of fear of reinjuring your Achilles tendon?".

There was a significant difference in power between the Fear and the No-fear group in both the ankle and the knee of the injured side. During landing and push-off the power of the ankle joint was lower and knee joint higher in the Fear group compared to the

No-fear group (Table 5). When evaluating the frontal plane of the hip, there was a 3-way interaction between the groups, sides and phases (landing and push-off) (Table 5).

Conclusion: There was greater symmetry between the sides in the No-fear group than in the Fear group, where the asymmetry was greatest in the ankle and knee. If not corrected at an early stage, there might be a risk of asymmetry between the sides leading to complications in the form of overuse injuries.

TABLE 5: Results of the groups mean peak power.

POWER (W/kg)		LANDING		PUSH-OFF	
MEAN (SD)		Injured	Uninjured	Injured	Uninjured
ANKLE*†	FEAR	9.3 (3.9)	12.7 (3.0)	7.9 (1.9)	7.9 (1.9)
	NO-FEAR	11.8 (3.7)	13.5 (2.8)	8.8 (2.1)	10.9 (2.2)
KNEE*	FEAR	11.3 (3.8)	9.3 (2.4)	6.4 (2.3)	5.2 (2.0)
	NO-FEAR	10.1 (3.4)	10.9 (2.7)	5.7 (3.0)	5.5 (1.8)
HIP-SAGITTAL‡	FEAR	4.2 (2.2)	4.2 (2.1)	3.5 (1.8)	3.9 (2.0)
	NO-FEAR	5.2 (4.6)	5.2 (3.4)	4.4 (2.6)	4.3 (2.5)
HIP-FRONTAL**	FEAR	3.9 (1.8)	4.1 (1.7)	1.9 (0.8)	1.8 (0.8)
	NO-FEAR	3.5 (1.6)	3.5 (1.7)	1.5 (1.0)	1.9 (1.1)

SD: standard deviation

*Significant group by side interaction ($p<0.001$)

†Significant group by phase interaction ($p<0.001$)

‡Main effect of side ($p<0.05$) and phase ($p<0.05$)

**Significant group by side by phase interaction ($p<0.001$)

STUDY IV

Factors that affect return to sports after an Achilles tendon rupture - A qualitative content analysis

Aim: To explore and describe the factors that influence the participant to return to physical activity after an Achilles tendon rupture.

Method: A qualitative content analysis was used to analyse 20 interviews with 14 men and six women (mean age: 46 years) who had ruptured their Achilles tendon 4-6 years previously. Meaning units were identified, extracted and coded. Similar codes were sorted into 19 sub-categories, which were further grouped into six categories, generating an overarching theme.

Results: The overarching theme was “Help me and then I can fix this”. Examples of the categories, sub-categories and codes are presented in Table 6.

Conclusion: The theme “Help me and then I can fix this” characterizes the patients’ need for support to achieve the first steps of recovery. When the participants are back on their feet, they can continue their recovery without or with only minimal assistance. The support can come from various sources, but its importance is undeniable.

TABLE 6: Examples of categories, sub-categories and codes.

Categories	Sub-categories	Codes
1) One’s own drive to succeed	A. The importance of having something to work towards (goal)	a) Important to have a reason for the exercises
2) Having a supportive social network	A. Flexibility at work during the rehabilitation period	a) Had great understanding and help from my supervisor
3) Trusting the support from health and social systems	A. Accessibility or availability to be mobile	a) Would not have been able to take the bus, so I needed help with transport
4) Receiving and adapting information from others drives persistence in returning to activity	A. Experience of others that have ruptured their Achilles tendon to promote self-improvement	a) Athletes inspired, if they can do it so can I
5) The impact of the injury on psychological factors	A. Acceptance and adaptation to the situation	a) Having had previous injuries, helped adapting
6) The influence of physiological aspects	A. How physical fitness before the injury affected the process	a) Had always exercised; that helped to understand how important rehabilitation is

CHAPTER 8

DISCUSSION

DISCUSSION

After an injury such as Achilles tendon rupture, the road to recovery is long and without doubt will test an individual's patience. Making the decision to perform similar rehabilitation exercises every day requires commitment and motivation. Sometimes one has a bad day when progress is below expectations but postponement is out of the question if one wishes to achieve optimal recovery after an injury. Both in Icelandic and Swedish there is a term to describe that what you do today is dependent on your ability on that very day. This term is "dagsform" (English: "current state"), i.e., your achievements today are influenced by both your physical and psychological state. If your "dagsform" is not at its best, you cannot expect good results. To achieve optimal recovery, the patient's "dagsform" needs to be above average every day for the motivation to make the effort to perform the rehabilitation in a focused way.

The overall purpose of this thesis was to evaluate different factors that may influence patients to return to activity after an Achilles tendon rupture. By evaluating both physiological (Studies I, II and III) and psychological factors (Studies III and IV) it was possible to deepen the knowledge and move closer to answers in terms of what is optimal treatment and rehabilitation after an Achilles tendon rupture. Hopefully these results will help healthcare personnel when assisting patients to reach their goals and return to activity. In the longer term, these results might add a piece to the puzzle of how to minimize interlimb difference, thereby ensuring a safe return to activity as well as reducing the risk of overuse injuries. In the following sections, the results will be discussed in the light of other studies on similar topics.

Achilles tendon rupture appears to affect various factors concerning movement of the lower limb. Biomechanics [22,145], endurance [20,129] and strength [22,103,110] are altered, in addition to functional outcomes measured by means of PROMS [88,103,109,110,129]. When digging a little deeper, it is reasonable to ask why these factors change after an Achilles tendon rupture. Tendon elongation is likely to be a major factor in these changes as well as the inelastic scar tissue that develops in the tendon during healing [92,115]. Moreover, during recovery the patient is partly immobilized and during that period the strength of the limb decreases. Not only is the strength reduced in the triceps surae, but possibly also in other muscles in the injured side, while the uninjured limb might become stronger from carrying an additional, compensatory load.

In Study I the function of the foot muscles is indirectly assessed through measurements of foot structure and tendon length. The rationale was that decreased strength in the intrinsic foot muscles due to weeks in a cast/brace after Achilles tendon rupture will result in increased pronation or pes planus. Although our results did not support this, they showed that there is a difference between the injured and the uninjured foot. The difference was illustrated by higher values for the uninjured foot, i.e., it had a higher longitudinal arch and the movement of the navicular bone increased in line with greater load. Dynamic measurements were not included in this study, but it would be interesting to measure these factors during walking, jumping and running to assess whether the difference between the sides would be the same.

In the 21 studies included in the systematic review and meta-analysis by Neal et al. [102], there was limited evidence that pronated foot posture was a risk factor for patellofemoral stress syndrome and strong evidence that it was a risk factor for medial tibial stress syndrome. No further evidence of other lower extremity foot pathologies was presented in the study [102]. The same group of researchers also published a second systematic review and meta-analysis, where they evaluated dynamic foot posture [41]. The outcome of the 12 included studies did not show conclusive results with either limited or very limited effect on the risk of plantar loading increasing the likelihood of patellofemoral pain syndrome and Achilles tendinopathy, respectively [41].

The foot structure measurements have been evaluated in terms of reliability, the key factor being that they were all performed by the same experienced examiner [14]. Not only was the examiner who performed the measurements in the present study experienced but the same person performed all the measurements. A limitation is the lack of a control group.

In **Study I** comparison of Achilles tendon length between the injured and the uninjured side was also included. Like many other studies [39,131,147,149], the Achilles tendon was significantly longer on the injured side. As the triceps surae is one of the strongest supinator in the ankle joint [116] it is interesting to study what effect an elongated Achilles tendon has on foot structure. The results showed differences in navicular drop and drift with the uninjured side having increased movement from the neutral to the loaded foot. The question is whether the injured side might have already had a fairly flat foot in the neutral position, which makes the movement negligible when loading the foot. The measurements of the longitudinal arch angle (measured in a loaded position) revealed a lower value for the injured side, which means that the foot is flatter. It remains to be confirmed if the explanation is that the Achilles tendon is longer and therefore cannot support the longitudinal arch or that the intrinsic foot muscles are weaker than on the uninjured side, and the plantar ligaments give way more easily after immobilisation.

Evaluations of the elongation of the Achilles tendon have been shown to be reliable, both when measuring the ruptured Achilles tendon and when comparing it with the uninjured limb [130]. The results of tendon length measurements are similar to those presented in the systematic review by Diniz et al. [39].

Endurance and strength are other factors that need to be considered. It may be that alterations in the foot structure after Achilles tendon rupture e.g., Achilles tendon elongation affect these factors. To evaluate the endurance of the triceps surae, the single-leg standing heel-rise test is often used [17,20,109,129]. The test measures heel-rise height, counts the repetitions and calculates the work used when performing the test. The validity of the test is good when evaluating heel-rise repetition, heel-rise height and heel-rise work as well as for determining the difference between the injured and the uninjured side [129]. In Study II, the test was used as part of the fatigue protocol and revealed a considerable average deficit on the injured side in all evaluated factors (heel-rise height, repetitions and work) as presented in the limb symmetry index. A main concern was what effect this lack of endurance would have on lower leg biomechanics when measuring kinematics and kinetics during the drop CMJ. To our knowledge, the effect of fatigue on changes in these factors has not been previously evaluated after an Achilles tendon rupture, but the effect is well known when evaluating risk factors for ACL injuries [15,18,72,94,113].

The results showed that fatigue had an effect on ankle joint peak power during landing and push-off and that there was a difference between the sides. However, the effect was greater in the ankle joint of the uninjured limb, while there was no difference between the sides in the knee or hip joints. This is probably because the uninjured side has more power before the fatigue protocol and therefore might compensate for the injured side during the fatigue protocol, making the effect of fatigue greater. This difference between the sides is a matter of concern, as the fatigue protocol merely comprised five minutes of lateral slides on a slide board in addition to the heel-rise standing single-leg test. Thus, the difference between the sides could be greater when playing a football match for 90 min or running in a marathon. It would be interesting to examine an athlete before and after participation in sport to see what effect the activity has on peak power during landing and push-off.

Apart from the fact that the lateral slides on a slide board were only performed for five minutes (followed by the heel-rise single-leg test), this test might not be the most obvious choice when trying to induce fatigue in the Achilles tendon. Some might even argue that running would be a better choice. However, the lateral slide test was deemed appropriate due to inducing fatigue in many muscles of the lower extremity.

Interlimb asymmetry during jumping and landing has been shown to lead to an increased risk of recurrent ACL injuries [64,71]. Although our theory does not assume an increased risk of recurrent Achilles tendon rupture with lower limb asymmetry, it might increase the risk of overuse injury, for which further studies are required.

The population in **Study III** was divided into two groups depending on the answer to a question: *"Do you ever refrain from any activity due to the fear of reinjuring your Achilles tendon?".* While it would have been possible to use a questionnaire related to fear of movement (e.g. the Tampa Scale of Kinesiophobia, TSK), the authors felt that it did not exactly correspond to our aim, i.e. whether there was fear of another injury or re-rupture of the Achilles tendon. Therefore, the above-mentioned question was employed instead, even though to our knowledge, it has not been used before and is therefore not validated. With a cohort of 25 patients, the Fear and No-fear groups were very small (12 and 13, respectively), which is a limitation. But even these small groups demonstrated a difference in biomechanics during landing and push-off, where the asymmetry between the sides was greater in the Fear group.

In a clinical review evaluating fear of reinjury, Hsu et al. [67] concluded that such fear will hinder a successful return to sports. They suggested submitting a questionnaire to athletes during the rehabilitation period that would serve as an indicator of their readiness to return to sport. Different kinds of questionnaire are available, and it might be helpful to discuss in greater detail which one is best. Hsu et al. [67] stated that "Fear of reinjury in athletes is similar to fear of movement/reinjury, also called kinesiophobia", which statement we disagree with, as mentioned earlier in this chapter. The five questionnaires outlined in the clinical review comprised two for athletes in general, two for those who sustained ACL injuries and one for chronic pain. Of those five, the one called "Return to sport after serious injury" might be the most appropriate for athletes after an acute Achilles tendon rupture [117].

The results demonstrating increased asymmetry between the sides within the Fear of reinjury group are in agreement with those of Paterno et al. [112] where the patients who were afraid (as measured by the Tampa scale of Kinesiophobia) were more likely to exhibit asymmetry between sides in a hop test after an ACL injury. The group with high fear values was more likely to have a lower activity score, which although nonsignificant, is also in agreement with the results of the present study (Physical activity scale: Fear group=3.8; No-fear group=4.6, p=0.09). Those with higher fear values in the study by Paterno et al. [112] were also more likely to suffer another ACL injury. A second study about fear after an ACL injury reported a higher likelihood of returning to sport in patients with less fear of reinjury and more confidence after an ACL reconstruction [84].

A study from 2021 by Slagers et al.[132] employed several questionnaires to "gain insight into the changes in psychological factors during rehabilitation after Achilles tendon rupture and to explore the association between psychological factors during rehabilitation and functional outcome 12 months after Achilles tendon rupture". The questionnaires were:

A) Injury Psychological Readiness to Return to Sport Questionnaire [50];

B) Tampa Scale for Kinesiophobia [98];

C) Expectations and motivation of participants regarding return to preinjury activity level [133];

D) Achilles tendon Total Rupture Score [104];

E) Oslo Sports Trauma Research Centre Overuse Injury Questionnaire [32].

The participants completed the questionnaires at 3, 6 and 12 months after the injury and performed functional outcome measures at 12 months. The results showed that motivational scores were high through the whole process, while kinesiophobia decreased, confidence improved and psychological readiness increased. The participants considered good follow-up and compliance with physiotherapy as the most important factors for their ability to return to sport [132].

Although questionnaires are often useful and accessible, it was decided to base **Study IV** on interviews, using qualitative content analysis to analyse which factors influence a return to activity after an Achilles tendon rupture. It was our perception that questionnaires often fail to provide the specific information of relevance for our study and therefore we decided to conduct an interview study. We believed a content analysis guided by an experienced researcher in the field of qualitative studies would expand the knowledge gained from questionnaires and increase insight into the factors that lead to an optimal recovery.

The overarching theme from our analysis was “Help me and then I can fix this”. This theme highlights a similar point to that previously mentioned by Slagers et al. [132], namely the importance of good medical care and physiotherapy as well as help from friends, family and colleagues/employer. If the support is strong, the patient can work towards recovery and achive the desired results. The categories that emerged comprised both internal and external factors. The internal factors were the patient’s own motivation, psychological adaptation and changes in physiological ability. The external factors, which included support from family and friends, support from the social and health care systems as well as information from others in a similar situation, were beyond the patient’s control. These factors had a great impact on the recovery process and return to activity.

A recent qualitative study on return to sports after an Achilles tendon rupture repair [114] presented the results in three themes: personal motivation, shift in focus and confidence in the healthcare system [114]. There are obvious similarities between these themes and the categories in our study. What is interesting in the aforementioned study is that the participants were divided into two groups depending on whether or not they returned to their preinjury level of sport. Of the 23 participants, six returned to their preinjury level, while 17 did not. There was no difference between the groups in terms of demographics, but there was a difference related to the time since surgery. The longer the time since injury/surgery, the less likely was the individual to return to a preinjury level of sports. There were no differences between groups in terms of PROMs. It was concluded that even though the athletes did not reach their previous level, type or frequency of activity, they were often happy with the results after an Achilles tendon rupture and how the road to recovery had evolved [114].

CLINICAL IMPLICATIONS

Acute Achilles tendon rupture is an injury that has a major impact on the patient's quality of life. Compared with other injuries that have a long recovery time and are mainly sustained by individuals in association with their activity, Achilles tendon rupture probably has one of the longest healing processes. Even when compared with the well-known ACL injury where the rehabilitation period can be up to one year, the process after Achilles tendon rupture is more disabling, especially at the beginning, due to the need to wear a cast/brace for eight weeks and using crutches.

There are different treatment methods for Achilles tendon rupture. The first decision concerns surgical or non-surgical treatment. Thereafter, rehabilitation and mobilization are in focus, where the question is whether early mobilization and weightbearing or non-weightbearing with limited movement is best for a full recovery. Finally, strength exercises for up to a year will ensure an optimal recovery.

The difference between the two initial treatments (surgical and non-surgical) in terms of outcome does not appear to be significant after a few months although the re-rupture rate and other complications are still relevant. Even though the difference is minor, it appears to be valuable for the patient. According to the findings in Study IV, some of the participants experienced themselves as "second class" because they did not receive surgical treatment. They also questioned how the treatment decision was made. A useful tool has been developed to support decision making in cases where there is more than one alternative. The International Patient Decision Aid Standards (IPDAS) is an information sheet used to help patients make decisions in terms of their own health [46,134]. It has already been developed for Achilles tendon ruptures but no high-quality study evaluating the significance of the tool has yet been published. The sheet contains information about the pros and cons of the treatments available (surgical versus non-surgical). The aim is to give the patient an opportunity to discuss the next steps after the injury with a healthcare professional and to have a stronger platform on which to base their questions and decision-making [46].

When the patient has undergone the initial treatment, the next step is rehabilitation. As discussed earlier, the patient places a great deal of trust in the guidance of a healthcare professional, usually the physiotherapist. Rehabilitation is a key factor for optimal recovery, but for the rehabilitation to be successful, the patient must be prepared to invest a great deal of work. If the initial treatment has gone as well as expected, rehabilitation starts as early as two weeks after the injury, when the cast is removed and replaced by a brace. The brace is usually worn for six weeks, but it is possible to remove it when the limb is not bearing weight. Formal rehabilitation can start two weeks after the injury aimed at connecting the triceps surae and the Achilles tendon by means of exercises. When using crutches and a brace during this period, the patient can bear some weight. Thus, if the rehabilitation progresses as planned, the muscle should be in a better condition at eight weeks post injury than would be if fully immobilized.

At approximately eight weeks the brace can be removed, and the patient can use the foot with some dos and don'ts. At this point it is important for the healthcare professional (doctor or physiotherapist) to look for signs of delayed healing, complications or whether the patient might need extra support or reassurance to embark on the next steps if her/his motivation to achieve recovery is not 100%. It may be necessary for the healthcare professional to step in and possibly guide the patient to a sports psychologist, who can help the patient on her/his road to activity if she/he lacks the courage to engage in increased movement despite greater mobility and strength.

The rehabilitation protocol after eight weeks varies between studies, but the aim is always to increase the strength of the triceps surae and the Achilles tendon without any risk of further injury. According to a systematic review from 2020 by Harrington et al. [68] the above-mentioned SMART programme has the lowest re-rupture rate after non-surgical treatment [60]. Another important parameter to consider is the ATRS [104]. In the above-mentioned systematic review, the SMART programme resulted in the lowest ATRS, suggesting dissatisfaction with the results of the rehabilitation [60]. The programme presented by Lim et al. [88] with an early start of physical therapy and low re-rupture rate appears to be favoured by patients, demonstrated by the highest ATRS score in the same systematic review [60].

LIMITATIONS

Study I: The foot structure of 90 participants was evaluated at a mean of six years after Achilles tendon rupture. As such research has not been published previously, no power calculation was performed.

When performing the study, the optimal conditions would have been the availability of the measurements prior to the injury for comparison purposes in order to determine its impact on the foot structure. However, that was not feasible, as the group evaluated would have had to be very large. Another possibility would have been to have a control group measured by the same physiotherapist for comparison. That would have been more feasible and might have answered some questions related to comparison with a healthy population.

The results of Study I raise several questions. Why does the uninjured foot in the group that underwent surgery differ from that in the group treated non-surgically? And why is the uninjured foot in the non-surgically treated group the same as the injured foot in both groups? Had there been a large comparison group, it might have been possible to answer, or at least discuss, the questions raised by the results.

Study II: A sample size calculation (statistical power of 95% and alpha =0.05) was performed before the data collection in Study II (and Study III), indicating that 25 participants would be required to detect side to side difference during landing and 28 participants for push-off. Thirty participants were included in the data collection, but due to technical difficulties, biomechanical data from just 27 participants were used for the calculations.

As already mentioned, another limitation is that the fatigue protocol was not similar to real life exhaustion. Adjusting the fatigue protocol to the participant would also have been valuable, as physical fitness differs between individuals. However, the perceived exertion was measured using the well-known Borg scale [28]. All participants reached the limits decided beforehand, where the minimum was 15 on the Borg scale.

Study III: The above-mentioned sample size calculation also applies to Study III. The data were collected from 30 participants, but biomechanical data were missing for three participants and two did not answer the question about fear of reinjury. Therefore, the sample size used in the data analysis was 25 participants. In the study, there is a division into subgroups which would indicates the need for an even higher number of participants (possibly 56, as there are two subgroups).

Another limitation is the lack of validation of the question used to identify which participants had refrained from activity because of fear of reinjuring their Achilles tendon.

Study IV: The main concern is that bias might be unavoidable. The interviewer cannot separate her/his own experience when conducting interviews and analysing the data. On the other hand, the interviewer's experience can also be an advantage. When analysing the data, an experienced healthcare professional can identify the relevant parts of the participants' experience. Regarding the transcripts, two interviews were analysed by all authors for comparison of the meaning units. Furthermore, two interviews were jointly analysed by the most experienced author and the first author. The first author then analysed and coded the remaining 16 interviews.

Another factor that can be questioned is the consistency and accuracy when studying and analysing such a large amount of data. It is difficult to deny this fact, as it is impossible to guarantee that the analysis is totally accurate and consistent.

CHAPTER 9

CONCLUSION

CONCLUSION

The factors that influence the return to physical activity after Achilles tendon rupture comprise many different elements.

Study I - Foot structure

Achilles tendon rupture can have an impact on the structure of both the injured and the uninjured foot. In the present study the injured foot had lower navicular drop and drift values as well as a lower longitudinal arch angle. As the longitudinal arch is lower on the injured side, it can be assumed that there is less room for movement, i.e., during navicular drop and drift.

The results did not show any difference between the surgical and the non-surgical group on the injured side, only on the uninjured side. However, it is unclear whether this difference indicates a benefit for the surgical or the non-surgical group. The difference was still present at a mean of six years after Achilles tendon rupture.

Study II – Lower limb kinetics and fatigue

The effect of fatigue on lower limb kinetics during a single-leg drop CMJ after Achilles tendon rupture was only apparent in the ankle joint, not in the knee or hip joints. The decrease in power from before to after fatigue was greater on the uninjured side than the injured side.

Before fatigue, the power measurements were higher on the uninjured side, which suggests the possibility that the participants were using that side more during the fatigue protocol. A question that could arise is whether the lower limb on the injured side is generally weaker or if the participants are afraid to use full power during the fatigue protocol and/or during the jumps.

Study III – Lower leg kinetics and fear of reinjury

The effect of fear of reinjury on lower leg kinetics during a single-leg drop CMJ after Achilles tendon rupture was apparent in the ankle, knee and hip joints when the injured and uninjured sides were compared. The difference in power distribution was greater between sides in the Fear group than the No-fear group, hence the symmetry between sides was greater in the latter. Asymmetry in power distribution such as that found in the Fear group may lead to an increased risk of overuse injuries in later life.

These results give rise to a similar question as in Study II, namely, is the reason for this difference that the strength of the injured side in the Fear group was weaker overall or are the patients merely afraid of using the strength on the injured side during the drop CMJ?

Study IV – Return to activity after Achilles tendon rupture

The main theme that emerged in Study IV, “Help me and then I can fix this” was a common thread throughout the 20 interviews analysed. It refers to the help and support needed from family, friends, colleagues, healthcare professionals and society. However, as soon as the initial need for support has diminished, the patient must take responsibility for recovery her/himself. On the other hand, if the patient fails to take responsibility for her/his recovery, all the support in the world will make no difference. What can the patient do to obtain support from relatives/friends/colleagues? What can we as healthcare professionals do to strengthen our patients' motivation for recovery? These questions remain unanswered.

CHAPTER 10

FUTURE PERSPECTIVES

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High quality research with multifactorial calculations is needed to reach a conclusion about cause and effect when evaluating the factors that healthcare professionals can change to obtain the best possible results after an Achilles tendon rupture. Validated and reliable outcome measures are important when choosing which methods to use for the factors under study. Fortunately, new methods for examining biomechanics, function, structure and PROMs are still being formulated and validated for future studies.

To ensure transferability, the cohort groups must be large and preferably multicentred to capture variations in the population and in initial treatment and rehabilitation. The relevant answers might be concealed in both microscopical and macroscopical factors and accurate evaluations are therefore required. A national registry could be very useful for obtaining a sufficiently large sample to compare multifactorial elements, which would otherwise be difficult to acquire.

Depending on the results from such research, the initial treatment and rehabilitation could be adjusted to the individual. More individualised treatment would lead to better recovery for the patient.

The alterations in foot structure that appear after an Achilles tendon rupture, as well as other factors, can be a reason for modifications in biomechanics in the lower extremities. On the other hand, it is also possible that the changes in biomechanics are a reason for the observed alterations in foot structure, which can be described as a chicken and egg situation. A multicentre, multifactorial study might be a better choice for determining cause and effect.

CHAPTER 11

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APPENDIX

APPENDIX

ATRS – SWEDISH

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?

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

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

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

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

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

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

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

5. Är du begränsad i ditt dagliga liv?

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

Achilles Tendon Rupture Score (ATRS)
Version 6, Katarina Nilsson-Helander 2006-01-12

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

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

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

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

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

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

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

10. Är du begränsad att utföra hårt fysiskt arbete?

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 2006-01-12

ATRS – ENGLISH

ATRS
(Achilles Tendon Total Rupture Score)

Today's Date: ____/____/_______ Date of Birth____/____/_______

Name:____

All questions refer to your limitations/difficulties related to your injured Achilles tendon.
Answer every question by grading your limitations/symptoms from 0-10.
Remember (0= Major limitations and 10= No limitations).

Please circle the number that matches your level of limitation

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 (No limitations)

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

0 1 2 3 4 5 6 7 8 9 10 (No limitations)

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

0 1 2 3 4 5 6 7 8 9 10 (No limitations)

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

0 1 2 3 4 5 6 7 8 9 10 (No limitations)

5. Are you limited during activities of daily living?

0 1 2 3 4 5 6 7 8 9 10 (No limitations)

6. Are you limited when walking on uneven surfaces?

0 1 2 3 4 5 6 7 8 9 10 (No limitations)

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

0 1 2 3 4 5 6 7 8 9 10 (No limitations)

8. Are you limited during activities that include running?

0 1 2 3 4 5 6 7 8 9 10 (No limitations)

9. Are you limited during activities that include jumping?

0 1 2 3 4 5 6 7 8 9 10 (No limitations)

10. Are you limited in performing hard physical labour?

0 1 2 3 4 5 6 7 8 9 10 (No limitations

Thank you very much for completing all the questions in this questionnaire.

PHYSICAL ACTIVITY SCALE – SWEDISH

Lundberglaboratoriet 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**

PHYSICAL ACTIVITY SCALE – 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

BORG SCALE – SWEDISH

	Borgs RPE-skala	
6	Ingen ansträngning alls	< 40 % maxpuls
7	Extremt lätt	
8	Extremt lätt	40-59 % maxpuls
9	Mycket lätt	
10	Mycket lätt	
11	Lätt	
12	Lätt	60-74 % maxpuls
13	Ganska ansträngande	
14	Ganska ansträngande	75-94 % maxpuls
15	Ansträngande	
16	Ansträngande	
17	Mycket ansträngande	
18	Mycket ansträngande	> = 95 % maxpuls
19	Extremt ansträngande	
20	Maximalt ansträngande	

BORG SCALE – ENGLISH

Original Borg scale		Modified Borg scale	
6		0	Nothing at all
7	Very very light	0.5	Very very light
8		1	Very light
9	Very light	2	Light
10		3	Moderate
11	Fairly light	4	Something hard
12		5	Hard
13	Somewhat hard	6	
14		7	Very hard
15	Hard	8	
16		9	
17	Very hard	10	Very very hard
18			
19	Very very hard		