Isolated gastrocnemius tightness in foot pathology – diagnostics, treatment and outcomes

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Table of contents

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Abbreviations

ADI – Ankle dorsiflexion index

AOFAS – American orthopaedic foot and ankle society

CI – Confidence interval

CMJ – Counter movement jump

FAAM – Foot and ankle ability measure

FFI – Foot function index

kPa - KiloPascal

IGT – Isolated gastrocnemius tightness

Nm – Newton meter

PMGR – Proximal medial gastrocnemius recession

PROM – Patient related outcome measure

RCT – Randomized controlled trial

ROM – Range of motion

SF-36 – Short form 36

VAS - Visual analogue scale

VISA-A - Victorian institute of sport assessment-Achilles

List of papers

1. Molund M, Paulsrud O, Ellingsen Husebye E, Nilsen F, Hvaal K. Results after gastrocnemius recession in 73 patients. Foot Ankle Surg. 2014;20(4):272-275.

2. Molund M, Husebye EE, Nilsen F, Hellesnes J, Berdal G, Hvaal KH. Validation of a new device for measuring isolated gastrocnemius contracture and evaluation of the reliability of the Silfverskiöld test. Foot Ankle Int. 2018;39(8):960-965.

3. Molund M, Husebye EE, Hellesnes J, Nilsen F, Hvaal K. Proximal medial gastrocnemius recession and stretching versus stretching as treatment of chronic plantar heel pain. Foot Ankle Int. 2018 Dec;39(12):1423-1431

General introduction

Historical perspective

The potential detrimental effects of a contracture in the Achilles or triceps surae complex have been recognized for a long time. Delpech is credited to be the first who performed an Achilles tendon lengthening in the early 1800s.[30] However, the first isolated lengthening of the gastrocnemius was popularized by Vulpius and Stoffel.[98] In their textbook from 1913, they described the Vulpius procedure in which the broad gastrocnemius tendon was cut transversely as well as the underlying soleus tendon, leaving continuity of the underlying soleus muscle.

John Joseph Nutt, in 1913, outlined that the gastrocnemius crosses three joints: the knee, the ankle and the subtalar joint.[74] He explained that the muscle is stretched to its greatest extent when the knee is fully extended, the ankle dorsiflexed and the foot inverted. He also pointed out that if the knee is flexed, the dorsal flexion and inversion of the ankle can be increased. Although this is a quite precise description of the test for isolated gastrocnemius tightness by Mr. Nutt, Nils Silfverskiöld has been credited to be the first to describe the test. In his paper that was published in 1924 he observed that he had to use more force to dorsiflex the foot while keeping the knee extended than when he was flexing the knee in spastics.[90] He also suggested a surgical method to overcome this by transferring the origin of the gastrocnemius from the femoral condyles to the tibia.

In 1950, Strayer described a gastrocnemius recession technique quite similar to the technique published by Vulpius in 1913.[93] However, instead of dividing both the gastrocnemius as well as the soleus aponeurosis, he solely divided the gastrocnemius at, or just distal to, the junction with the Soleus aponeurosis. Strayers' original procedure included suturing the gastrocnemius back to the Soleus at a more proximal level. The method of Strayer has later been modified and today most orthopaedic surgeons leave the gastrocnemius tendon unsutured.

The last decade several articles have been published about a gastrocnemius recession technique restricting the surgery to involve only the proximal medial gastrocnemius (PMGR). It was initially popularized by Barouk, and several authors have later published results with this technique.[1, 7, 67]

Even though the diagnostic test, and to some extent the biomechanical understanding of isolated gastrocnemius tightness, was described a century ago, the first article linking isolated gastrocnemius tightness (IGT) to foot pathology in non-spastic patients was published as late as in 2002.[33] This was the first paper describing reduced ankle dorsiflexion ability in patients with mid- and forefoot pain compared to a healthy control group.[33] During the last decade several case series have been published, all suggesting a favourable clinical outcome after gastrocnemius recession procedures for several foot and ankle conditions. However, there is a lack of prospective and/or randomized studies.

Relevant anatomy and biomechanics

The triceps surae consist of the gastrocnemius muscle and the soleus muscle, and is accounting for 80% to 90% of the plantarflexion power of the ankle.[20, 70] The gastrocnemius constitutes 40% of plantarflexion power.[20, 26, 70] The distal insertion for the conjoined tendon (Achilles tendon) of the m. gastrocnemius and m. soleus is at the tuber calcaneus. The junction point of the gastrocnemius and the soleus is located between the middle and the distal third of the leg. Proximally, the soleus originates on the posterior aspects of the tibia, fibula and interosseous membrane, while the gastrocnemius crosses the knee joint and originates on the femoral condyles. The origins of the muscles that connect to the foot through the Achilles tendon are at opposite sides of the knee, which create some interesting biomechanical aspects. It enables tightness of the Achilles complex to be present in only one or both muscles, and that the tightness could be variable depending on the position of the knee. An isolated tightness of the gastrocnemius will be obvious when the knee is extended because the gastrocnemius will be maximally stretched, while tightness occurring with the knee flexed will represent tightness of the soleus only, or both muscles.

During gait, power is transferred from the gastroc-soleus complex to the foot through the Achilles tendon. The foot has two functional demands. It has to accommodate to the surface at midstance and it must transmit the power from the calf at the propulsive phase of gait. To achieve this, the foot must be flexible through midstance, and stiff to work as a lever arm through propulsion. Several factors work together to achieve these functional demands of the foot, but critical factors is the position of the hindfoot joints and the function of the plantar fascia. The subtalar and midtarsal joints (talo-navicular and calcaneo-cuboid) work as a functional unit. If the hindfoot takes a pronated position the subtalar joint is everted and the axes of the midtarsal joints are parallel. This facilitates motion and flexibility. If the hindfoot is supinated, the opposite effect can be observed. The axis of the midtarsal joint are crossed and the foot is stiff. Muscular contraction of the tibialis posterior initiates inversion of the foot.[25] Further the function of the plantar fascia is critical. The plantar fascia is a strong fibrous band that originates on the plantar medial aspect of the tuber calcanei and inserts at the base of the proximal phalang of digitus 1-5. It is the strongest and most important stabilizer of the plantar part of the foot. The mechanic properties of the plantar fascia lead to the so-called windlass mechanism. When the toes are dorsiflexed through gait the plantar fascia will be passively tightened which leads to elevation of the foot arch. This ultimately stabilizes the foot through propulsion. At midstance, pressure under the metatarsal heads will tighten the plantar fascia, plantarflex the toes and thus increase the contact area and stabilize the foot.

At mid-stance phase of gait (second rocker) the knee is fully extended. The ankle shifts from plantarflexion to dorsiflexion while the tibia is rolling over the talus (Figure 1). Studies have demonstrated that 10° of ankle dorsiflexion is necessary for normal gait.[19, 24, 52, 94] If the gastrocnemius is tight the dorsiflexion of the ankle will be restricted at this phase, which leads to increased strain through the mechanical chain of the leg and foot. As the necessary degree of dorsiflexion of the ankle cannot be achieved, heel-off will occur earlier. At earlier heel off, the strain to the Achilles tendon and plantar stabilizing structures will increase. Evidence exists that increasing tension in the Achilles tendon increases strain on the plantar fascia.[18] However, the possibility to adapt gait to tightness of the gastrocnemius, could also be achieved by knee flexion or eversion of the tarsal joints.[19] Significant foot dorsiflexion can occur through the subtalar and midtarsal joints, and even possibly more dorsiflexion can occur through these joints than through the ankle joint itself.[62] Figure 2 illustrate a sagittal model that gives a simple overview of the forces acting on the foot through gait.

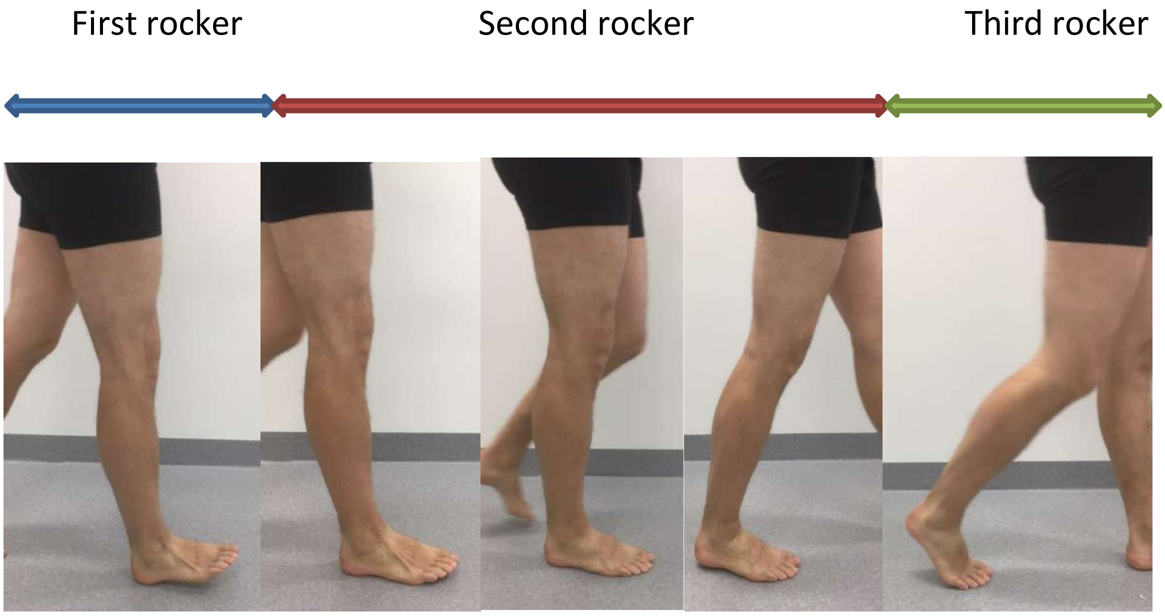

Figure 1. One gait cycle is illustrated with rocker 1-3. Picture 1: First rocker, where the heel hits the ground. Picture 2: First phase of second rocker where the tibia is still behind the talus. Picture 3: Mid phase of second rocker. The tibia is centred over the talus. Picture 4: Last phase of second rocker. This is the phase where the tight gastrocnemius would cause a problem. The knee is extended, and the heel is switching into inversion to stabilize the foot. The ankle is dorsiflexing to at least the necessary 10°. The gastrocnemius will be maximally stretched. Tightness would lead to gait adaptions. Picture 5: Third rocker. Toe off.

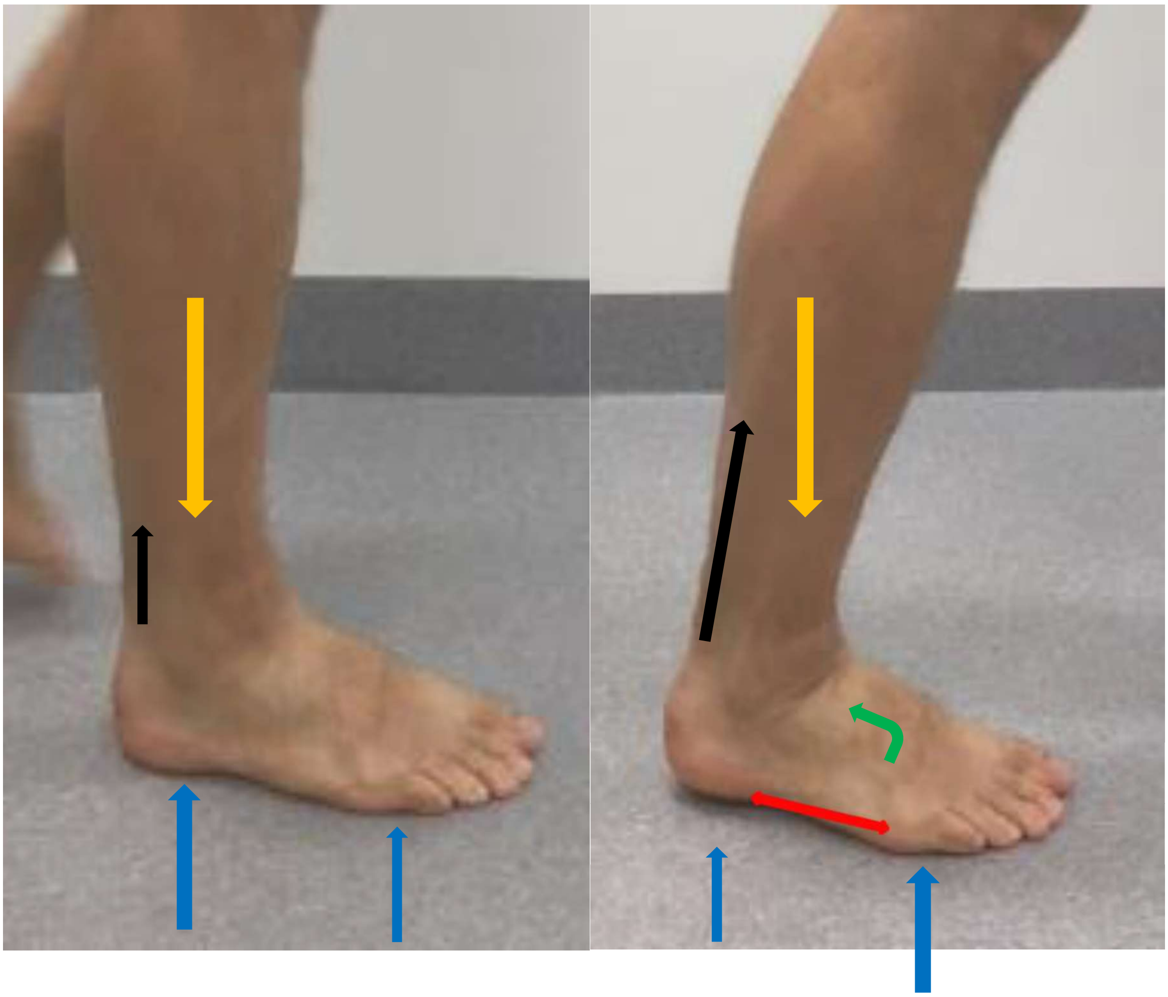

Figure 2. Sagittal plane model of the foot. The internal and external forces acting on the foot must be in equilibrium.[76] The size of the arrows illustrate amount of force. Although several components work as a chain to stabilize the foot through gait, this model is simplified to explain the concept. External forces working on the foot are body weight (yellow arrows) and ground reaction forces (blue arrows). Internal forces are Achilles tension (black arrows), tension to the plantar fascia (red arrow) and dorsiflexion moment (green arrow). On the left image the ankle is in a 90 degrees position. The forces acting on the foot are mainly balanced between body weight and ground reaction forces. Some tension of the Achilles also exists which is balanced by ground reaction forces to the forefoot. On the right image is the end of the second rocker. This is just before heel off. The knee joint is extended, which puts maximal tension on the gastrocnemius. If the gastrocnemius is tight, the ankle will be unable to dorsiflex, and forces must be balanced by increased strain to foot stabilizers. The increased tension of the Achilles lead to increased ground reaction forces to the forefoot. This in turn leads to dorsiflexion forces to the midfoot (green arrow) that tend to flatten the foot. This is counteracted by increased tension of the plantar fascia (red arrow).

Detecting isolated gastrocnemius tightness

To detect an isolated tightness of the gastrocnemius it is necessary to measure ankle dorsiflexion with the knee extended and flexed. If ankle dorsiflexion is restricted with the knee extended and ankle dorsiflexion normalizes with the knee flexed, this is due to an isolated tightness of the m. gastrocnemius. If dorsiflexion is restricted through both parts of the test this is caused by combined gastrocnemius-soleus tightness, given the absence of ankle joint pathology. To put maximal tension on the tendon while testing, it is crucial to lock the subtalar joint in a slight varus or neutral position. If the subtalar joint is allowed to move into an everted position this may cause significant ankle dorsiflexion and potentially a false negative test. The Silfverskiöld test is demonstrated on Figure 3.

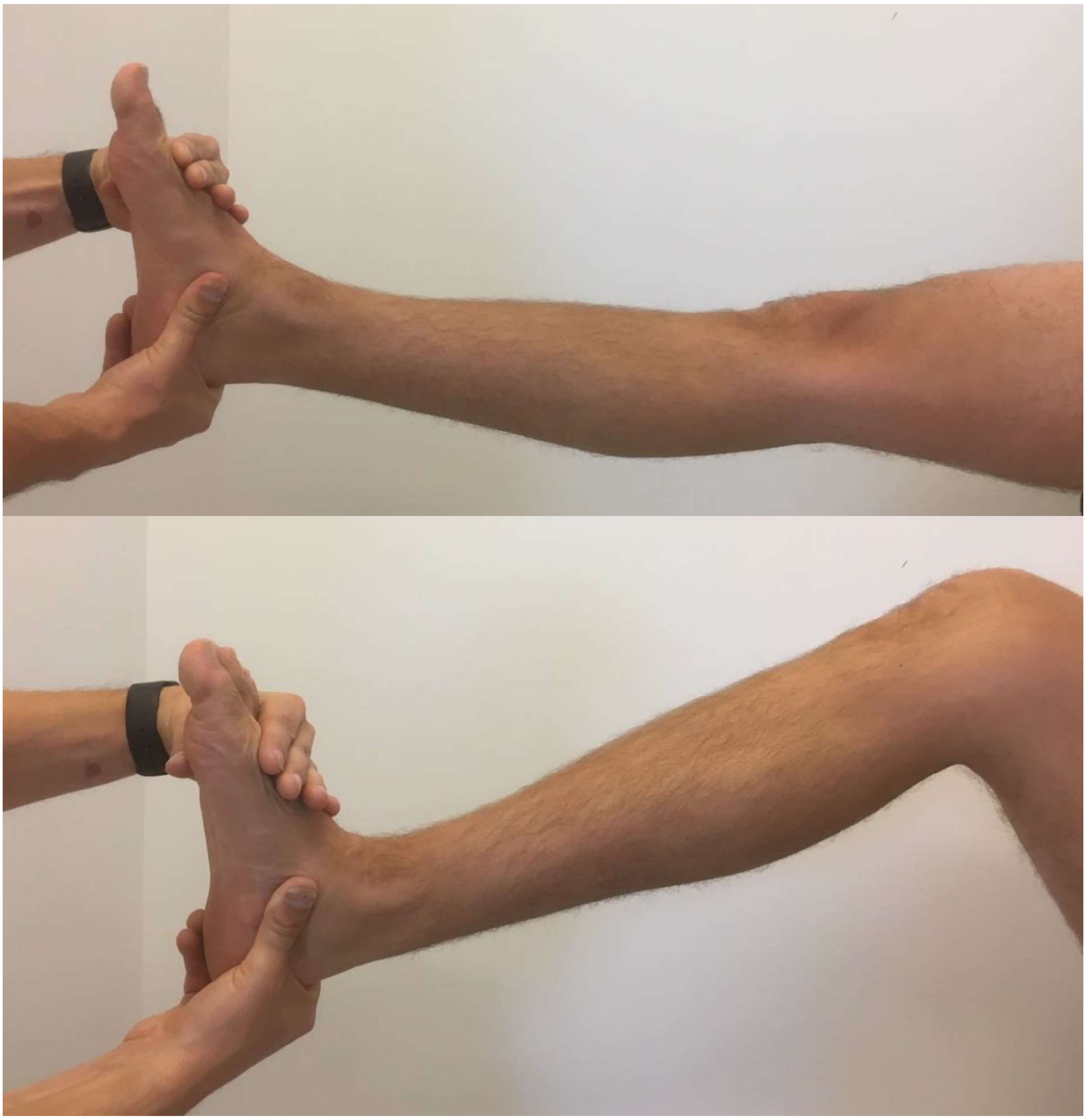

Figure 3. The Silfverskiöld test. First performed with the knee extended (top). The right hand of the examiner reduces the hind foot joints by inverting the heel and supporting the talo-navicular joint with the thumb. Dorsiflexion force is applied under the metatarsal heads by the examiners left hand. The test is repeated with the knee flexed, and the difference in ankle dorsiflexion is clearly illustrated (bottom).

The test is performed as a passive manoeuvre and different amounts of applied force or torque have been described.[6, 33] DiGiovanni et al. compared the prevalence of IGT in patients with foot pathology compared to a healthy control group. They used a torque of 10 Nm, arguing that this was the average pressure normally used by their investigators.

Barouk later suggested that the beginning of stretch resistance should be tested, meaning that applied force should dorsiflex the ankle until start of resistance was felt. He calculated that the resistance appeared when the applied plantar pressure to the forefoot equals 2 kg or 20N.[6] Other authors have demonstrated that the reliability of testing ankle dorsiflexion depends on the ability to control hind foot position more than controlling applied force as long as dorsiflexion is tested to end range of dorsiflexion.[38]

Even though the clinical test seems easy, accurate measuring is crucial for scientific use. Several authors have concluded that the use of a traditional goniometer while exerting clinical testing of ankle dorsiflexion is an unreliable method that should not be used for scientific purposes.[37, 38, 42] This, and the fact that the test is described in different ways regarding force applied, anatomical landmarks etc., makes comparison of results from different studies difficult. Some authors describe more meticulous methods with different devices made for testing ankle dorsiflexion.[33, 42, 99] These devices allow for controlling hind foot position as well as applied force. Electric goniometers used with these devices can increase the accuracy of such measurements.

When is the gastrocnemius tight?

The suggested definitions of isolated gastrocnemius tightness have varied. Barouk defines 0° ankle dorsiflexion with the knee extended and an increase of 10° ankle dorsiflexion with the knee flexed as the cut off for isolated tightness of the gastrocnemius.[6] DiGiovanni et al. suggested both ankle dorsiflexion of 5° and 10°with the knee extended as cut offs for gastrocnemius tightness.[33]

Both these authors seem to base their conclusions on expert opinion more than on hard evidence. Biomechanical studies, though, have demonstrated that at least 10° of ankle dorsiflexion is needed for the tibia to advance over the talus during stance phase of gait.[19, 24, 37, 52, 94]

Some studies have been designed to evaluate the normal values for ankle dorsiflexion at flexed and extended knee joint in healthy individuals. DiGiovanni et al. investigated 34 individuals without foot and ankle symptoms.[33] The average ankle dorsiflexion with the knee extended was 13° and with the knee flexed 22°. Baumbach et al. investigated 64 healthy young individuals, and reported that the average ankle dorsiflexion was 23°.[11] Approximately 10° increase in ankle dorsiflexion could be observed when flexing the knee. Jastifer et al. tested 66 study participants and reported 17° ankle dorsiflexion.[50] Malhotra et al. focused entirely on the difference in ankle dorsiflexion with the knee extended versus flexed, named the ankle dorsiflexion index (ADI).[63] In 291 healthy participants the ADI was 6°.

Several studies have reported much lower ankle dorsiflexion ability in patients with foot and ankle pathology, compared to the results in healthy individuals. DiGiovanni et al. observed 4.5° ankle dorsiflexion at knee extension and 17.9° at knee flexion in 34 patients with foot or ankle pathology.[33] Jastifer et al. reported 11.6° dorsiflexion in 66 patients presenting with foot or ankle pain.[50] Malhotra et al. described an ADI of 10.3° in patients with forefoot pathology. They considered >13° ADI as abnormal as this was more than 2 SD above the results of the healthy population.

Although some data exist, both in terms of normative data for a healthy population and ankle dorsiflexion measurements in foot and ankle patients, no consensus exists on when to consider the gastrocnemius as tight. Some authors mainly focus on ankle dorsiflexion at extended knee joint, while others focus entirely on the measured difference in ankle dorsiflexion with the knee extended versus flexed. The measurements were mainly done by a modified goniometer, but comparing the results is difficult as some use unvalidated measuring methods, and the testing is not standardized. The only reproducible evidence comes from biomechanical studies indicating the necessity to dorsiflex the ankle >10° in stance phase for the tibia to roll over the talus without gait alterations.[19, 24, 52, 94]

Stretching as treatment of tight gastrocnemius and overload conditions

The pathomechanical connections between gastrocnemius tightness and different overload conditions of the foot and ankle are increasingly being accepted. Studies have also reported a high prevalence of calf tightness in conditions like plantar fasciitis.[77] This logically leads to the conclusion that treatment should include lengthening of the gastrocnemius. Non-operatively this can be achieved by stretching exercises. For conditions like Achilles tendinopathy some studies have demonstrated a profound clinical effect of stretching exercises, and the treatment is widely accepted as the most effective conservative treatment for this condition.[66] Calf stretching exercises have also demonstrated to be effective in treating recalcitrant plantar fasciitis.[82] Other studies have reported additional effect of plantar fascia specific stretching exercises.[32] Although one review article concluded that the evidence for stretching exercises as treatment of chronic plantar fasciitis is weak and inconsistent, a recent current concepts review state that calf stretching with additional plantar fascia stretches could be considered the first line choice in non-operative treatment of chronic plantar fasciitis.[66]

Surgical techniques for gastrocnemius recession

The triceps surae could be lengthened at different levels (Figure 4). If a combined tightness of the soleus and gastrocnemius is detected, a lengthening procedure could be performed at the distal Achilles tendon. Achilles lengthening procedures include a long rehabilitation period, and a risk for overlengthening.[92] Cadaver studies have shown that tensional forces transmitted through the whole triceps surae, or just transmitted through the gastrocnemius, increase the forefoot pressure equally.[2] This logically leads to the conclusion that tightness occurring in the gastrocnemius exclusively, should be treated with a procedure intending to lengthen the gastrocnemius only.

Different surgical techniques for gastrocnemius recession have been described. The Vulpius technique, which is slightly distal to the Strayer, and the Silfverskiöld technique, which cuts both heads of the gastrocnemius at the proximal origin, have historical interest, but are rarely used today. From the literature it seems that a modified Strayer technique is frequently used. The surgical technique includes the transection of the gastrocnemius aponeurosis just distal to the junction with the soleus aponeurosis. The current practice does not include suturing it back to the soleus more proximally, as originally described. The Strayer technique is described to be unstable, meaning that there is a theoretical risk for overlengthening.[85] Early literature suggested the use of a cast for 2 weeks after surgery, but later series have described immediate mobilization after surgery without the use of a cast.[65, 92] Case series have revealed increased dorsiflexion up to 18° post operatively after the Strayer.[81] Cadaveric studies support that this technique produces the greatest increase in dorsiflexion of all the described techniques.[85] The Sural nerve is at risk when performing the procedure. Concerns have been raised lately regarding complication rates and post-operative weakness.[22]

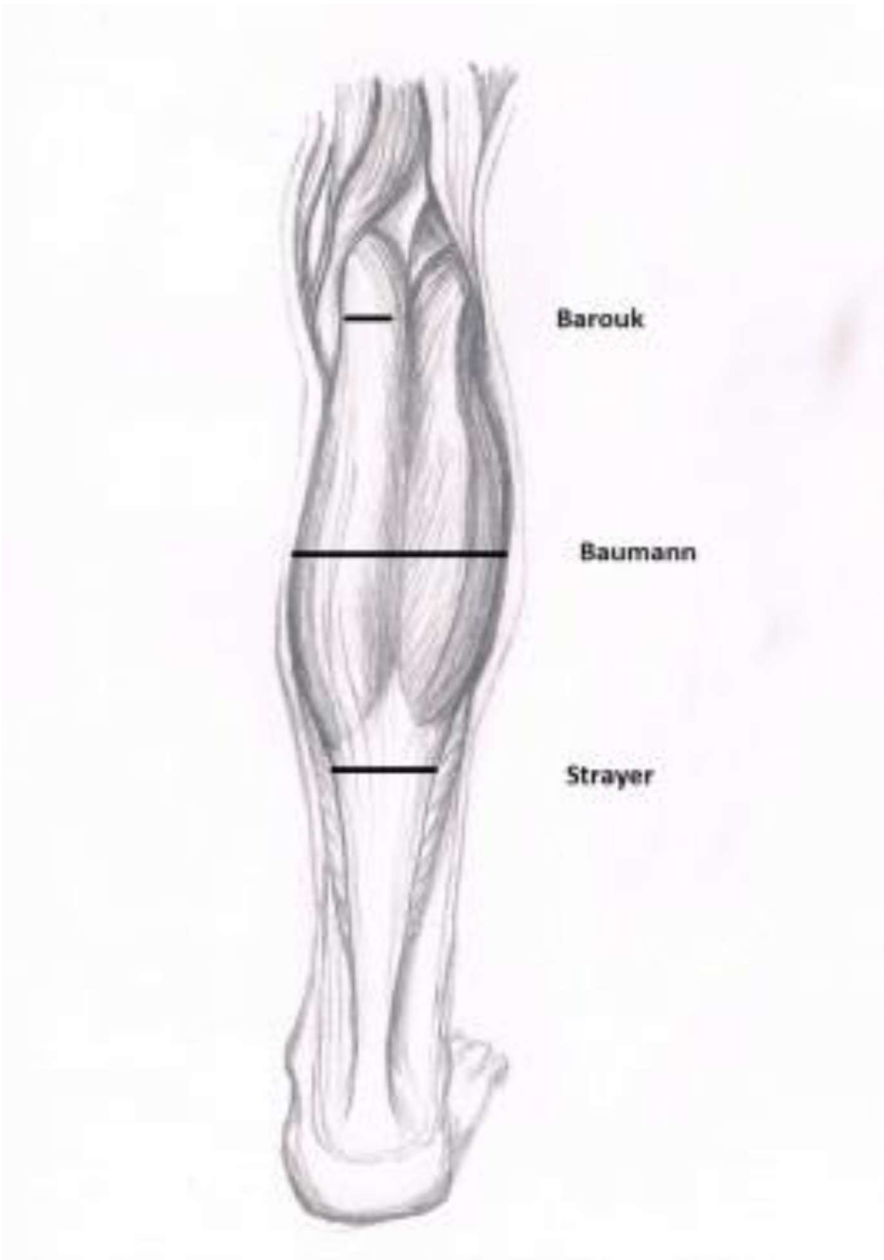

Figure 4. The levels of the three most common gastrocnemius recession techniques are illustrated: the methods of Barouk, Baumann and Strayer.

The Baumann technique is a mid-calf intramuscular lengthening technique. The spatium anterior to the gastrocnemius and posterior to the soleus is dissected. It allows adding more cuts if necessary, which has been demonstrated to improve ankle dorsiflexion.[85] It also enables simultaneously lengthening of the soleus. The saphenous nerve is at risk during the procedure.

The proximal medial gastrocnemius recession (PMGR), described by Barouk, has gained more popularity lately. The medial head of the gastrocnemius and it`s aponeurosis is 2.4 times bigger than the lateral head, and most of the tension goes through the medial head.[45]

Cadaveric studies have proved the PMGR to be safe and stable in achieving increased ankle dorsiflexion.[53, 85] The high stability of this procedure, meaning predictable lengthening and low risk of overlengthening, is probably because the underlying muscle as well as the plantaris tendon is preserved. This high stability makes it unnecessary to use a cast post operatively. In contradiction to other gastrocnemius recession procedures it can be performed under local anaesthetics. Barouk has described this surgical method of gastrocnemius lengthening to increase ankle joint dorsiflexion, but he has not given an exact value of the increased dorsiflexion.[7] No previous reliable data on how much increase in ankle dorsiflexion that can be expected following the method of Barouk can be found in the literature. Theoretically the potential for correcting an IGT is less with the PMGR compared to a more distal recession procedure, but potential advantages in anatomical safety, postoperative strength and cosmetic superiority exist.

Covariance between isolated gastrocnemius tightness and foot pathology

A short triceps surae, consisting of m. gastrocnemius and soleus contracture with equinus may be observed in congenital neurological conditions such as cerebral paresis, or acquired in post-traumatic/post disease conditions affecting muscles or nerves. Gait will often be severely disturbed with the patient walking on an overloaded forefoot, unable to position the foot plantigrade. Idiopathic toe-walking children constitute a subgroup, often without the presence of severe underlying pathology. These topics are, however, considered outside the main scope of this work.

DiGiovanni et al. did ground-breaking work detecting a covariance between isolated gastrocnemius tightness and foot pathology. 65% of patients with foot pathology had an IGT, which was significantly higher than in the healthy control group with IGT detected in 24% of individuals. However, the study does not explain causality, or even whether the gastrocnemius contracture disposes for foot pathology or vice versa. Later studies have confirmed high incidences of IGT for patients with foot pathology.[50, 63, 71] Especially the connection between IGT and plantar fasciitis has been studied. Patel and DiGiovanni found 83% of patients with plantar fasciitis to have restricted ankle dorsiflexion.[77] A recent study by Nakale et al. reported that 80% of 45 patients with plantar fasciitis had IGT.[71] Gastrocnemius tightness has been reported to be the most important risk factor for developing plantar fasciitis.[84]

Clinical and biomechanical outcomes after gastrocnemius recession

In the literature isolated gastrocnemius tightness has been coupled to several foot and ankle disorders. Gastrocnemius recession has been suggested as a single procedure or as an adjunct in conditions like plantar fasciitis, metatarsalgia, plantar ulcers, Achilles tendinopathy, flatfoot and posterior tibial tendon insufficiency, hallux valgus etc. However, the evidence supporting the effects of this procedure is insufficient and even absent for most of the above-mentioned conditions.

Some case reports and retrospective reviews describe a connection between IGT and Achilles tendinopathy, plantar fasciitis, metatarsalgia and plantar ulcers. Prior to our studies no randomized controlled trials existed. A review from 2015 that aimed to provide evidence based recommendations for the use of gastrocnemius recession for foot and ankle conditions in adults stated that there was grade B evidence (fair) to support the use of gastrocnemius recession for midfoot/forefoot overload syndromes in adults.[27] Grade C evidence (insufficient) exists for the use of this procedure in treating midfoot/forefoot ulcers and non-insertional Achilles tendinopathy.[27] This review included a total of 18 studies, whereof 17 of these were evidence level 3 or lower.

It should be of concern that the number of gastrocnemius recession procedures has been increasing for several years despite the lack of evidence regarding clinical effects and safety of the procedure. There is a mismatch between historical data and outcomes from more recent reports. Early case reports have reported gastrocnemius recession as a safe procedure with hardly any complications.[35, 64] Later patient series evaluating the Strayer procedure, in contrast, have reported complication rates between 10 and 20%.[48, 91] Although expert opinions and theoretical outlines are important, there is an urgent need to provide reliable prospective data.

As for the clinical outcome data, the same problem is present for biomechanical outcome data. There is insufficient data to answer even simple questions like potential postoperative weakness and expected increase in ankle dorsiflexion after gastrocnemius recession procedures. Alterations of gait patterns are described in only one small prospective study.[19] Postoperative changes in foot pressure were until recently no topic of interest, and recent low-quality studies report conflicting data.[87, 97] Most questioned has been the potential postoperative weakness. The gastrocnemius constitutes 40% of plantarflexion power.[20] Theoretically it would affect postoperative function to do a lengthening procedure. The first case series, using unvalidated outcome tools reported this as a minor problem.[35, 55, 64] Recently several series report a tendency for loss of power especially after the Strayer procedure.[65, 73] Although a more proximal recession e.g. Baumann and Barouk procedures are theorized to better maintain strength and power, no studies have compared this.

Plantar fasciitis

Plantar fasciitis is the most common foot and ankle disorder. 10% of the population will report heel pain during their lifetime.[40, 66] Plantar fasciitis is really a misnomer. Fasciitis refers to an inflammation, but histological studies have proved that there is no inflammation involved.[58] The condition has sometimes been named plantar fasciopathy, plantar fasciosis and lately plantar heel pain. Using the term plantar heel pain may be appropriate as studies suggest that the pathology is not only restricted to the plantar fascia, but is also in the surrounding bone and soft tissues.[58]

The diagnosis of plantar heel pain is made clinically. The condition is characterized by pain at the proximal origin of the plantar fascia to the calcaneus and that the patient experiences increasing pain after rest. These symptoms form the diagnostic criteria that seem to be fairly accepted in the literature.[58] Other conditions can mimic the condition of heel pain, and radiographic evaluations or MRI is used if necessary to rule out other causes.

A wide range of non-operative approaches have been suggested for the treatment of plantar heel pain. Although, common in clinical practice, devices like night splinting and procedures including extracorporeal shockwave therapy (ESWT) have no documented effect.[58] Cortisone injections have documented negative effects, and should be avoided.[58] Stretching of the triceps surae and plantar fascia have promising results in some studies although the long term effects are undocumented.[58, 66, 92]

It has been described that the majority of cases with plantar heel pain resolve over time regardless of the intervention received, including placebo or sham intervention.[58] This means that most authors recommend avoiding surgery to await spontaneous recovery. However, as the condition is so common, the small percentage of patients suffering prolonged symptoms constitutes a vast number of patients. Patients with chronic plantar heel pain can be severely disabled and have significantly reduced function and quality of life.[58]

The most common operative procedures during the latest decades have been partial or total plantar fasciotomy either through an open or endoscopic procedure. Success rates between 50 -76% have been reported.[4, 28] Following partial plantar fasciotomy a long recovery time and a high rate of complications have been described.[56, 58] Concerns regarding biomechanical changes to the foot have been raised. Patients frequently report dorsal or lateral pain after this procedure. [28] A recent review on treatment of plantar fasciitis states that no treatment has proven long term effect, and that surgery as plantar fasciotomy has undocumented effect, a high proportion of adverse effects and should be reserved for extreme cases only.[58]

Aims of this thesis

1. Evaluate patient satisfaction, functional outcomes and complications of the Strayer procedure in patients with different foot and ankle conditions.

2. Investigate the inter- and intrarater reliability of the clinical Silfverskiöld test, and the intra- and interrater reliability, validity and responsiveness of a new device designed to measure ankle dorsiflexion.

3. Evaluate the clinical and functional outcomes for patients with chronic plantar fasciitis treated with proximal medial gastrocnemius recession (PMGR), including patient related outcome scores, strength, range of motion and post-operative complications.

Materials and methods

Paper 1

The study was designed as a retrospective cohort study. Only patients treated with a Strayer procedure as a single procedure, or cases where it was combined with minor forefoot surgery were included.

We identified 93 patients eligible for inclusion in the chosen time period 2006-2011. Data were collected through second half of 2012. 73 patients responded to the invitation to participate. Median follow-up after surgery was 45 months (range 7-87 months). The patients received a questionnaire regarding satisfaction, whether the patient would have the procedure done again, now knowing the result, and whether they would recommend this procedure to someone else with the same problem. In addition they were requested to report any complications, their self-perceived strength for plantarflexion and grade their pain by the Visual analogue scale for pain (VAS) now and retrospectively as they remembered their pain before the surgery. Hospital records were also checked for all patients to discover any readmissions, detect unreported complications and confirm reported complications.

From the 73 patients, 18 were diagnosed with plantar fasciitis, and 28 with metatarsalgia. All other groups, based on diagnosis, constituted 5-7 patients.

No power analysis was performed prior to study 1. We did not know the number of patients and we planned to include all patients meeting the inclusion/exclusion criteria.

Paper 2

This study was designed as a prospective cohort study. It included two cohorts. A cohort of health care personnel for the reliability testing of the Silfverskiöld test and the new measuring device, and a cohort of patients for testing the validity and responsiveness of the device.

The new ankle measuring device (Figure 5) was designed to be able to use secure anatomical landmarks, to control hind foot joint position, to fit any foot size and to be able to control the applied force. We used a Biometrics SG 150 goniometer, Biometrics Ltd, Units 26-26, Nine Mile Point Ind. Est, Newport UK.

According to the producer it has an accuracy of ±2 degrees and a repeatability of 1 degree (biometricsltd.com).

Consensus on the amount of force that should be applied when testing for isolated gastrocnemius tightness has not been established. Some have stated that force should be applied until the start of resistance, which approximates 20N pressure to the forefoot.[6] Other authors have stated that controlling hindfoot position is more important, and that controlling force is unnecessary as long as the ankle is pushed until end of dorsiflexion range.[6, 38] We investigated the study participants by both setups. The measured parameters were defined as ankle dorsiflexion with extended knee, and the measured difference between ankle dorsiflexion with extended knee and flexed knee.

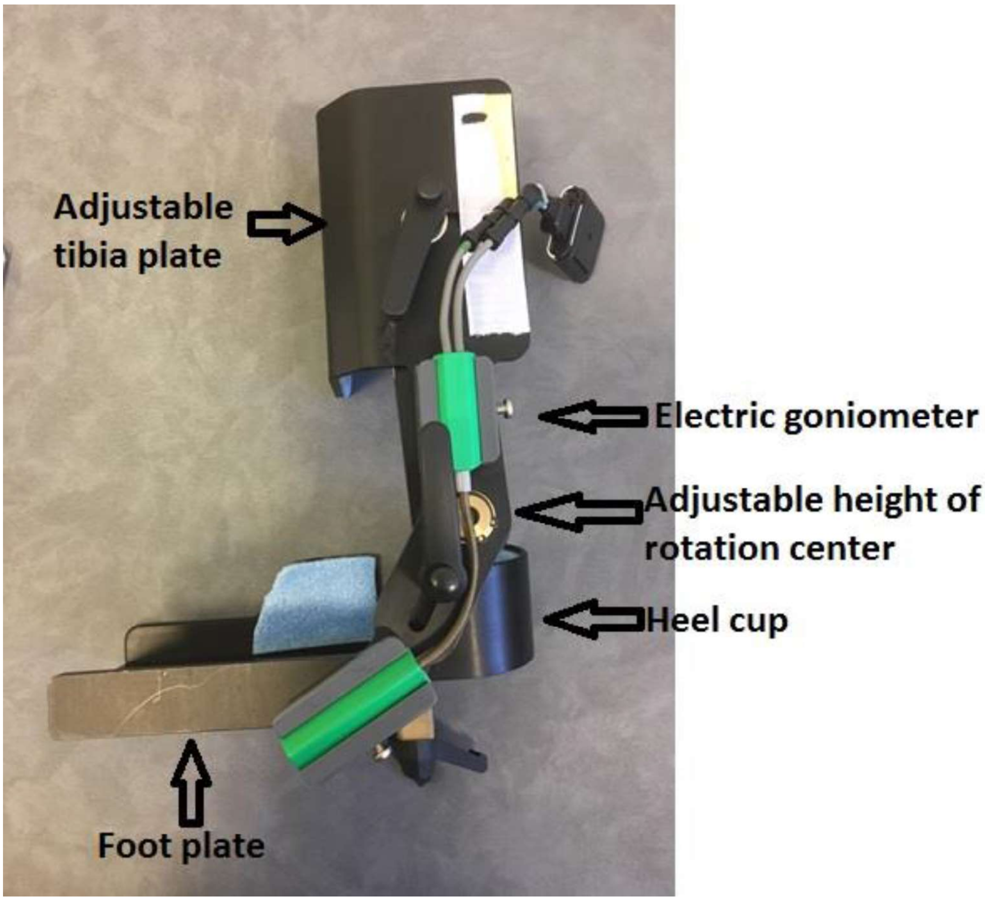

Figure 5. Ankle ROM measuring device.

The reliability testing of both the new device as well as the clinical Silfverskiöld test was performed on a sample of 12 health care personnel (24 feet) (Figure 6 and 7). 4 blinded examiners tested all feet at 3 different occasions with 4 weeks interval. In the clinical Silfverskiöld test the electric goniometer was not used, but a standard goniometer.

Figure 6. Left: The ankle measuring device was carefully adjusted to the patient. Adjustments of all moveable segments were done to make it fit perfect for each individual. Right: First part of the examination is performed with the knee extended. Exerting controlled force underneath the head of the second metatarsal. The result is registered by the primary investigator on a computer, which can not be observed by the tester or the study participant.

Figure 7. The clinical Silfverskiöld test is performed with the knee extended and flexed. Notice the hand of the investigator actively controlling the position of the hind foot joints by inverting the subtalar joint and supporting the talo-navicular joint.

To test the validity and responsiveness of the new device it was decided to include patients referred for a PMGR. Prior to the study a power analysis was performed. It was based on a chosen smallest clinical significant change in ankle dorsiflexion of 5°. A standard deviation of 4.5 was estimated based on a similar study.[33] With a power of 80 and level of significance of 5%, 13 feet were needed. We chose to include 15 feet (11 patients) to account for possible loss to follow up. These patients were all previously referred for a PMGR based on the finding of an isolated gastrocnemius tightness evaluated by the clinical Silfverskiöld test, as well as long lasting symptoms of plantar fasciitis (n=5), calf pain (n=5) and metatarsalgia (n=1). Ankle dorsiflexion was tested prior to surgery, right after surgery as well as three months post-surgery. The surgical procedure of PMGR was performed as described by Barouk (Figure 8).[5]

Figure 8. From top left to bottom right. Picture 1 and 2 identify the knee crease and the incision is marked just distal to the knee crease, slightly medial to the midline. In picture 3

and 4 the skin and subcutaneous tissues are infiltrated with local anaesthesia before advancing the syringe into the underlying gastrocnemius muscle. Picture 5 and 6 show the incision through skin and subcutaneous tissue and the underlying fascia cruralis is exposed. Picture 7 the fascia is incised in the same direction as the skin incision. Picture 8 shows the gastrocnemius aponeurosis which is always located posteriorly and medially. In picture 9 the incision through the aponeurosis starts posteriorly and in picture 10 advances medially. In picture 11 the aponeurosis is lifted by Kocher's to reach the most ventral medial part of it. The incision is closed in layers picture 12.

Paper 3

This study was a single centre randomized controlled trial including patients with chronic plantar heel pain, defined as more than 12 months of symptoms. The diagnosis was established by clinical examination and included typical pain at the proximal origin of the plantar fascia and pain at first step in the morning. Another prerequisite for inclusion was the finding of an isolated tightness of the gastrocnemius evaluated by the clinical Silfverskiöld test.

The power analyses revealed that 16 patients were needed in each group (80% power and 5% significance level). This was based on the smallest clinical significant change in American orthopaedic foot and ankle society ankle-hindfoot scale of 10 scale points. A standard deviation of 10 was estimated based on a similar study.[4] We chose to include 40 patients to compensate for loss to follow-up.

Patients included in the study were randomized to either a home exercise stretching program or a surgical proximal medial gastrocnemius recession in addition to the same stretching program. The stretching program included four exercises focusing on stretching the posterior calf muscles, the hamstrings and the plantar fascia (Figure 9). The stretching exercises were done twice daily with a duration of each exercise of 60 seconds. The surgical procedure of PMGR was performed as described by Barouk (Figure 8).[5] No additional procedures were performed for any of the patients. The main outcome was the American orthopaedic foot and ankle society ankle-hindfoot scale (AOFAS). Secondary outcomes were visual analogue scale (VAS) pain and Short form 36 (SF-36). Achilles function was evaluated by a test battery consisting of 6 independent tests (Figure 10).[89] The Musclelab (Ergotest Technology, Porsgrunn, Norway) measurement system was used. Change in ankle dorsiflexion was measured with the new measuring device that was validated in paper 2 and changes in plantar pressure were evaluated by pedobarography (Tekscan HR mat (Tekscan Inc., South Boston MA) with Tekscan research software).

Figure 9: The 4 stretching exercises that all participants were instructed to perform.

All 40 patients that were included completed the study, and no loss to follow up was registered.

Statistical analyses for all three studies were performed using Statistical package for social science software (SPSS), version 21.0 for Windows (SPSS Inc., Chicago, Il, USA).

Figure 10. The figure shows the setup for the Achilles test battery. Top left: Drop counter movement jump test with starting position on a 20 cm box. Top right: Concentric and eccentric-concentric heel rise in weight machine measured with the linear encoder. Bottom left: Toe raise endurance test with 10° dorsal inclination measured with a linear encoder attached to the heel. Bottom right: Counter movement jump- and hopping test was performed and measured with a jump mat with an infrared beam field.

Main results

Paper 1

14/18 patients from the plantar fasciitis group claimed to be satisfied with the result, while only 14/28 from the metatarsalgia group reported to be satisfied with the result (Figure 11). The VAS pain revealed the same tendency with an obvious improvement in pain for patients with plantar fasciitis from 7.0 to 1.8 (p=0.015) and from 5.6 to 2.3 (p<0.01) for the metatarsalgia group.

16/73 (22%) patients reported their self-perceived plantarflexion strength as reduced or much reduced. The remaining reported no problem or even better function post-operatively (Figure 12).

The self-reported complication rate was high with a total of 28/73 patients reporting a post-operative complication. 9 patients reported prolonged pain and/or swelling, 8 patients reported leg cramps and 3 were classified as others. 8/73 (11%) patients reported serious complications including 3 infections, 2 nerve injuries, 1 pulmonary embolus, 1 chronic regional pain syndrome and 1 deep venous thrombosis.

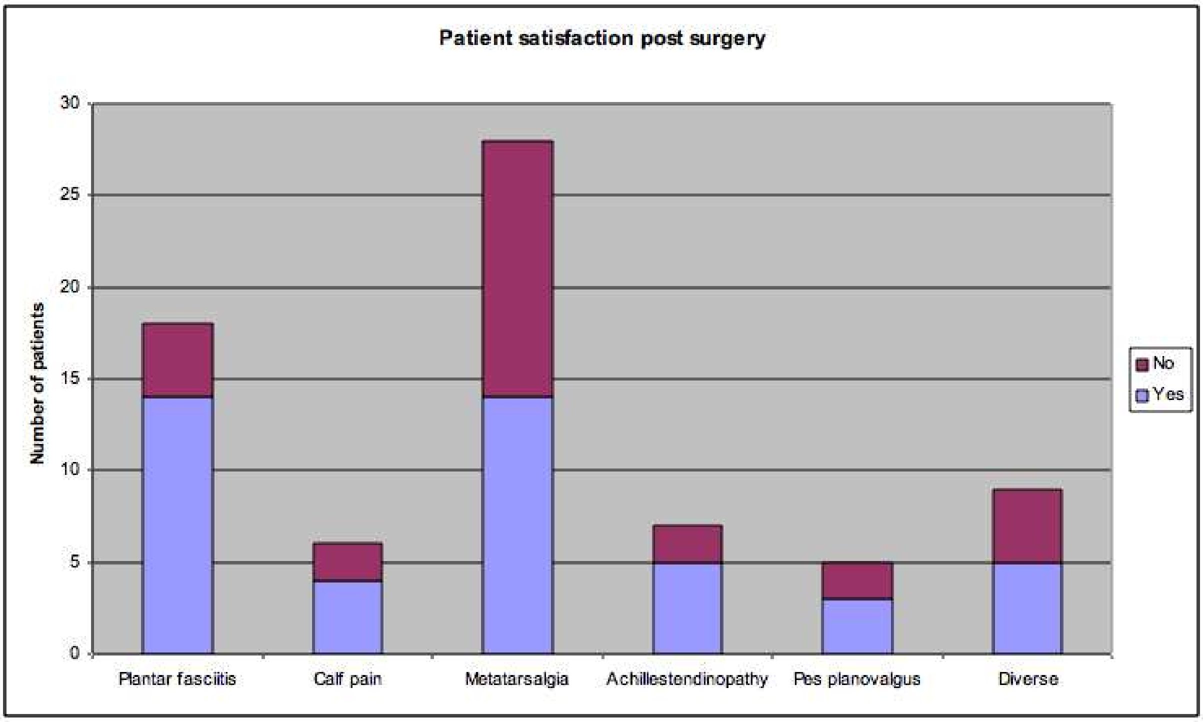

Figure 11: Patients' self-reported satisfaction with the result after surgery.

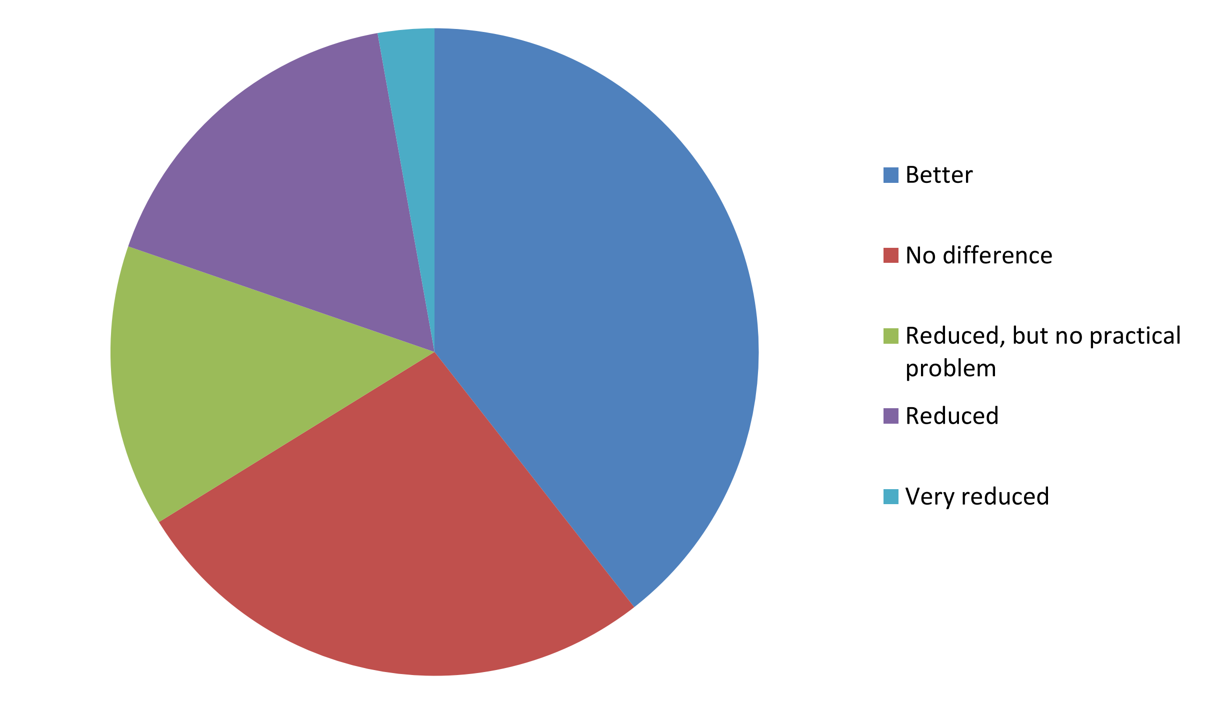

Figure 12: Patients` self-reported strength for plantarflexion after surgery.

Paper 2

The ICC values for the new ankle ROM device were 0.855-0.925 for the intra and interrater reliability testing with the maximum dorsiflexion method. The ICC values for the clinical Silfverskiöld test were 0.399-0.748. Figure 13 gives complete data for both testing with the ankle ROM measuring device as well as the clinical Silfverskiöld test.

	Ankle ROM measuring device	**Maximum dorsiflexion**		**20 N**	
	Ankle dorsiflexion	**ICC**	**CI**	**ICC**	**CI**
Interrater	Extended knee	0.925	0.858-0.964	0.758	0.554-0.883
	Difference ext. vs. flexed knee	0.855	0.719-0.932	0.762	0.562-0.885
Intrarater	Extended knee	0.894	0.690-0.959	0.804	0.618-0.908
	Difference ext. vs. flexed knee	0.869	0.741-0.939	0.732	0.472-0.876
	Clinical Silfverskiöld test				
Interrater	Extended knee	0.694	0.392-0.858	0.760	0.560-0.884
	Difference ext. vs. flexed knee	0.399	0.028-0.681	0.230	0.158-0.569
Intrarater	Extended knee	0.748	0.503-0.882	0.791	0.592-0.903
	Difference ext. vs. flexed knee	0.562	0.178-0.790	0.649	0.318-0.835

Figure 13: Inter- and intrarater reliability for the new ankle ROM measuring device and the clinical Silfverskiöld test from paper 2. ICC: intraclass correlation coefficient, CI: 95% confidence interval, N: Newton

The testing of patients operated with PMGR revealed ankle dorsiflexion measured with the maximum dorsiflexion method, with extended knee, of median 3° before surgery, which increased to 10° after surgery and further to 12° at 3 months follow-up (p=0.003). Ankle dorsiflexion measured with the knee flexed was unchanged at all follow-ups (Figure 14).

Maximum dorsiflexion	**Before surgery**			**After surgery**				**3 months after surgery**			
	median	min	max	median	min	max	p-value	median	min	max	p-value
AD ext. Knee	3	-7	14	10	-4	21	0.001	12	4	20	0.003
AD flexed knee	23	-2	30	22	0	32	0.053	21	6	33	0.066
AD ext. vs. flexed knee	16	5	22	11	4	20	0.001	8	2	23	0.012
20-N method											
AD ext. knee	-6	-17	1	0	-14	12	0.001	1	-4	11	0.001
AD flexed knee	10	-13	17	9	-11	19	0.071	10	-3	25	0.003
AD ext. vs. flexed knee	12	4	18	7	3	17	0.002	8	0	22	0.046

Figure 14: Ankle dorsiflexion measured before surgery, after surgery and 3 months after surgery in a cohort of 11 patients (15 feet) treated by PMGR. Results for both the maximum dorsiflexion as well as the 20-N method are given. AD; ankle dorsiflexion.

Paper 3

The results revealed significantly improved AOFAS ankle-hindfoot scores compared to baseline at both 3- and 12-months follow-up for the PMGR group (Figure 15). No such improvement could be observed for the non-operative group. The AOFAS ankle-hindfoot scores of the operative group were significantly higher than the non-operative group at all follow-ups. Similarly, the VAS pain improved at both 3 and 12 months in the operative group but not in the stretching group (Figure 16). For the SF-36 all 8 subgroup parameters significantly improved from baseline for the operative group and significant better scores for all 8 subgroup parameters were observed for the operative group compared to the non-operative group 12 months after surgery.

The testing of Achilles function revealed no between group differences at 12 months follow-up. However, the performance decreased from baseline for the counter-movement jump (CMJ) and drop CMJ tests, while the performance for the toe raise endurance test improved for the operated feet (Figure 17).

Ankle dorsiflexion for the operated feet (n=28) increased from median 6° to 10.5° at follow-up ($p<0.001$) with the knee extended. A significant decreased difference in ankle dorsiflexion tested with the knee extended versus flexed was also observed for the operative group from before surgery (16.5°) to 12 months follow-up (12°) ($p=0.004$). For the control group, receiving stretching exercises only (n=40 feet), pre-operative ankle dorsiflexion with extended knee of 10.0° and post-operative 11.0° could be observed ($p=0.118$). The difference in ankle dorsiflexion between extended and flexed knee were 17.0° pre- and 16.0° post-operatively for this group (0.337).

For the pedobarographic evaluation, average peak plantar pressure to the forefoot increased from 536 to 642 kPa ($p<0.001$), and the average peak heel pressure increased from 393 to 451 kPa ($p<0.001$). Heel off, expressed as % of total stance, was unchanged at 71% of stance ($p=0.227$).

No major complications were observed, although three patients experienced prolonged swelling or pain in the popliteal fossa. For one of these patients the pain persisted at 12 months follow-up. One additional patient reported increased calf cramps.

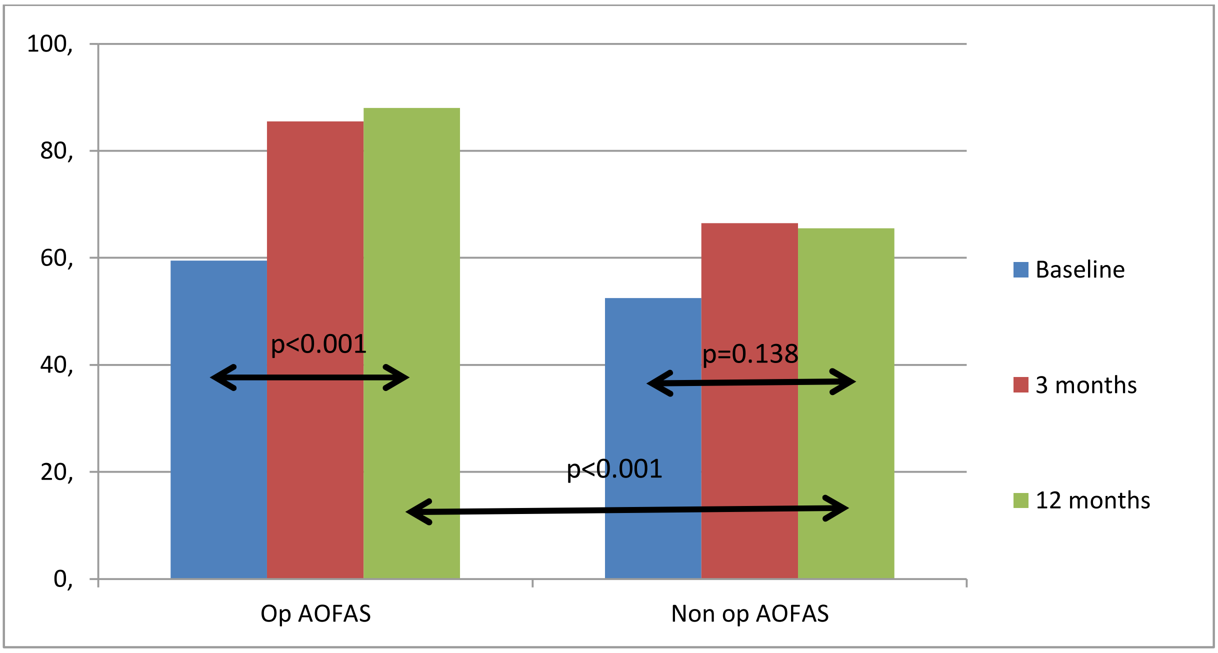

Figure 15. AOFAS ankle-hindfoot score at baseline, 3 months follow up and 12 months follow up for both the operative and non-operative group are illustrated. P-values for the difference from baseline to 12 months follow-up as well as between group differences at 12 months follow up are marked with black arrows.

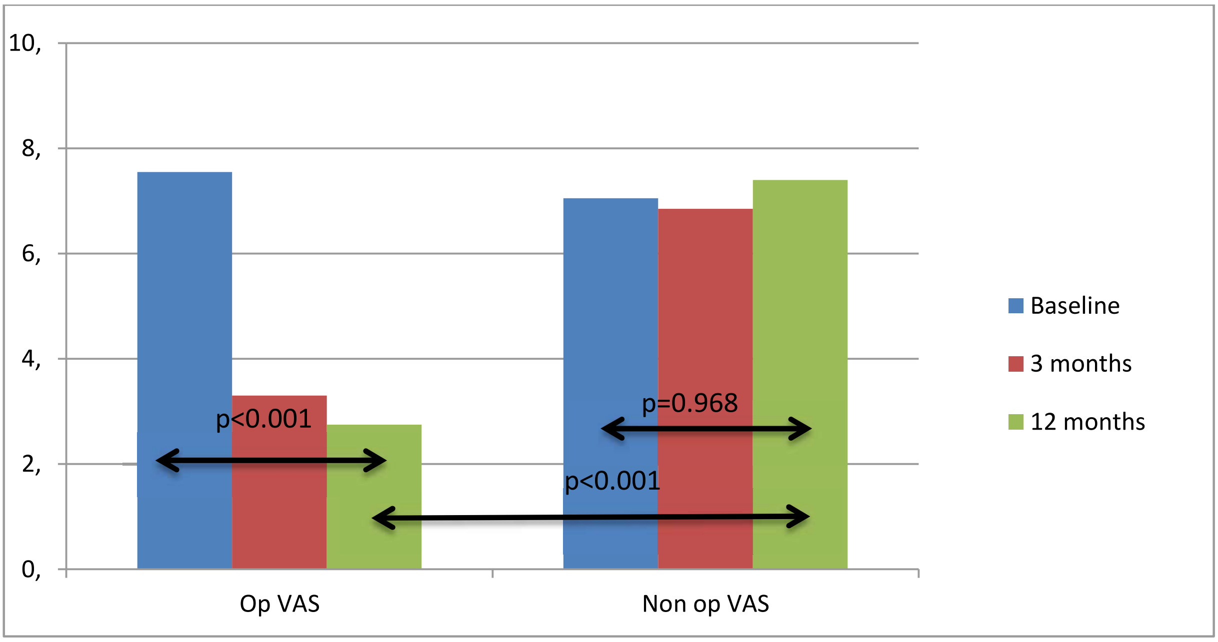

Figure 16. The Figure shows VAS pain at baseline, 3 months follow-up and 12 months follow-up for both the operative and non-operative group. P-values for change from baseline to 12 months follow-up as well as between groups differences at 12 months follow-up are marked with black arrows.

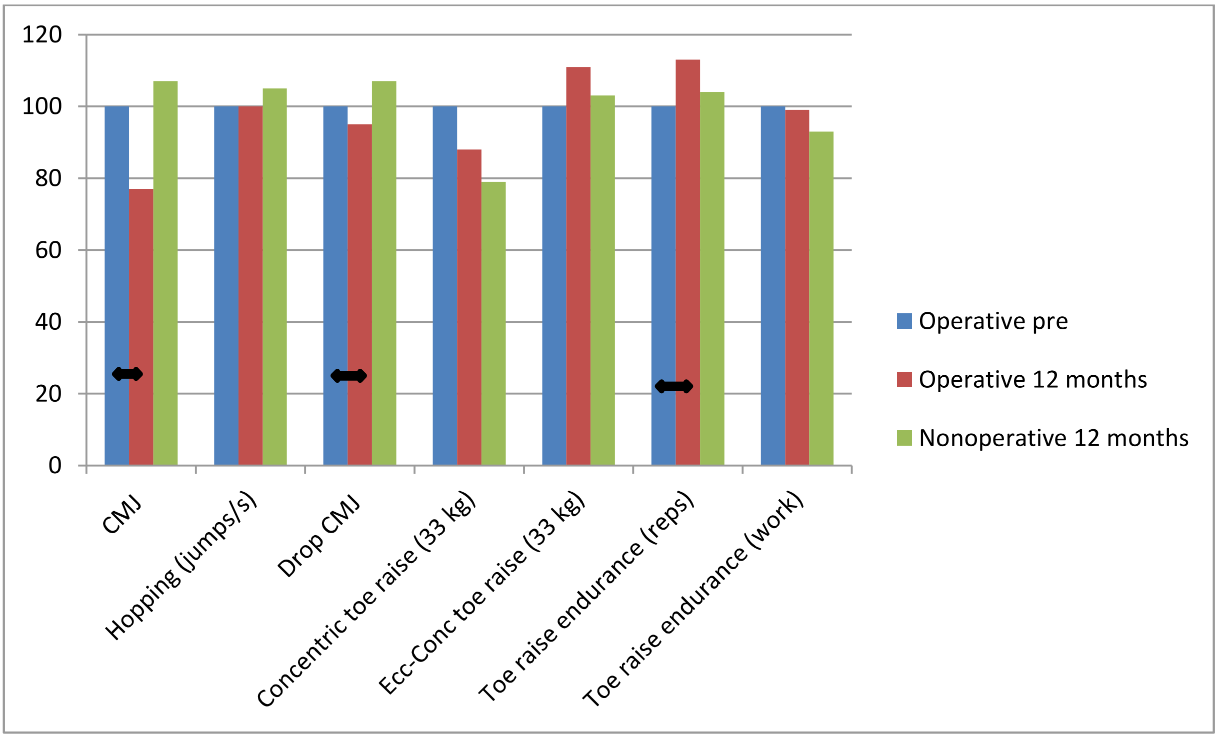

Figure 17. Illustration of performance for the functional Achilles tests compared to baseline level of the operative group. The illustration is based on a modified limb symmetry index (performance at follow-up for operative group/performance at baseline for operative group and performance at follow-up for non-operative group/performance at baseline for operative group). Preoperative level is set at 100 and the performances 12 months post-operative as well as the performance of the non-operative affected limb at follow-up are illustrated based on this. Black arrows (⬌) indicate p- values <0.05.

General discussion

Purpose

Scarce literature existed about the importance of isolated gastrocnemius tightness and the clinical effects of gastrocnemius recession.[1, 64] However, the surgical method has undoubtedly increased in popularity, and surveys among AOFAS members deemed it the most popular method for treating chronic plantar fasciitis.[31] Only small retrospective case series have been published. Indications for surgical gastrocnemius recession are not established. The purpose of study 1 of this thesis was to evaluate the outcomes of a large group of patients, with different foot and ankle pathologies, that had been treated by a Strayer procedure. The patient perceived post-operative function and the complication rate could guide us on the safety of the Strayer procedure. Further dividing patients into groups based on diagnosis could suggest which diagnosis groups that would be appropriate to investigate in future studies.

Clinical practice and other studies have indicated that measuring ankle dorsiflexion is challenging. The Silfverskiöld test is difficult to perform correctly, the clinical cut-off values are not established and measuring this test with a traditional goniometer is insufficient for use in science. Previous studies have concluded that the test is valid, but the method used for validation could be questioned.[33]

For scientific use it is necessary to have methods that in a reliable way can quantify change in ankle dorsiflexion. It is necessary to be able to measure ankle dorsiflexion with the knee both extended and flexed. Other authors have described devices that more accurately can measure ankle dorsiflexion.[38, 42, 99] The main challenge is that none of these devices are commercially available, and the protocols for testing the properties of the devices have limitations.[42, 99] Although intrarater reliability has been confirmed excellent, none of the studies have described interrater reliability, validity or responsiveness of the devices.[42, 99] Another challenge is that no agreement exists on how much torque or force that should be applied when performing the test. The suggestions have ranged from the start of stretch resistance to the end range of dorsiflexion motion.[6, 38] Study 2 was designed with the purpose of testing the properties of the clinical Silfverskiöld test, as well as testing the properties of the new device constructed to accurately measure the Silfverskiöld test. This was done to plan for future clinical studies. In addition, we wanted to follow a group of patients operated with the proximal medial gastrocnemius recession to evaluate the change in ankle dorsiflexion after the procedure. The aim was to evaluate the immediate effect of surgery as well as to investigate whether the post-operative stretching protocol was sufficient for maintaining ankle dorsiflexion.

The purpose of study 3 was based on the results from the two first studies. Study 1 told us that patients suffering from recalcitrant plantar fasciitis seem to respond to gastrocnemius recession. Our results showed satisfactory results in nearly 80% of these patients and other studies also supported this trend.[1, 67] The reported high complication rate from study 1 made us question the safety of the modified Strayer procedure. Some authors had meanwhile described a method, the proximal medial gastrocnemius recession, which theoretically would avoid many of the problems experienced with the Strayer procedure.[1, 5, 67] The PMGR was described as an easy, fast and safe procedure.[1, 5, 67] However, clinical outcome data and biomechanical effects had not been described. We wanted to examine the clinical results for patients suffering from chronic plantar fasciitis treated by PMGR, as well as to evaluate the biomechanical outcomes in terms of change in ankle dorsiflexion, strength and function of the Achilles complex and changes in plantar pressure through the gait-cycle.

Study design

In study 1 the cohort of patients previously treated with the Strayer procedure was large. All patients had been treated by a consistent regime including indications for surgery, standardized surgical procedure and standardized post-operative protocol. Based on this, and the purpose of this study, we planned a retrospective cohort study, acknowledging obvious limitations in possible selection bias and lack of pre-operative data to compare the outcomes to. A retrospective study design gives a variance in time from surgery to follow-up. In this study the range in follow-up time was 7 to 87 months. This represents a limitation to the interpretation of the data, as some patients have a long follow-up, while others have a shorter follow-up.

73 patients responded to the request (78%), making it the largest series evaluating outcome after gastrocnemius recession till then. Although the loss to follow-up represents an obvious limitation and a potential bias, a follow-up rate of nearly 80% in a retrospective series could be considered acceptable.

The aim of study 2 was to investigate the properties of the clinical Silfverskiöld test, as well as the properties of the new ankle ROM device. We deemed a prospective cohort study to be the preferred design of the study. To establish inter- and intrarater reliability it is necessary to have several testers and to repeat the testing at several occasions. Complete blinding of the testers was an important point for increasing the quality of the study.

Other authors have tested the properties of ankle measuring devices on convenience samples of healthy people.[42, 99] This practice has been criticized, and it has been suggested to perform the testing on actual patients.[37] We conducted the reliability testing on a cohort of health care personnel, but the testing of validity and responsiveness of the new tool was performed in a population of patients.

No level 1 evidence regarding outcome data after gastrocnemius recession procedures existed. Study 1 of this thesis suggested that patients with plantar heel pain could benefit from gastrocnemius recession. Study 2 proved the new ankle measuring device to be valid and reliable in measuring ankle dorsiflexion as well as changes after surgery. The results also suggested that the PMGR was able to increase ankle dorsiflexion. We wanted to add high level evidence and therefore we planned to conduct a randomized controlled trial as the best design to answer our questions for study 3. The choice of treatment for the control group was debated. No protocol, neither operative or non-operative has proven long-term effect for the condition of plantar fasciitis.[58] However, some authors argue that stretching exercises seem to be the most effective treatment, and additionally, the stretching exercises have no adverse effects.[27, 59, 66] This treatment was also logically a part of our study as the protocol for PMGR includes stretching exercises post-operatively. Studies have described effect on plantar heel pain from Achilles stretching alone, while others have demonstrated added value from plantar fascia specific stretching exercises.[32, 82] We developed a stretching regimen consisting of calf specific stretches as well as plantar fascia specific stretches and stretches for the hamstring. We believe that designing the study this way could tell us the true effect of the surgery as the only difference between groups was the surgical procedure. Ideally, a double-blind design would be optimal. This, however, is difficult in surgical studies. Conducting a sham study is possible, but in this case the research group deemed it to be unethical.

All 40 patients who were included completed the study. We consider the 100% follow up rate to be a strength of this study.

Choice of outcomes and evaluation methods

The aim of study 1 was to evaluate the safety of the surgical procedure of gastrocnemius recession ad modum Strayer according to complication rates and plantarflexion strength. In addition, we wanted to screen the self-reported satisfaction with clinical outcome and pain grouped by primary diagnosis.

No patient reported outcome measure score (PROM) has been validated for evaluating outcomes after gastrocnemius recession. We therefore used unvalidated questionnaires for this purpose. The self-reported complication rate was very high suggesting that the patients' understanding of complications probably was somewhat different than intended. Further grouping into complications or subjective discomfort was done by the authors. This outcome was cross-checked and verified with hospitals records for all patients. We did, however, not consider discomfort like prolonged pain and/or swelling nor leg cramps as a complication.

Ankle plantar flexion strength was evaluated by a 5-point scale ranging from better strength than before to very reduced function. Other authors have used similar methods with questions evaluating the patients' subjective strength post-operatively.[1, 64] However, this method is clearly not able to quantify strength, nor detect minor changes in strength. As no preoperative measurements existed and no matched control group was available, the changes in plantar flexion strength from pre- to post-operatively could be a topic for a future well-designed prospective study. We believe the patients' self-reported perception of plantar flexion strength is an interesting observation, although the results should be interpreted with caution.

As for the evaluation of strength, the outcomes of patient satisfaction and pain were evaluated with unvalidated questionnaires. Pain was evaluated by the VAS pain scale, which has also been used in comparable studies.[64] The postoperative VAS pain could therefore be compared to other studies. Pre-operative VAS pain, however, was retrospectively evaluated and thereby representing a method with weaknesses, especially considering the time interval from surgery to study follow-up. The question regarding patient's satisfaction was formed as: "are you satisfied with the result after surgery?" In the text in the article it could look like a Likert scale has been used, although the question was formed as categorical options. We have interpreted a yes response as an excellent or good result. This represents a possible inaccuracy in the evaluation of the outcome.

Due to the aim of this study, which was to screen patient satisfaction based on primary diagnosis, we believe that the method of self-evaluation questionnaires is useful. We believe that due to the design of this study, as well as the chosen outcomes, the results should be read with caution.

Study 2 aimed to evaluate methods for measuring IGT. The clinical Silfverskiöld test as well as a new device constructed for measuring ankle dorsiflexion was tested extensively. The documentation stating that simple goniometric methods for evaluating ankle dorsiflexion are unreliable is solid.[37, 42] However, other authors have stated that the Silfverskiöld test is reliable and valid.[33] As our clinical experience tells us that the clinical Silfverskiöld test is difficult to perform, we wanted to investigate the reliability of the test. The investigation of reliability of the Silfverskiöld test was performed by repetitive testing of ankle dorsiflexion on healthy individuals by four investigators. The investigators were blinded, and the order of patients and investigators were randomly chosen. Test- retest was done with a four weeks interval to assure that it was not possible to recognize the patients or the previous test results. To our knowledge no previous study has tested both the inter- and intrarater reliability of the clinical Silfverskiöld test.

For scientific use and future studies, we designed a device to accurately measure ankle dorsiflexion. The main principles of the device were based on the description of a similar device that has been used in previous studies.[33, 99] The reliability testing of the device followed the same protocol as for the clinical Silfverskiöld test. The device was removed and calibrated between every tester. The tester did not get access to the test results as this only appeared on the computer administered by the first author. A minimum of three measurements were performed at all occasions and the median value chosen. Other authors have used similar devices and also proven them to be reliable.[38, 42, 99]

The main challenge when evaluating the properties of such a device is to establish the validity and responsiveness, as no gold standard for comparison exists. Some authors argue for radiographic comparison, while others have used optoelectronic motion analysis system for comparison.[37, 38, 100] We recruited a cohort of patients with overload foot pathology in addition to a verified IGT evaluated by the clinical Silfverskiöld test. The evaluation of validity of the new device was based on the finding of an IGT in these patients when examined pre-operatively. Responsiveness of the device was evaluated based on the findings of no sign of IGT in the same patients three months post-operatively. This way of establishing validity could of course be discussed. Using the clinical Silfverskiöld test, that previously demonstrated to have a low inter- and intrarater reliability, as a gold standard is problematic. However, no better way exists as no established gold standard exists. The use of healthy study participants to validate instruments for measuring ankle motion has been criticized. Gatt and Chockalingam state that actual patient populations should be used, otherwise papers would score poorly on methodological quality assessment.[37, 38] We included both a cohort of healthy study participants for the reliability testing and a cohort of patients for the testing of validity and responsiveness of the measuring device.

One of the obvious key elements when measuring ankle dorsiflexion is how much force or torque that should be applied. Barouk has argued that the beginning of stretch resistance of the m. gastrocnemius is to be tested, which he has estimated to be no more than 2 kg or 20 N force applied to the forefoot.[6] Other authors have stated that controlling hindfoot joint position is more important than applied force as long as dorsiflexion is tested to end-range of motion.[38] We performed testing with both setups to evaluate the reliability of both methods.

Study 3 aimed to describe clinical outcome as well as biomechanical changes after PMGR. The AOFAS ankle-hindfoot score has been heavily criticized for limited precision, lack of responsiveness, inability to demonstrate clinical differences, and producing skewed data.[15, 44] It consists of one part answered by the patient and one answered by the investigator. However, it is by far the most frequently used outcome score in evaluating foot and ankle conditions.[15, 49] The widespread use makes the score suitable in terms of comparing results to other studies. As no other score has proven validity for plantar fasciitis, we chose to use the AOFAS ankle-hindfoot score as our main outcome measure, despite its limitations. To compensate for the AOFAS ankle-hindfoot score`s limitations we added two more clinical outcome measures. Both the VAS pain and SF-36 are frequently used in similar studies.[49] The SF-36 is unspecific for foot and ankle conditions, which make it unfit to be the main outcome measurement. However, as a secondary outcome instrument we believe it is of great value.
For the biomechanical outcomes three main parameters were chosen. Change in ankle dorsiflexion after surgery, the impact on Achilles function after surgery, and changes in plantar pressure. Changes in ankle dorsiflexion were examined with the new ankle ROM device that was tested and validated in study 2. Regarding Achilles function different authors have used different methods. Self-evaluation questionnaires, like in study 1 is one method that has been utilized.[64] The limitations of this method have already been discussed. Other authors have used isokinetic and isometric testing.[20, 72] Although this evaluation is quantifying strength it is very unlikely to quantify function. Questions have been raised about the isokinetic strength assessments` ability to correlate with patient reported functional deficits.[72] In the study by Nawoczenski et al. the patients performance on isokinetic testing was more or less similar to the control limb after gastrocnemius recession procedures, but the sports subscales score on the Foot and ankle ability measure score (FAAM)

were significantly lower than for the control group.[72] Other authors have used number of heel raises as an outcome parameter.[1] However, a method including 6 different dynamic functional tests has been extensively tested and validated for conditions known to impair Achilles function.[89] In contradiction to all other methods it evaluates different aspects of the triceps surae function, as both power, endurance and the ability of the stretch-shortening cycle are tested.[89] We believe this evaluation method adds substantial new data about expected postoperative function.

The foot pressure changes, and gait pattern changes were evaluated by pedobarography. Pedobarography can be used to measure static or dynamic plantar foot pressure. The aim of this study was to detect dynamic changes to plantar foot pressure. Studies have previously demonstrated that increased tension of the Achilles tendon lead to increased static plantar forefoot pressure and increased tension to the plantar fascia.[2, 16] Further it has been shown that the forefoot pressure increased equally if isolated gastrocnemius tightness is present, as if the tightness is caused by combined gastrocnemius soleus tightness. Although, this logical connection has been established through laboratory studies, no previous study has investigated dynamic foot pressure changes after surgical gastrocnemius lengthening. Different outcomes could be extracted from a pedobarographic investigation. Based on the previously mentioned laboratory studies we theorized that gastrocnemius recession would decrease forefoot plantar pressure and that heel off possibly would occur earlier when measured dynamically at gait. We predefined to use peak average forefoot pressure and peak average heel pressure as outcomes. Plantar pressures could also be described by pressure-time integral. Peak pressures give a measure of the highest pressure to a defined area, whereas pressure-time integral describe area under the peak pressure time curve. However, peak pressures are most commonly reported in other studies, which makes it suitable for comparison, and studies have questioned the added value of reporting pressure-time integral.[14] To investigate the theorized earlier heel lift after gastrocnemius recession we defined to report heel off (third rocker) as percentage of total stance as an outcome. Other authors have used estimates of lateral or medial trajectory or heel stance time instead of percentage.[87, 97]

Statistics

Study 1

The data for VAS pain were normal distributed making the 2-sided t-test applicable. All other groups were too small to perform useful statistical analysis.

Study 2

Reliability measures are expressed as intraclass correlation coefficient (ICC) with confidence intervals. Several methods for expressing agreement have been described. The intraclass correlation coefficient is frequently used. An application of the ICC is the assessment of consistency or reproducibility of quantitative measurements made by different observers measuring the same quantity. Weaver et al. used daily variation and standard deviation as the main outcome when testing the properties of their device, while Greisberg et al. reported intrarater reliability as ICC.[42, 99] Guidelines for interpreting the results of the ICC have been suggested. In 2016, Koo and Li suggested the following guidelines for interpreting ICC levels: ICC < 0.5 poor, ICC 0.5 - 0.75 moderate, 0.75 – 0.90 good and > 0.90 excellent.[57]

The change in ankle dorsiflexion from before to after surgery was not normal distributed and non-parametric statistics were used. Non-parametric data are presented as medians with ranges. Wilcoxon tests were used for statistical analyses, and differences were considered statistically significant if $p < 0.05$. Data from three measurements were used for analyses, and other statistical methods than the Wilcoxon test could have been used. One possibility is a mixed effects model (with patients as random effects) since measurements from the same patient obviously are correlated. The time points could have been used as a fixed effect, and we could have tested post operative and 3 months results against baseline.

Reasons for not using the mixed effects model are that the data are not normally distributed, no obvious transformation is present and because there were only few measurements for each individual. As we intended to compare 3 months data to baseline and 12 months data with baseline the Wilcoxon test is appropriate.

A weakness when using the Wilcoxon test is loss of power. This is because the Wilcoxon test has less power than parametric tests and testing with multiple comparisons further reduces the power.

Study 3

The data from study 3 were not normal distributed. The dataset, in particular for several clinical outcomes, had a skewed tendency. The AOFAS hindfoot score has previously been criticized for producing skewed data, but the same tendency was also observed for the SF-36 and VAS. Using t-tests are in many ways preferable due to the analytic strength. However, skewed data are known to be unfit for t-tests. We think using the Wilcoxon tests for nonparametric data is safer and more robust in this case. As for study 2, the same considerations regarding choice of statistical method are present for this study, as data from three repeated measurements were analysed.

Discussion of results

Evaluation of isolated gastrocnemius tightness

The results from study 2 showed that the clinical Silfverskiöld test had moderate inter- and intrarater reliability when measuring ankle dorsiflexion with the knee extended with ICC respectively 0.694 and 0.748. The ICC was poor to moderate when testing the difference in ankle dorsiflexion between extended and flexed knee with ICC values of 0.399 and 0.562).

Evaluation with the new measurement device demonstrated good to excellent intra- and interrater reliability, with all ICC values in the range 0.855 to 0.925.

Testing ankle dorsiflexion with a traditional goniometer is described to be an unreliable method, and should not be used for scientific purposes.[37, 38, 42] The Silfverskiöld test could be even more challenging as the tension of the gastrocnemius and the soleus are tested separately, with respectively the knee extended and flexed.

DiGiovanni et al. have claimed that the correct diagnosis of IGT was found by two raters in 76%-94% of cases when testing with the clinical Silfverskiöld test, and comparing with an electro goniometric equinometer device as gold standard for ankle dorsiflexion.[33] The testers evaluated the test as positive or negative without specifying exact degrees. DiGiovanni et al. tested both a cohort of patients with different foot and ankle pathologies, and a healthy control group. No retesting was performed, and no estimate of reliability of the test was given. In our study the testers were instructed to describe the result of the clinical Silfverskiöld test by degrees of dorsiflexion, and not simply as a positive or negative test. The reliability was described by ICC. The ICC in our study show a moderate reliability when measuring ankle dorsiflexion with the knee extended with interrater ICC of 0.694 and intrarater 0.748, and a poor to moderate reliability when testing the difference in ankle dorsiflexion between extended and flexed knee with ICC 0.399 and 0.562 respectively. This correlates with the levels previously reported with interexaminer ICC 0.65 and intraexaminer ICC 0.74.[51] Several studies have described a poor reliability when evaluating ankle dorsiflexion with a traditional goniometer.[37, 38] However, in clinical practice many patients will have ankle dorsiflexion far beyond the diagnostic cut-off, probably making it possible to establish the correct diagnosis in most cases as demonstrated by DiGiovanni et al.[33] For scientific use, more accurate methods should be used and the low inter- and intrarater reliability of the Silfverskiöld test constitutes a major challenge.

Previously, other authors have described devices with properties permitting standardization of ankle dorsiflexion evaluation.[33, 38, 42, 99] None of these devices are commercially available. For scientific and clinical use we constructed an ankle ROM measuring device based on many of the principles previously described, including the possibility to control applied force, ability to control hindfoot joint position and the utilization of an electric goniometer with high accuracy.[99]

We expected the reliability of the ankle ROM measuring device to be better than the reliability of the clinically performed Silfverskiöld test. Higher ICC values for the measuring device compared to the clinical Silfverskiöld test confirmed our expectations.

Evaluation of the new device demonstrated good to excellent ICC with values in the range 0.85-0.93 for both intra- and interrater reliability for the maximum dorsiflexion method. Other authors have used similar devices and also proven them to be reliable.[38, 42, 99] In the study by Weaver et al. they did not use ICC as the primary outcome, but described an intrarater reliability with ICC as high as 0.98.[99] The reason why Weaver et al. demonstrated higher intrarater reliability for their device than we did in our study is possibly because they had fewer observations, only one day interval between testing, only one tester and no blinding. Greisberg et al. reported an intrarater ICC 0.96 when testing their ankle measuring device.[42] They also repeated the test only once immediately after the first test. Our study is also the only study reporting both inter- and intrarater reliability as other studies report only intrarater reliability.[42, 99]

The measurements with the new device met the criteria we used for the diagnosis of IGT in 13/15 feet preoperatively, while 10/13 feet were evaluated as Silfverskiöld negative three months after surgery. In our understanding this demonstrates a good validity and responsiveness of the new device. To our knowledge no other studies have evaluated validity and responsiveness for measuring devices evaluating IGT. Another way to interpret this result is that the present test setup has a high sensitivity and specificity. Sensitivity is in this study setup defined as how many with the actual pathology do get a positive test result, while specificity will be defined as how many without the actual pathology do get a negative test result. Assuming that all included patients do have an isolated gastrocnemius tightness before surgery, which is corrected after surgery, the test will have 13/15 = 87% (CI 0.60-0.98) sensitivity and 10/13 = 77% specificity (CI 0.46-0.95). However, as previously discussed, it should be acknowledged as a limitation that no gold standard for comparison exists.

Some authors argue that the clinical Silfverskiöld test must be performed with a standardized force or torque. Barouk et al. claim this to be the beginning of stretch resistance which should not exceed 2 kg, corresponding to a pressure of 20 N applied to the forefoot.[6] DiGiovanni et al. used 10 Nm torque based on an estimate that this was the normal average pressure used when performing a clinical Silfverskiöld test by their team members. Other authors have demonstrated that controlling hindfoot position is more important than the force applied to the forefoot, as long as the ankle is dorsiflexed to end range of dorsiflexion.[38] Our tests with both a standardized force of 20 N applied to the forefoot as well as testing to maximum dorsiflexion, while controlling the hindfoot position, show a better inter- and intrarater reliability for the maximum dorsiflexion method**.** The measured increase in ankle dorsiflexion after surgery was equal for both the maximum dorsiflexion method as well as for the 20 N method. We believe that both methods are useful for diagnosing an IGT, but the diagnostic cut-off values for an IGT must be different depending on the method chosen. Based on our findings we do not believe that we can conclude on the superiority of one of these methods, although the maximum dorsiflexion method seems to be more reproducible than the 20 N method. The suggested cut-off of 10° ankle dorsiflexion when testing dorsiflexion to end range of motion is also in concordance with biomechanical studies, supporting that 10° dorsiflexion of the ankle is needed for a normal gait.[19, 24, 52, 94] In addition, when testing to end of dorsiflexion motion, it actually omits the problem of controlling torque or force as the as the test simply measures the angle when no more ankle dorsiflexion is achieved by pushing.

Measuring ankle motion under load has been suggested by some authors, and has been described to be more reproducible than measuring ankle motion non-weightbearing.[60] The original method described measuring ankle motion only with the knee flexed.[60] Recently, a modified weight bearing lunge test has been described for evaluating IGT.[11] The person to be measured is leaning forward until just before heel lift off, and the ankle dorsiflexion is measured. The test is performed with both the knee extended and flexed 20° to examine the tension of the soleus and gastrocnemius separately.[10-12, 63] The authors focus on the difference in ankle dorsiflexion with the knee extended versus with the knee flexed, defined as ankle dorsiflexion index (ADI). Using this method could be reasonable as it seems to be reproducible and obviously is easy to perform, but the results could not be equated to studies measuring ankle dorsiflexion with the Silfverskiöld test due to the obvious differences in test characteristics.

Impact on ankle dorsiflexion after stretching and surgical gastrocnemius recession

Several authors suggest stretching exercises as first line of treatment for conditions related to gastrocnemius tightness.[66] Although, a promising effect in terms of pain reduction has been reported, the effects in term of measured increase in ankle dorsiflexion are rarely reported.[82] The control group in study 3 received stretching exercises as the only treatment of chronic plantar fasciitis. The stretching protocol was comprehensive with 4 exercises focusing both on calf stretches, hamstring stretches as well as stretches of the plantar fascia. However, no significant increase in ankle dorsiflexion could be measured at 12 months follow-up compared to pre-operative values, (respectively 10 and 11 degrees, p =0.118). This result is comparable to other studies. In a recent RCT Searle et al. could not find any difference in non-weightbearing or weightbearing ankle dorsiflexion between a group that were doing static stretching exercises for 8 weeks compared to a control group.[88] Although stretching exercises are commonly prescribed in clinical practice, the documented effect in terms of increased ankle dorsiflexion could be questioned.

Study 1 evaluated outcomes after the Strayer procedure, but as no pre-operative measurements existed for comparison, no attempt was made to measure ankle dorsiflexion at follow-up.

In study 2 the three months follow-up of 11 patients (13 feet) operated with PMGR revealed an increased ankle dorsiflexion, measured with an extended knee, from a median of 3^o before surgery to 10^o immediately after surgery and 12^o three months after surgery ($p=0.003$).

In study 3 the ankle dorsiflexion with extended knee joint increased from a pre-operative level of median 6^o to 10.5^o at 12 months follow-up in the cohort of 20 patients operated with PMGR ($p<0.001$).

Several surgical approaches for lengthening the gastrocnemius have been described, from which the Strayer technique seems to have been the one most frequently used.[9, 27] Later, the method of lengthening restricted to involve only the proximal medial head of the gastrocnemius was popularized by Barouk and is termed PMGR.[5] The PMGR is suggested to have a low complication rate, cosmetically superiority, fast recovery, and reduced incidence of postoperative calf weakness.[1, 5, 27, 67, 92] However, a distal recession targeting both muscle heads is supposed to have a greater impact on ankle dorsiflexion than a proximal recession.[85] The Strayer procedure has been described to increase ankle dorsiflexion up to 18°.[81] The PMGR`s ability to increase ankle dorsiflexion has never been quantified in clinical studies, although it has been described to increase ankle dorsiflexion.[5] The only study describing the effect on ankle dorsiflexion following PMGR is a cadaveric study showing an increase of 14.8° ankle dorsiflexion. [85] The same study demonstrated an even greater ankle dorsiflexion after the Strayer procedure with an increase of 22.4°.

Based on the lack of evidence regarding the effects of the PMGR on ankle dorsiflexion in a clinical setting, one part of study 2 included measuring ankle dorsiflexion before surgery, immediately after the PMGR as well as 3 months later. The aim was both to evaluate the immediate effect of this surgical procedure, which has not previously been quantified, as well as evaluating whether the post-operative rehabilitation protocol was effective in maintaining the increased ankle dorsiflexion. The patients were instructed to do the same post-operative stretching exercise protocol as in study 3. We found that the ankle dorsiflexion, measured with an extended knee, increased from a median of 3° before surgery to 10° immediately after surgery and 12⁰ three months after surgery (=0.003). The difference in ankle dorsiflexion with extended knee versus flexed knee was 16° pre-surgery and 8° 3 months post-surgery. Although this clearly demonstrates the effect of the PMGR on ankle dorsiflexion, and that the effect is maintained at three months, it also suggests that the method possibly has less ability to increase ankle dorsiflexion than the Strayer procedure when comparing to previous reports.[81] We also interpret the results as the post-operative stretching protocol is sufficient for maintaining ankle motion after PMGR.

In study 3, the RCT, the ankle dorsiflexion with extended knee joint increased from a baseline level of median 6⁰ to 10.5⁰ at 12 months follow-up in patients operated with PMGR ($p<0.001$). The difference in ankle dorsiflexion measured with extended vs. flexed knee decreased from 16.5° pre-operatively to 12° at one-year follow-up. These improvements were somewhat smaller than the results from study 2, smaller than demonstrated in cadaver studies, and smaller than described for other techniques.[81, 85] Unfortunately, no study comparing clinical outcomes after the different surgical methods for gastrocnemius recession have been published. Both the lack of previous studies evaluating the effect of different methods for gastrocnemius lengthening and the lack of consensus regarding the definition of gastrocnemius tightness make the interpretation of the measured increase in ankle dorsiflexion difficult. The unanswered question remains: how much increase in ankle dorsiflexion is sufficient? As previously outlined, different authors have used different cut-off values for defining an IGT, ranging from < 0° to < 10° ankle dorsiflexion with the knee extended.[6, 33] Biomechanical studies suggest that >10° dorsiflexion of the ankle through stance phase is needed for normal gait. [19, 24, 52, 94] Recently, some larger studies have tried to quantify prevalence of gastrocnemius tightness in the normal population and to establish norm values.[11, 17] Baumbach et al. examined 64 young subjects without foot pathology both with the Silfverskiöld test as well as with the weight bearing lunge tests. Ankle dorsiflexion measured with the Silfverskiöld test with the knee extended was approximately 23°, and an increase of approximately 10° was observed when flexing the knee.[11] They suggested 20° as a limit for impaired ankle dorsiflexion. Chan et al. and Malhotra et al. performed large studies using the weight bearing lunge test and reported ADI of 6° in the normal population and ADI of >10° in a group with forefoot pathology.[17, 63] They suggested that ADI greater than 13° may be considered abnormal, as this represented more than 2 standard deviations from the norm value.

The findings in study 2 and 3 of more than 10° ankle dorsiflexion with extended knee after surgery, thus correspond to biomechanical studies. The ADI also decreased beyond 13° which is the suggested value for abnormality. It therefore looks like the PMGR can increase ankle dorsiflexion sufficiently in most patients. The explanation for the difference in results between study 2 and 3 of this thesis could be that the evaluation in study 2 was done 3 months post operatively, while in study 3 the measurements were done 12 months post operatively. In study 3 the patients were encouraged to continue stretching for the first 3 months. We did not, however, have any follow-up visits ensuring the continuity of stretching exercises between 3 and 12 months. The importance of stretching exercises post-operatively has not been verified, but study 2 revealed that ankle dorsiflexion was maintained three months after surgery ($p= 0.086$). The effect of stretching exercises following surgery has not previously been evaluated in studies on patients undergoing gastrocnemius recession.

It might be reasonable to individualize the choice of gastrocnemius recession procedure for each case, as other methods of gastrocnemius recession at least theoretically have a higher potential than the PMGR for increasing ankle dorsiflexion.

Strength and function of the Achilles complex after gastrocnemius recession

The patient self-evaluation of postoperative plantarflexion strength in study 1 revealed that 16/73 (22%) patients reported a severe decrease in plantar flexion power after the Strayer procedure, while 28/73 (38%) patients reported increased strength after surgery.
The test battery evaluating function of the Achilles complex after PMGR in study 3 revealed no difference between the operated legs and the affected legs from the control group at 12 months follow-up. However, a decrease in performance for two of the jump tests could be observed between baseline and 12 months follow-up for the operated feet, while the performance on the endurance test increased post-operatively.
Distal gastrocnemius recession procedures, as for instance the Strayer procedure, are expected to have a greater impact on function than the proximal recession, but no study has verified this. The only papers assessing strength and function after the PMGR use insufficient methodology.[1, 5, 67] We used a functional test battery described by Silbernagel et al. consisting of six independent tests through which maximum power, endurance and the stretch shortening cycle of the muscle-tendon complex were tested.[89] This functional test battery has been proven to have excellent validity and reliability in evaluating Achilles tendon pathology.[89] In study 3, no differences were observed between the operated legs and the affected legs in the control group at one-year follow-up. When comparing performance in the operated group at baseline and at one-year follow-up, a decreased performance at one year compared to baseline for two of the jump tests was found. The result for the toe-raise endurance test was on the other side significant better for the operated feet at one-year follow-up compared to baseline levels. In the non-operative group, a decreased performance at 12 months follow-up for the drop counter movement jump test compared to baseline was also observed. The reason for the patients` decreased jump test performance for both groups is difficult to explain. Both theoretically and clinically observed, the drop counter movement jump-test is the most painful test to perform when having heel pain. It could therefore be expected that the performance of this specific test

would increase, due to diminishing pain at one-year follow-up. The decrease in performance on two of the jump tests in the operative group could be a true reflection of a minor weakening of the muscle due to the surgical lengthening. Nevertheless, three tests showed no significant change and the toe-raise endurance test showed improvement in performance from baseline to one year. A safe conclusion is difficult to make, although it seems that the changes are small from baseline to 12 months follow-up, and that the groups are comparable at follow-up concerning the functions studied with the functional test battery.

The impact of gastrocnemius recession procedures on the performance of the Achilles muscle-tendon complex has previously been reported in some minor retrospective studies.[1, 64, 67] These retrospective studies have used non-validated self-evaluating forms, or heel-rise tests evaluating number of heel-rises. [1, 67] Other studies have evaluated return to physical activity. It has been reported that 91% of patients returned to their pre-operative level of sports at a mean time of 7.5 months after surgery.[95] The limitations of all previous studies are low numbers of patients included, the retrospective character, the lack of validated outcome measures, as well as the lack of pre-operative data and control groups.

Post-operative Achilles function, quantified by isokinetic and isometric testing, have been reported for distal gastrocnemius recession procedures but not for the PMGR. Sammarco et al. reported 74% peak torque compared to the contralateral leg in 40 patients undergoing a Vulpius procedure at an average follow-up of 25.3 months.[86] Schmal et al. examined 26 patients at 6 and 24 weeks after a Strayer procedure.[87] A significant increase in function occurred between 6 and 24 weeks, but statistically significant impairments remained for plantar flexion in concentric, eccentric and isometric mode at 24 weeks follow-up. Nawoczenski et al., in their comparative retrospective level III study, reported the results of isokinetic testing in 13 patients with Achilles tendinopathy operated with a Strayer procedure, and 10 healthy controls at a mean follow-up of 18 months.[72] Although, only minor between-group differences were observed on isokinetic testing, the authors question the use of isokinetic strength assessment as an outcome, because patients reported lower sport and activities of daily living subscales on the FAAM outcome compared to the control group.

To our knowledge only two retrospective studies reported outcomes based on functional tests validated for describing Achilles function.[65, 73] Both studies evaluate function for patients who underwent a Strayer recession for Achilles tendinopathy. Both studies show a tendency for weakness of the operated limb. The study by Nawoczenski et al. used a control group for comparison. The results show that ankle power was reduced for the Strayer group compared to the control group for all activities.[73] The other study using validated Achilles function outcomes was a retrospective cohort study.[65] The patients were examined by the same examination protocol for evaluating Achilles function as in study 3 of this thesis. The performance of the Achilles complex of the operated limb was compared to the unaffected limb for 10 patients. Although the study concluded that no statistical significant difference between legs could be found, there was a tendency for impaired function of the operated limb. Both studies may be underpowered and have weaknesses in terms of the retrospective design, lack of preoperative evaluation, and the fact that Achilles tendinopathy is a condition itself known to impair the function of the Achilles muscle-tendon unit. The methodological shortcomings make it difficult to conclude whether, and to which degree, the Strayer procedure impairs Achilles muscle-tendon function.

Gait and plantar foot pressure alterations after gastrocnemius recession

The pedobarographic evaluation of 20 patients in study 3, before and 12 months after PMGR revealed that average peak plantar pressure to the forefoot increased from 536 to 642 KPa ($p<0.001$) and the average peak heel pressure increased from 393 to 451 KPa ($p<0.001$). Heel-off, expressed as % of total stance, was unchanged at 71% of stance ($p=0.227$).

A contracture of the Achilles muscle-tendon complex or isolated tightness of the gastrocnemius muscle-tendon is postulated to increase plantar forefoot pressure and the tension of the plantar structures of the foot. [2, 18, 19, 76, 92] It is further postulated that a gastrocnemius recession would decrease the plantar forefoot pressure and strain to the plantar stabilizers. The results from study 3 show an increase in both forefoot and heel peak plantar pressure, while heel-off, expressed as % of total stance, was unchanged after surgery. This is not in accordance with previous cadaver studies, case reports and theoretical outlines.[2, 8] On the other hand the biomechanical implications of an IGT are also known to be more complex than just affecting plantar pressure.[19] Patients with contractures could develop gait strategies to reduce painful foot loading such as increased ankle plantar flexion or increased knee flexion during stance.[19, 54, 75] The literature on kinetic adaptations of IGT is mainly based on spastic IGT due to neurologic conditions. Although this may not be directly transmissible to non-spastic patients, it has been demonstrated that spastic patients with IGT walk with reduced ankle dorsiflexion and/or increased knee flexion. Kinetic adaptations in these patients include reduced peak ankle plantar flexion moment.[3, 78, 79] The only study on non-spastic IGT, however, showed no difference in peak plantar flexion moment after gastrocnemius recession.[19] That study also showed that other gait strategies such as increased knee flexion are more common to reduce plantar fascia tension than reduced ankle dorsiflexion and ankle plantar flexion moment.[19] The results also revealed that 5 of 6 patients seemed to adapt gait by walking with increased knee flexion, while only 1 in 6 patients adapted gait by reduced ankle dorsiflexion. No statistical significant changes occurred after surgery although a tendency for improvements concerning knee flexion could be observed. The study by Chimera et al. only included 6 patients, and possibly a larger cohort could have resulted in significant findings concerning post-operative gait changes.[19] In addition, the follow-up time after surgery was only 3 months which leave the possibility that gait adaptions still remained after surgical treatment.

Recently two studies evaluating changes in plantar foot pressure by pedobarography after gastrocnemius recession have been published.[87, 97] Vinagre et al. studied 52 patients treated by PMGR for metatarsalgia.[97] They reported significant post-operative decreases for the area of plantar contact surface, the maximum and mean pressure and the forefoot force. Significant increases were observed for hindfoot force and bearing time. The authors interpret this decreased forefoot load and increased hindfoot bearing time as an improvement in gait biomechanical standards after the surgery. Schmal et al. reported the results of 26 patients operated with a Strayer procedure for forefoot overload syndrome.[87] The results implicate a relocation of plantar contact time from the fore- to the hindfoot. However, the results also show an increased peak plantar pressure plantar to the first metatarsal head. The results from our study suggest an increase in both fore- and hindfoot pressure. These results are supported by the results from Schmals` study but are partly contradicted by the results in Vinagres` study. Some of the explanation may be caused by the fact that 80% of the patients included in Vinagres study had additional forefoot corrective procedures including hallux valgus correction and/or Weil osteotomies, which are prone to change pressure loads. In addition, the follow-up time is short, ranging from 40 days to 3 months, leaving the possibility that post-operative gait adaptations remain because of pain. Both the study of Vinagre and that of Schmal suggest a relocation of plantar contact time from the fore- to the hindfoot. The change of load from the fore- to the hindfoot is not supported by our findings as heel-off, expressed as percent of total stance, is unchanged. The lack of consistency between the findings from our study, and the two above mentioned may be due to different ways of expressing heel contact time. Both the study by Schmal et al. and Vinagre et al. express heel contact time in time units instead of as percentage of stance like in our study. Although statistical insignificant, a tendency for increased forefoot contact time could also be observed in both the study by Schmal and Vinagre.[87, 97] Theoretically, this difference in how to express heel contact time could be the explanation for the apparent inconsistent findings.

Although it is recognized that ankle dorsiflexion and knee extension are coupled motions during mid-stance of gait, it must be kept in mind that the gastrocnemius also crosses the subtalar joint.[19] Thereby some of the explanation to our findings may be that neither kinematic studies nor pedobarography can fully detect the impact of increased dorsiflexion through the triple joint complex in patients with IGT. It has been demonstrated that much dorsiflexion could be achieved by pronation of the hindfoot.[62, 96] IGT has previously been coupled with development of tibialis posterior insufficiency and flatfoot.[27, 34] It is possible that the increased strain to the plantar structures of the foot in patients with IGT occurs through this detrimental pronation of the foot and therefore could not be measured by simple plantar pressure measurements or kinematic studies. As ankle dorsiflexion ability improves after surgery and pain resolves, the changes in peak plantar pressure could reflect an unrecordable normalization of gait mechanics in the ankle and subtalar joint.

Another obvious explanation is that the pedobarographic result could reflect that patients tend to adapt gait to avoid painful foot loading associated with the plantar heel pain condition. Previous studies, have acknowledged the inability of pedobarography to detect the patient`s tendency to avoid painful loading.[83] Studies have also reported a low correlation between pedobarography and areas with clinical signs of overload. However, this correlation between pedobarography and clinical findings was far better for neuropathic patients, which could be explained by the lack of pain sensation and thereby no need to develop an antalgic gait.[21] The heel pain in the group treated with PMGR in our study was significantly reduced at one year follow-up compared to baseline. The increased plantar pressure observed in the operative group from baseline to 12-month follow-up could simply be an expression of reduced pain in these patients allowing them to fully load the foot through gait.

Foot and ankle biomechanics are complex, and pedobarographic measurements may be a too simple model to catch changes after surgery. The gastrocnemius influences joint kinematics of the knee, ankle and subtalar joints, and adaptions to a tight gastrocnemius could probably occur at all segments. This could also explain that gastrocnemius tightness does not uniformly lead to one clinical condition but probably is a contributing factor in several foot and ankle disorders.

Gastrocnemius recession as treatment of different foot and ankle conditions

The results in study 1 revealed that 62% of the patients were satisfied with the postoperative result after the Strayer procedure. This result is inferior to other clinical studies previously published.[1, 35, 64, 67] The explanation for the lower satisfactory percentage in our study could be that we included patients with a wide range of diagnoses. Previous studies have described good clinical outcomes, but these studies have mainly focused on patients with plantar fasciitis.[1, 64, 67] Good results have also been reported for patients treated with gastrocnemius recession for metatarsalgia and Achilles tendinopathy, but those studies had few included patients.[35, 55, 64]

When evaluating the patient satisfaction rate based on diagnosis groups we found a high satisfaction rate for patients with plantar fasciitis, 14/18 (78%), which is comparable to other studies.[1, 64, 67] A more thorough discussion of the clinical outcomes for plantar fasciitis will follow.

When gastrocnemius recession was performed in patients with metatarsalgia, which was the largest group of patients in study 1, only 14/28 (50%) of the patients reported to be satisfied with the postoperative result. This was not in accordance with the study by Maskill et al. that reported good results, although only for six patients with metatarsalgia.[64] A review from 2015 that aimed to give evidence-based recommendations for gastrocnemius recession in foot and ankle conditions assigned a grade B evidence rating (fair evidence) for midfoot-forefoot overload syndrome, including metatarsalgia, arch pain and plantar fasciitis.[27] The recommendation was based on a total of 7 studies, none of them level I or II studies, and mainly studies describing results of gastrocnemius recession for plantar fasciitis. The inclusion of other foot conditions, like metatarsalgia, in the recommendation is therefore questionable.

The metatarsalgia group is a non-homogenous group including different pathologies. A prospective cohort study by Morales-Munoz et al. tried to avoid this problem by including 52 patients (78 feet) with only mechanical metatarsalgia and gastrocnemius tightness.[68] The patients initially had no other surgical procedures. The patients were further subdivided into second rocker metatarsalgia, third rocker metatarsalgia and mixed second and third rocker metatarsalgia. 69.2% of the patients were satisfied with the result at six months follow-up. The VAS pain improved from 7.4 to 3.5 and the AOFAS ankle-hindfoot score improved from 46.8 to 83.6 ($p<0.01$). The outcome of VAS pain was comparable to the results from study 1 with VAS pain scores improving from 5.6 to 2.3. The improvements reported by Morales-Munoz et al. were higher in the groups of second and third rocker metatarsalgia compared to the group with mixed second and third rocker metatarsalgia (AOFAS ankle-hindfoot score 73.6, VAS pain 4.3). Interestingly, they evaluated the need for additional forefoot corrective surgery after a follow-up period of 6 months. 16/52 patients were in need for additional surgery, consisting in most cases of triple Weil osteotomies. The authors discuss the possibility that further patient selection could improve the outcomes of the gastrocnemius recession procedure for patients with metatarsalgia.

In study 1, the number of patients treated with gastrocnemius recession because of calf pain (n =6), Achilles tendinopathy (n =7) and pes plano valgus (n =5) were too small to draw any conclusions.
In the literature the evidence supporting a favourable clinical outcome for gastrocnemius recession as treatment for non-insertional Achilles tendinopathy is increasing. The already mentioned review from 2015 assigned grade C evidence (insufficient) for the treatment of non-insertional Achilles tendinopathy, but more studies have been published since then.[27] Smith et al. reported 21/25 patients with total or significant pain relief in their retrospective series of 25 patients that underwent a Strayer procedure for non-insertional Achilles tendinopathy.[91] The VAS pain dropped from 8.9 preoperatively to 2.0 at an average follow up of 13 months. Foot function index improved from 73.5 to 27.4. Nawoczenski et al. have published 2 level III series including 13 and 14 patients respectively.[72, 73] These patients were operated with a Strayer procedure and the VAS pain improved from a pre-operative level of 6.8 in both studies to 1.4 and 1.6, respectively. However, the FAAM score showed significantly inferior results for the patient groups compared to the healthy control groups for both activities of daily living and sports. Molund et al. published a retrospective series of 30 patients with chronic Achilles tendinopathy treated with a Strayer procedure that support the promising results from other studies.[65] 28/30 patients reported to be satisfied with the outcome. High Victorian institute of sport assessment-Achilles (VISA-A) scores of 91.4 was detected, and VAS pain reduction from 7.5 to 0.8 was reported.
The evidence supporting a good clinical effect of gastrocnemius recession for chronic Achilles tendinopathy is increasing, although all studies are level III or IV studies.

Treatment of chronic plantar fasciitis.

In study 1, 14/18 patients from the plantar fasciitis group reported to be satisfied with the result, and the VAS pain revealed the same with an improvement in pain for patients with plantar fasciitis from 7.0 to 1.8 (p=0.015).

Study 3 included 20 patients with chronic plantar fasciitis randomized to PMGR and stretching exercises, and 20 patients randomized to stretching exercises only. The results demonstrated improved AOFAS ankle-hindfoot scores from baseline to both 3- and 12-months follow-up for the PMGR group, whilst no such improvement could be observed for the non-operative group. The AOFAS ankle-hindfoot score in the operative group was significantly higher than the non-operative group at all follow-ups. Similarly, the VAS pain improved at both 3 and 12 months in the operative group but not in the stretching group. For the SF-36 all 8 subgroup parameters significantly improved from baseline for the operative group and significant better scores for all 8 subgroup parameters were observed for the operative group compared to the non-operative group 12 months after surgery.

Plantar fasciitis is known as a self-limiting condition and most authors recommend non-operative treatment in cases with short duration of symptoms.[29, 41, 101] However, about 5% of the patients develop persistent and often disabling symptoms lasting more than 12 to 18 months.[13]

Studies have demonstrated effect on plantar fasciitis, in terms of pain relief, for calf stretching exercises, as well as additional effect of plantar fascia stretches.[32, 82] Stretching exercises seem to be accepted as the first choice of non-operative treatment for chronic plantar fasciitis.[58, 66] The stretching exercises prescribed in study 3 for all patients included both calf specific, as well as plantar fascia specific stretches (Figure 9). Despite the previously described promising effects of stretching exercises, no such effect could be demonstrated in our study. A small non-significant increase in the AOFAS ankle-hindfoot score could be observed at 12 months follow-up (p=0.138) for the stretching group.

If non-operative treatment fails after one year, surgical treatment could be an option, and is advocated by several authors.[4, 58] The last 20 years most studies describe partial plantar fasciotomy as the treatment of choice. This can be done either by open surgery or endoscopically. Plantar fasciotomy is known to have adverse effects, a high complication rate, and a long recovery period. The success rate has been described as low as 50%, and a recent review states that due to many potential adverse effects, and essentially no evidence that it is beneficial, it should solely be reserved for extreme cases.[28, 58] The relationship between plantar fasciitis and gastrocnemius contracture has been studied by Patel et al.[77] They found that the majority of patients with plantar fasciitis also had reduced dorsiflexion of the ankle and most of them because of an IGT. The reduced dorsiflexion of the ankle has by several authors been considered as the most important risk factor for the development of plantar fasciitis.[2, 84] The results from some level III and IV series have described promising results of gastrocnemius recession as treatment of plantar fasciitis.[1, 64, 67]

AOFAS ankle-hindfoot score demonstrated a significant increase from baseline to three- and 12-months follow-up in the operative group in study 3. However, AOFAS ankle-hindfoot score above 90 is usually considered an excellent result, and a median score in the operative group at one-year follow-up of 88 possibly reflects that not all patients achieve complete functional recovery. Monteagudo et al. who have published the only level III study on this topic, report comparable AOFAS ankle-hindfoot score at one year of 90 for patients treated with PMGR, and only 66 in the group that underwent plantar fasciotomy.[67] The AOFAS ankle-hindfoot score at the intermediate follow-up is also comparable to the reported AOFAS ankle-hindfoot score of 85 at six months follow-up from the study by Monteagudo et al., whereas we found our patient's score to be 85.5 at 3-months follow-up. Other studies have used other outcome measures. Ficke et al. used the Foot function index (FFI) in their retrospective evaluation of 17 obese patients with plantar fasciitis.[36] They reported an improvement from 66.4 to 26.5 at a mean of 20 months follow-up. We interpret the AOFAS hindfoot scores in Study 3 to be comparable to the results presented by Monteagudo et al.[67]

A correlation between the AOFAS ankle-hindfoot score and the VAS pain score was present in study 3. A significant reduction of pain was observed in the operative group, but not in the non-operative group, at both three- and 12-months follow-up. However, even surgically treated, the patients were not pain free one year after surgery (median VAS pain 2.8). VAS pain is reported to be even better in other studies at 12 months follow-up.[64, 67] Monteagudo et al. and Maskill et al. report VAS pain scores at respectively 0.9 and 2.[64, 67] The patients with plantar fasciitis in Study 1 also demonstrated a significant VAS pain reduction from 7.0-1.8 after gastrocnemius recession (p=0.015). Abbassian et al. reported 17/21 patients (81%) with chronic plantar fasciitis to have total or significant pain relief on average 24 months after the PMGR.

The somewhat higher VAS pain score in our study compared to other studies could possibly be explained by the way the VAS pain was monitored. We defined this as: “report the worst pain you have experienced within the last 24 hours”, as we believe this best reflects the true nature of plantar heel pain conditions. It is well known that the intensity of pain can vary a lot for plantar fasciitis through the day, with typical maximum of pain at first step in the morning or after rest. The way the question was formulated could clearly influence the measured outcome. Exactly how VAS pain was measured is not clearly defined in other comparable studies.[64, 67] The VAS pain outcome could also reflect that the pain is reduced, but not completely resolved.

General health was evaluated with SF-36, and as for the VAS pain and AOFAS ankle-hindfoot scale, higher scores were observed in the operative compared to the non-operative group at 12 months. An increase from baseline was also observed for all eight parameters of SF-36 for the operative group, but only for two parameters in the non-operative group. Although the SF-36 is not a foot and ankle specific score, it is widely used and evaluated as a valid and reliable score. The results of the SF-36 strongly support the results of the AOFAS ankle-hindfoot scores and VAS pain scores. All the clinical outcome scores point in the same direction with significant improvements for the PMGR group. The same degree of improvement could not be observed for the control group.

Complications to surgery

In study 1 that reviewed patients operated with a Strayer procedure 8/73 (11%) patients operated reported a major complication after surgery.

In study 3 including 20 patients with a total of 28 PMGR procedures, only one patient reported prolonged pain in the popliteal fossae. No other serious complications were observed.
The first studies reporting results after gastrocnemius recession procedures reported a very low complication rate. Most of the reports were on distal gastrocnemius recession, like the modified Strayer procedure. Sammarco et al. reported 2 sural nerve affections in 40 patients operated with the Vulpius procedure.[86] The reports by Maskill et al., Duthon et al. and Kiewiet et al. reported no complications after the Strayer procedure in 34, 17 and 12 feet, respectively.[35, 55, 64] The results from Study 1 contradicted the results from

all previous reports as the rate of major complications was 8/73 (11%). The complications included 3 infections, 2 nerve injuries, 1 pulmonary embolus, 1 deep venous thrombosis and 1 chronic regional pain syndrome. Additionally, 20/73 patients reported pain, swelling and leg cramps. These latter were considered as subjective discomfort and not major complications. Later studies support our findings and report high complication rates after the Strayer procedure. A critical review from 2016 reported a mean complication rate of 14%, but this included all methods for gastrocnemius recession.[39] Recent studies have reported complication rates in patients operated with the Strayer procedure in 2/30 patients (7%), 3/25 patients (12%), 10/64 (16%) operated limbs and even as high as in 11/41 procedures (26.8%).[46, 48, 65, 91]

Endoscopic gastrocnemius recession procedures have also been described. Usually this is performed at mid-calf level. The complication rate might be lower than with the open Strayer technique. Phisitkul et al. reported 3.4% sural nerve dysesthesia in their retrospective series of 320 endoscopic gastrocnemius recessions.[80] Harris et al. compared the complication rates in 41 open Strayer procedures to 39 endoscopic procedures and found a lower complication rate following the endoscopic procedure than the open procedure, respectively 2.6% and 26.8%.[46]

The potential advantages of the PMGR include a theoretically lower risk for complications. The high complication rate after the Strayer procedure in Study 1, as well as promising early reports on the effects and safety for the PMGR, made us convert our approach from the Strayer procedure into the PMGR for the following study 2 and 3. Both the study by Abbassian et al. [1] and Monteagudo et al. [67] reported only one minor post-surgery complication in studies including 21 and 30 patients, respectively. Even though the first studies had small numbers of patients, later studies have supported that the PMGR is a procedure with low risk for complications. Gurdezi et al. reported one deep venous thrombosis in 16 procedures.[43] Morales-Munoz reported no complications in 52 patients with a total of 78 procedures.[68]. The results from our RCT are comparable to other studies. In 20 patients with a total of 28 procedures, only one patient reported prolonged pain in the popliteal fossae. No other serious complications were observed.

The results from study 1 and 3, evaluating complication rates after different gastrocnemius recession procedures, correspond to the results from other studies. The Strayer procedure entails a higher risk for complications compared to the PMGR, which could have different explanations. Anatomically the sural nerve is at risk when performing the Strayer procedure, as opposed to the PMGR.[45, 47] The incision is placed in a more visible and vulnerable location in the Strayer compared to the PMGR, and the dissection is deeper. It has also been documented that the Strayer procedure has a lower stability than the Baumann and PMGR, meaning that there is a risk for overlengthening.[85] Early literature described to apply a cast for 2 weeks after the Strayer procedure to maintain a correct length of the gastrocnemius.[92] However, later studies have reported a protocol with immediate mobilization without the use of a cast after the Strayer procedure.[65] With the PMGR there is no need for a cast and the patients are mobilized with weightbearing as tolerated immediately after PMGR which might reduce the risk of deep venous thrombosis and pulmonary embolus.

Limitations and challenges

The main limitation of the first study is its retrospective nature, the lack of a control group, and the small number of patients in each group. No pre-operative baseline data existed, meaning that the pre-operative VAS pain was done in a retrospective manner.

Only 78% of the total number of patients that were operated with gastrocnemius recession accepted to be included in study 1. However, this is to our knowledge, the largest patient series treated with open gastrocnemius recession presented.[1, 35, 64, 67]

There is no consensus regarding outcome scores for the evaluation of patients treated with gastrocnemius recession. We have used non-validated self-reported outcome scores regarding post-operative satisfaction as was also used in the report by Maskill et al.[1, 64] The VAS pain score is well established and has also been applied as outcome measure following gastrocnemius recession in other studies.[64, 67]

The indications for gastrocnemius recession in foot pathology are not established. The Silfverskiöld test is normally used to diagnose an IGT. However, 25-44% of the normal population has a positive Silfverskiöld test.[33]

The patients in study 1 were offered gastrocnemius recession if they suffered from a condition that could be explained by IGT, and the passive dorsiflexion of the ankle with an extended knee was restricted to 0° or less and increasing to at least 10° with the knee flexed. However, no consensus exists to what level the ankle dorsiflexion is to be restricted to diagnose tightness, with suggestions ranging from 0-10⁰. [6, 33, 77] Gait analysis studies, on the other hand, suggest that 10-18⁰ of ankle dorsiflexion is needed for a normal gait. [19, 24, 52, 94]

For the RCT we chose our diagnostic criteria for an IGT based on these gait analysis studies, and the assumption that correction of even a discrete gastrocnemius tightness would favour patient outcome. We defined a contracture as less than 10⁰ of ankle dorsiflexion when testing with the knee extended, and an increase of at least 10⁰ when flexing the knee joint.

Due to the obvious shortcoming of using traditional goniometric methods for measuring changes in ankle dorsiflexion, we tested the properties of a new ankle ROM measuring device in study 2. One possible limitation of this study is that the reliability was tested on healthy people, and not patients with foot and ankle pathology. The validity and responsiveness of the device was, however, tested on patients with foot and ankle pathology. Confirming validity of the measuring method is challenging as no gold standard exists. We chose to use the clinical assessment of patients with foot and ankle conditions that are known to be connected to IGT and the clinical findings of an IGT evaluated by the clinical Silfverskiöld test as gold standard.

The main limitation of study 3 was that neither the patients were blinded for group-affiliation, nor was the investigator examining the clinical outcomes, for the chosen treatment at follow-up. Blinding of participants is difficult in studies comparing surgical procedures to non-surgical treatment. The investigator examining biomechanical outcomes, however, was blinded for group affiliation.

There is no objective way to establish the diagnosis of the condition plantar heel pain. It is also known that other conditions could mimic this condition.[59] From the literature, it seems that the typical history of pain at first step in the morning, pain on palpation of the proximal plantar fascia insertion, and increased pain when stretching the plantar fascia are fairly accepted as diagnostic criteria.[58, 59] We used these diagnostic criteria to establish the diagnosis. Radiography, MRI, or EMG was only used when other causes as nerve compression syndrome or stress fractures had to be ruled out.

Even the terminology could be challenging. Previously the condition was known as plantar fasciitis. As research indicated that there was no inflammation, other terms such as plantar fasciosis or fasciopathy have been suggested. It might, however, be most appropriate to use the term plantar heel pain as increasing evidence show that the pathology is not only restricted to the plantar fascia but also to the heel bone and surrounding tissue.[58] We have used the term plantar heel pain, but as far as we understand, in the same clinical meaning as other authors have used the terms plantar fasciitis, fasciosis, or fasciopathy.

The choice of outcomes could also be debated. The AOFAS ankle-hindfoot score is, as all other scores, not validated for chronic heel pain. It is by far the most used outcome in other comparable studies, making it suitable in terms of understanding, comparing and interpreting the results.[49] The VAS pain is a well-established method used in many similar studies as an outcome measure.[49] The SF-36 is an outcome known to be reliable and valid in detecting patient general health and change in patient health over time. It has been used frequently in literature reporting outcomes of foot and ankle conditions, and it has been validated for a normative Norwegian population.[49, 61] A review on the use of clinical outcome measurement tools in foot and ankle research concluded that the three most frequently used scores are the AOFAS score (55.9%), VAS pain score (22.9%) and the SF-36 health survey (13.7%).[49] There has been increasing interest regarding the validity of foot and ankle PROMs recent years, and studies have tested the properties of different foot and ankle specific PROMs.[23, 69] Study 3 of this thesis was planned before other studies demonstrated possible better properties of other foot and ankle PROMs than the AOFAS score. With the current knowledge, other options than the AOFAS score could be preferable as the main outcome choice for future studies.

The results of the functional tests and pedobarographic evaluation in study 3 could be influenced by the resolved or reduced heel pain at follow-up. Previous literature has discussed foot pain and thereby gait adaptations as a limitation for the evaluation of pedobarography.[83] The patients in our study reported far less pain at follow-up, which again could have influenced the results.

Conclusions

- Most patients with plantar fasciitis operated with the Strayer procedure reported to be satisfied with the post-operative result, but the complication rate of the Strayer procedure is high.
- The clinical Silfverskiöld test has a low inter- and intrarater reliability and should not be used for scientific purposes.
- The new ankle range of motion measuring device is valid for detecting isolated gastrocnemius tightness, with an excellent inter- and intrarater reliability and good responsiveness.
- The proximal medial gastrocnemius recession is a safe method in terms of a low risk of complications and maintained post-operative strength, although the increase in ankle dorsiflexion is smaller than previously reported after other methods of gastrocnemius recession.
- The proximal medial gastrocnemius recession is an efficient method for treating chronic plantar heel pain and should be the preferred operative treatment for this condition.

Suggestions for future research

As gastrocnemius recession procedures are used as treatment for several foot and ankle conditions prospective randomized studies are needed to confirm the effectiveness of this surgical method for other conditions than plantar fasciitis.

Long term results regarding gastrocnemius recession procedures are needed.

Large scale prospective gait analysis studies are needed to better understand the implications of gastrocnemius recession procedures on gait biomechanics.

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Appendix

II

Article

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Validation of a New Device for Measuring Isolated Gastrocnemius Contracture and Evaluation of the Reliability of the Silfverskiöld Test

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Abstract

Background: Important aspects on the diagnostics of isolated gastrocnemius contractures (IGCs) have been poorly described. This study was designed to validate a new ankle range of motion (ROM) measuring device for diagnosing an IGC. In addition, we wanted to investigate the reliability of the clinical Silfverskiöld test.

Methods: Twelve health care personnel (24 feet) were examined by 4 testers on 3 different occasions for the reliability testing of the new ankle ROM measuring device. The same participants were examined using the Silfverskiöld test to examine the reliability of the clinical test. Eleven patients (15 feet) with IGC were examined before gastrocnemius recession, immediately after surgery, and 3 months after surgery to examine the validity and responsiveness of the ankle ROM device.

Results: An intraclass correlation coefficient (ICC) >0.85 was found for both inter- and intrarater reliability for the new ankle ROM device. The device confirmed an IGC in 13 of 15 feet before surgery and 3 of 13 feet at 3-month follow-up. At baseline, the measured ankle dorsiflexion was median 3 degrees with the knee in extension, which increased to 10 degrees ($P < .001$) immediately after surgery and 12 degrees ($P = .003$) at 3-month follow-up. ICC values of 0.230 to 0.791 were observed for the inter- and intrarater reliability testing of the clinical Silfverskiöld test.

Conclusion: The new ankle ROM measuring device was reliable and responsive for detecting IGC. The Silfverskiöld test had poor inter- and intrarater reliability.

Level of evidence: Level II, prospective cohort study.

Keywords: gastrocnemius recession, isolated gastrocnemius contracture

Gastrocnemius recession procedures are used as the treatment for several foot and ankle overload conditions, and the evidence supporting the clinical effect of these procedures is increasing.[1,9-13] The clinical test for detecting an isolated gastrocnemius contracture (IGC) is the Silfverskiöld test, where ankle dorsiflexion with the knee extended is evaluated, thus tensioning the gastrocnemius, followed by the evaluation of ankle dorsiflexion with the knee flexed, thereby relaxing the gastrocnemius. If dorsiflexion motion restriction is present in the first part of the test and the ankle dorsiflexion normalizes in the second part, an IGC is present. Despite the increasing literature on the connection between IGC and several foot and ankle disorders, we found that the diagnostic method and accuracy of the diagnostic method are sparingly described in the literature. Only 2 articles describe devices used to accurately measure ankle dorsiflexion with the knee both extended and flexed,[5,7] and the validity of the Silfverskiöld test has been tested in only 1 study.[5]

The aim of this study was to investigate the validity, inter- and intrarater reliability, and responsiveness of a new device designed for measuring ankle range of motion (ROM) in order to diagnose an IGC. In addition, we wanted to test the inter- and intrarater reliability of the Silfverskiöld test.

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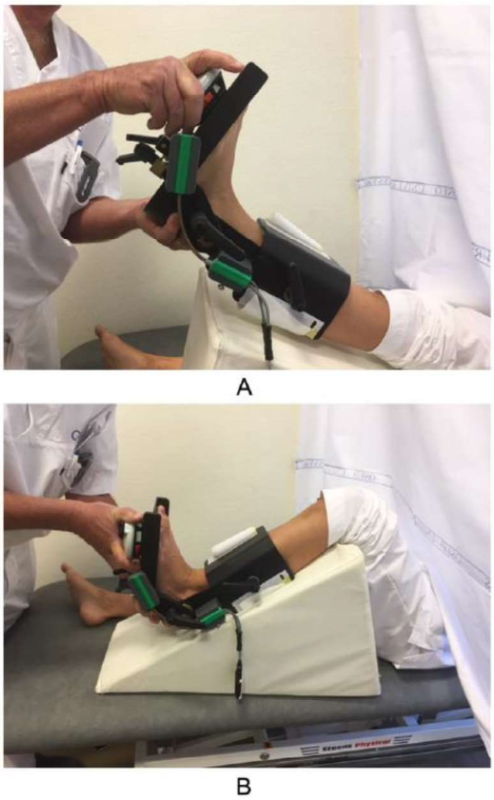

Figure 1. The ankle range of motion (ROM) measuring device has been applied on the patient. Force is applied under the head of the second metatarsal by a dynamometer, and the testing of ankle dorsiflexion is conducted. Ankle dorsiflexion is first tested with the knee extended and thereafter with the knee flexed.

Methods

We constructed a device for measuring ankle dorsiflexion according to the principles described by DiGiovanni et al.[5] It consisted of a foot plate with a separate adjustable heel cap, an adjustable hinge joint that could be positioned at the axis for sagittal ankle motion, and an adjustable leg component that was fixed to the leg (Figure 1). The device controlled the position of the hindfoot joints. The subtalar joint was locked in neutral or slight varus to avoid eversion or valgus throughout the dorsiflexion test. Anatomical landmarks were the anterior side of the tibia and the plantar aspect of the foot. An electric goniometer (Biometrics SG150; Biometrics Ltd, Units 25-26, Nine Mile Point Ind Est, Newport, UK) was connected to the device. According to the producer, it has an accuracy of ±2 degrees and a repeatability of 1 degree (biometricsltd.com). The device was calibrated before every new participant. Controlled force was applied directly beneath the head of the second metatarsal by a dynamometer (Hoggan MicroFET2 Dynamometer; Hoggan Health Industries Inc, Salt Lake City, UT, USA). All participants were tested in 2 different ways: (1) with enough force applied to reach maximum dorsiflexion and (2) with 20-N force as described and emphasized by other authors.[3] Ankle dorsiflexion was measured with the knee in extension and thereafter with the knee flexed 90 degrees while resting the knee on a cushioned support (Figure 1).

Different cut-off values for defining an IGC have been suggested.[3,5] We defined a positive test result for the maximum dorsiflexion method to be less than 10 degrees dorsiflexion of the ankle when testing with the knee extended; for the 20-N method, we defined this as less than 0 degrees.[3] To define it as an IGC and not a combined gastrocnemius-soleus contracture, an increase of at least 10 degrees dorsiflexion of the ankle with the knee flexed had to be observed for both methods.[5]

A sample of 12 health care personnel (24 feet) were included for the reliability testing of the new ankle ROM measuring device. These participants were examined on 3 different occasions, with an interval of 4 weeks, by 4 investigators. Two of the investigators were orthopedic surgeons, and 2 were physical therapists. All investigators received standardized information about the theoretical background of the Silfverskiöld test and were instructed in how to use the ankle ROM measuring device. Only 2 of the testers were familiar with the use prior to the testing. The testers were blinded by a curtain and could not identify the participant. The device was completely removed between every tester and was calibrated before every new tester. The tester was unable to see the result, as this was registered by the primary investigator only. A minimum of 3 recordings were obtained, and the median score was used. In the following, the term "Silfverskiöld test" is used for measurements with the above-mentioned device, while "clinical Silfverskiöld test" is used for measuring ankle dorsiflexion without the measuring device.

The same participants were examined for testing the reliability of the clinical Silfverskiöld test. The test was performed by 4 investigators (3 orthopedic surgeons and 1 physical therapist), with the same intervals and the same setup as described above. The testers were allowed to use a standard goniometer for measuring and were allowed to do the test as many times as they wanted. The result was described in degrees and not solely as a positive or negative test result.

For testing the validity and responsiveness of the new ankle ROM measuring device, we included 11 consecutive patients (15 legs) referred to a proximal medial gastrocnemius recession (PMGR) for a variety of causes, such as plantar fasciitis (5 patients), calf pain (5 patients), and metatarsalgia (1 patient). The inclusion criteria were an IGC evaluated by the clinical Silfverskiöld test, in addition to

Figure 2. (A) The anatomy and the planned incision for the proximal medial gastrocnemius recession (PMGR). The solid horizontal line marks the knee crease. The dotted vertical lines mark the hamstring tendons, and the dotted horizontal line marks the planned incision. (B) The deep crural fascia is visualized and then incised in the same direction as the skin. (C) The aponeurosis of the proximal medial gastrocnemius can be seen. It is always located on the posterior and medial side of the muscle. (D) The separation of the aponeurosis is visualized. Careful palpation of the muscle is done while performing a dorsiflexion maneuver of the ankle to confirm complete separation.

having a condition that could be treated by a gastrocnemius recession. Conditions that could be considered for gastrocnemius recession as a single procedure, in our practice, were plantar fasciitis, Achilles tendinopathy, calf pain, and metatarsalgia. Exclusion criteria were previous surgery of the foot or ankle. Ankle dorsiflexion was examined with the ankle ROM measuring device immediately before surgery. The operation was performed under local anesthetics. A horizontal incision in the knee crease was made. The deep fascia was opened in the same direction. The medial head of the gastrocnemius was localized and the aponeurosis was cut, taking care not to cut the muscle fibers (Figure 2). Careful palpation of the muscle was done to ensure complete separation. The wound was closed in layers, and only adhesive dressings were applied.[2] Then the examination of ankle dorsiflexion was repeated after wound closure, to assess the immediate response to surgery. The postoperative protocol included full weightbearing from the first day after surgery. The patients were instructed in simple stretching exercises of the Achilles without routine follow-up by a physical therapist. The examination of ankle dorsiflexion was repeated 3 months postoperatively. Two patients (2 legs) were lost to follow-up at 3 months, and data at this time are presented for 9 patients (13 feet).

A power analysis was performed prior to the study. The smallest clinically significant difference in the main outcome of increased ankle dorsiflexion with the knee in extension was set to be 5 degrees. A standard deviation of 4.5 was estimated based on the results from a comparable study testing dorsiflexion in foot and ankle patients.[5] With a power of

Table 1. ICC for the New Ankle ROM Measuring Device in 12 Health Care Personnel (24 Legs).

		Maximum Dorsiflexion		20 N	
	Ankle Dorsiflexion	ICC	CI	ICC	CI
Interrater	Ext. knee	0.925	0.858-0.964	0.758	0.554-0.883
	Difference ext. vs flexed knee	0.855	0.719-0.932	0.762	0.562-0.885
Intrarater	Ext. knee	0.894	0.690-0.959	0.804	0.618-0.908
	Difference ext. vs flexed knee	0.869	0.741-0.939	0.732	0.472-0.876

Abbreviations: CI; confidence interval; ext, extended; ICC; intraclass correlation coefficient; ROM, range of motion.

Table 2. ICC for the Clinical Silfverskiöld Test Measured in 12 Health Care Personnel (24 Feet).

		Maximum Dorsiflexion		20 N	
	Ankle Dorsiflexion	ICC	CI	ICC	CI
Interrater	Ext. knee	0.694	0.392-0.858	0.760	0.560-0.884
	Difference ext. vs flexed knee	0.399	0.028-0.681	0.230	0.158-0.569
Intrarater	Ext. knee	0.748	0.503-0.882	0.791	0.592-0.903
	Difference ext. vs flexed knee	0.562	0.178-0.790	0.649	0.318-0.835

Abbreviations: CI, confidence interval; ext, extended; ICC, intraclass correlation coefficient.

80 and level of significance of 5%, 13 feet were needed. We chose to include 11 patients (15 feet) to compensate for possible loss to follow-up.

Statistical analyses were performed using SPSS, version 21.0 for Windows (SPSS Inc, Chicago, IL, USA). Nonparametric data are presented as medians with ranges. Wilcoxon tests were used for statistical analyses, and differences were considered statistically significant if $P < .05$. Reliability measures are expressed as intraclass correlation coefficient (ICC) with confidence intervals.

Results

The testing for inter- and intrarater reliability with the new ankle ROM measuring device revealed a high inter- and intrarater ICC with all measures >0.85 for the maximum dorsiflexion method. The same measures for the 20-N method were an ICC of 0.732 to 0.804 (Table 1).

The inter- and intrarater reliability of the clinical Silfverskiöld test, however, demonstrated lower ICC values (ankle dorsiflexion at extended knee ICC, 0.694-0.791; difference in ankle dorsiflexion between flexed and extended knee ICC, 0.230-0.649) (Table 2).

A significantly increased ankle dorsiflexion occurred after surgery and at 3-month follow-up when testing with the knee extended ($P < .05$) (Table 3). When considering the defined cut-off values for a positive Silfverskiöld test result, the measurements preoperatively showed that 13 of 15 feet were considered Silfverskiöld positive with the maximum dorsiflexion method and 14 of 15 with the 20-N method. Three months after surgery, 10 of 13 feet were Silfverskiöld negative with both methods.

Discussion

Testing ankle dorsiflexion with a traditional goniometer has been described as an unreliable method and should not be used for scientific purposes.[6,7] The Silfverskiöld test is even more challenging as the tension of the gastrocnemius and the soleus are tested separately with the knee extended and flexed. For scientific and clinical use, we constructed an ankle ROM measuring device according to Silfverskiöld's principles of diagnosing an IGC. The properties of the device were verified through several steps. First, 3 experienced orthopedic surgeons from the study group evaluated and highlighted elements of the diagnostic test that the device had to control. The device was reevaluated on several occasions and tested after production. The second step was to conduct a series of tests and retests to check the inter- and intrarater reliability. The testing revealed an ICC of 0.85 to 0.93 for both intra- and interrater reliability for the maximum dorsiflexion method, which is considered good to excellent. Step 3 was performed by testing ankle dorsiflexion in patients with foot and/or ankle overload conditions who had been previously clinically evaluated as having an IGC, before surgery, after surgery, and 3 months after surgery. The measurements with the new device confirmed the diagnosis of IGC for 13 of 15 feet preoperatively, while 10 of 13 patients were evaluated as Silfverskiöld negative 3 months after surgery. In our understanding, this shows good validity and responsiveness of the new device. Certainly,

Table 3. Ankle Dorsiflexion Measured With Respective Force Applied to Reach Maximum Dorsiflexion or 20-N Force Applied in 11 Patients (15 Operated Legs).[a]

		Before Surgery			After Surgery				3 Months After Surgery			
		Median	Minimum	Maximum	Median	Minimum	Maximum	*P* Value	Median	Minimum	Maximum	*P* Value
Maximum dorsiflexion	AD ext. knee	3	−7	14	10	−4	21	.001	12	4	20	.003
	AD flexed knee	23	−2	30	22	0	32	.053	21	6	33	.066
	AD ext. vs flexed knee	16	5	22	11	4	20	.001	8	2	23	.012
20-N force	AD ext. knee	−6	−17	1	0	−14	12	.001	1	−4	11	.001
	AD flexed knee	10	−13	17	9	−11	19	.071	10	−3	25	.003
	AD ext. vs flexed knee	12	4	18	7	3	17	.002	8	0	22	.046

[a]Ankle dorsiflexion was measured with the knee extended and flexed, and the difference between these values was calculated. All measures were done before surgery, after surgery, and 3 months after surgery. Abbreviations: AD, ankle dorsiflexion; ext, extended.

this way of establishing validity, by using an expert opinion as the gold standard, could be criticized. However, as no gold standard exists, we believe that using these patients, with convincing signs of foot or ankle overload conditions and with a positive clinical Silfverskiöld test result for comparison, is the best way of establishing validity and responsiveness of the ankle ROM measuring device.

Some authors argue that the clinical Silfverskiöld test must be performed with a controlled force or torque. Barouk and Barouk[3] claim this to be the beginning of stretch resistance, which should not exceed 2 kg, corresponding to 20 N applied to the forefoot. Other authors have demonstrated that controlling hindfoot position is more important than the force applied as long as the ankle is dorsiflexed to its end range of dorsiflexion.[6] This has, however, not been described for the clinical Silfverskiöld test.[6] Our testing with both methods showed a better inter- and intrarater reliability for the maximum dorsiflexion method. The increase in ankle dorsiflexion after surgery was equal for both test methods. We believe that both methods are reliable and valid for diagnosing an IGC, but the diagnostic cut-off values for an IGC must be different depending on the method chosen. Based on our findings, we do not believe that we can conclude on the superiority of one of these methods. We can conclude, however, that the maximum dorsiflexion method seems to be more reproducible and in compliance with biomechanical studies indicating that 10 to 18 degrees dorsiflexion of the ankle is needed for a normal gait.[3-5]

We expected the reliability of the ankle ROM measuring device to be better than for the clinically performed Silfverskiöld test. This was confirmed by the results, demonstrating lower ICC values for the clinical Silfverskiöld test compared with the measuring device. DiGiovanni et al[5] noted that the correct diagnosis of IGC was found by 2 raters in 76% to 94% of cases when testing with the clinical Silfverskiöld test, using an electro goniometric equinometer device as the gold standard for comparison. They tested both a cohort of patients and a healthy control group. No retesting was performed, and no measure of reliability of the test was given. We chose to let the testers grade the measurements by degrees, and not simply as a positive or negative test result, and to use ICC as a measure of the test reliability. The results show good reliability when just measuring ankle dorsiflexion with the knee extended and in the same range as previously reported.[8] The ICC, however, is regarded as poor when testing the difference in ankle dorsiflexion between extended and flexed knee. This is not surprising knowing that several studies have described very poor reliability when evaluating ankle dorsiflexion with a traditional goniometer.[6] However, the low ICC for inter- and intrarater reliability testing of the clinical Silfverskiöld test may not be clinically important as most patients will have ankle dorsiflexion far beyond the diagnostic cut-off, making it possible to establish the diagnosis correctly in most cases, as demonstrated by DiGiovanni et al.[5] For scientific use, more accurate methods should be used.

In conclusion, we found the newly designed ankle motion measuring device to be valid, with excellent inter- and intrarater reliability and good responsiveness. It was easy and fast to use, and it could easily be constructed by others. The clinical Silfverskiöld test had low inter- and intrarater reliability and should not be used for scientific purposes. We believe, due to the low reliability, it should be used with caution in the clinical setting.

Declaration of Conflicting Interests

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III

Article

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Proximal Medial Gastrocnemius Recession and Stretching Versus Stretching as Treatment of Chronic Plantar Heel Pain

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Abstract

Background: Plantar heel pain is a common disorder that can lead to substantial pain and disability. Gastrocnemius recession has been described as an operative treatment option, but there is a lack of prospective clinical and biomechanical outcome data. The aim of this study was to evaluate the clinical and biomechanical outcomes of gastrocnemius recession and stretching compared with a stretching exercise protocol for patients with plantar heel pain lasting more than 12 months.
Methods: Forty patients with plantar heel pain lasting more than 1 year were randomized to a home stretching exercise program only or to surgery consisting of a proximal medial gastrocnemius recession in addition to stretching exercises. The main outcome was the American Orthopaedic Foot & Ankle Society (AOFAS) ankle-hindfoot score at 12 months. Secondary clinical outcomes were the Short Form–36 (SF-36) and visual analogue scale (VAS) pain scores. The biomechanical outcome parameters were ankle dorsiflexion, Achilles function evaluated by a test battery with 6 independent tests, and plantar pressure evaluated by pedobarography. All data were obtained at baseline and at 12-month follow-up.
Results: The AOFAS score increased from 59.5 (42-76) to 88.0 (50-100; $P < .001$) for the operative group and from 52.5 (37-73) to 65.5 (31-88; $P = .138$) for the nonoperative group. The AOFAS, VAS pain, and SF-36 scores were significantly better in the operative compared with the nonoperative group at 12-month follow-up ($P < .05$). Ankle dorsiflexion increased from 6 degrees (–3 to 15) to 10.5 degrees (0 to 23; $P < .001$). No between-group difference was observed for Achilles function at follow-up. The average forefoot plantar pressure for the operative group increased from 536 KPa (306-708) to 642 KPa (384-885) at follow-up ($P < .001$).
Conclusion: Proximal medial gastrocnemius recession with a stretching program was a safe and efficient method of treating chronic plantar heel pain.
Level of Evidence: Level 1, randomized clinical trial.

Keywords: heel pain, plantar fasciitis, gastrocnemius recession

Plantar heel pain, often termed *plantar fasciitis*, is characterized by soreness or tenderness of the heel restricted to the sole of the foot.[22] The etiology is largely unknown.[22] Plantar heel pain is a common problem in the adult population, with a prevalence of 4% and accounting for more than 1 million visits per year to physicians in the United States.[18,34] The condition is in most cases self-limiting, but 5% to 10% will not respond to conservative treatment and have symptoms exceeding 12 months.[12,22,39] If symptoms related to plantar heel pain endure for more than 1 year, several authors suggest operative treatment.[1,23,28]

The most frequently used operative method in the past 20 years has been open or endoscopic partial plantar fasciotomy, demonstrating a success rate of 50% to 76%.[4,14] Following partial plantar fasciotomy, a long recovery time, high rate of complications, as well as subsequent alterations of foot

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biomechanics have been described.[21,22] A recent review implied that there are many potential adverse effects and little evidence of a clear beneficial effect related to the operative procedure involving plantar fasciotomy.[22] It concluded that the effectiveness of surgery for plantar heel pain is unknown.[22]

The impact of an isolated contracture of the gastrocnemius, and thereby reduced dorsiflexion of the ankle joint, is proposed to increase the load on the plantar fascia and forefoot and has been introduced as a contributing factor for the development of plantar heel pain.[15,23,28] Laboratory studies support the assumption that increased tension of the calf muscles increases the strain to the plantar fascia.[10] Gastrocnemius recession has been proposed as a treatment option.[1,28] Some level III and IV studies describe excellent outcomes following treatment with gastrocnemius recession for plantar heel pain.[1,24,27,28] Even though gastrocnemius recession procedures are performed more frequently, important postoperative outcome parameters such as change in ankle dorsiflexion, Achilles function, and plantar pressure have been less frequently investigated.[17] We designed this study to investigate the clinical and biomechanical effects of gastrocnemius recession and stretching exercises as treatment of chronic plantar heel pain compared with stretching exercises only.

Methods

This study was a randomized controlled study. It was conducted at a single university hospital between June 1, 2014, and December 31, 2016. This study was approved by the hospital ethical board and the regional committee for ethics. It was registered at clinicaltrials.org (ref NCT02116478). Written informed consent was obtained for every participant.

Participants

The study included patients aged 18 to 70 years with plantar heel pain lasting more than 12 months that was unresponsive to conservative treatment. The diagnosis was made based on the clinical symptoms including pain at first step in the morning and pain on palpation of the plantar fascia insertion on the medial plantar aspect of the calcaneus. An isolated contracture of the gastrocnemius, evaluated by the Silfverskiöld test, had to be present.[6,15] The Silfverskiöld test was considered positive if ankle dorsiflexion was restricted to 10 degrees or less with the knee extended and there was an increase of ankle dorsiflexion of at least 10 degrees when flexing the knee. Exclusion criteria were degenerative arthritis of the hindfoot joints or systemic joint disease; previous injury or surgery to the foot or ankle; inability to be informed about the study due to, for example, insufficient language skills; or patient considered inoperable due to comorbidity. If all inclusion criteria were confirmed and no exclusion criteria detected, the patient was offered inclusion in the study. Radiography, magnetic resonance imaging, or electromyography were not routinely used but reserved for patients for whom it was necessary to exclude other causes.

From June 2014 to December 2015, 61 patients with plantar heel pain lasting more than 1 year were seen at the outpatient clinic. Three patients were excluded due to previous surgery or injury to the foot. Four patients could not be properly informed because of lack of language skills and were therefore excluded. Four patients had a negative Silfverskiöld test, and 10 patients refused to participate in the study. Forty patients were included. All patients enrolled in the study completed the study protocol (Figure 1).

Randomization

After baseline data were obtained, the patients were randomized into 2 groups. Sealed envelopes containing "surgery" or "stretching" were drawn. The physical therapist performing all biomechanical outcome testing was blinded to group affiliation, but neither the orthopedic surgeon at follow-up nor the patient was blinded.

Procedures

All patients from both groups were instructed by a physical therapist in a standardized stretching exercise home program. Patients were instructed to perform the exercises at least twice per day, with a minimum stretching duration time for each exercise of at least 60 seconds. The program included stretching of the plantar fascia, triceps surae, and hamstrings. The patients received written information, including pictures describing all exercises. The patients were encouraged to continue this program for at least 12 weeks. They were instructed to contact the physical therapist by phone if they had questions about the exercises. All patients recorded their stretching exercises in a log book, which was reviewed at 3-month follow-up.

Patients randomized to surgery were operated with a proximal medial gastrocnemius recession (PMGR) as described by Barouk[5] (Figure 2). No additional procedures were performed. The operation was performed with the patients in a prone position under local anesthetic or general anesthesia. A 3-cm transverse skin incision was made in the popliteal fossa, the fascia was opened, and the medial gastrocnemius with its tendon was located. The tendon was then cut while lifting the gastrocnemius with clamps, and care was taken to cut only the white tendon while sparing the underlying muscle. While performing a dorsiflexion movement of the ankle, careful palpation of the muscle was done to ensure that all tendon strands were cut completely. The incision was closed in layers, and only soft dressings were applied.

Patients were instructed to continue the stretching exercises and fully weight-bear from the first postoperative day. If

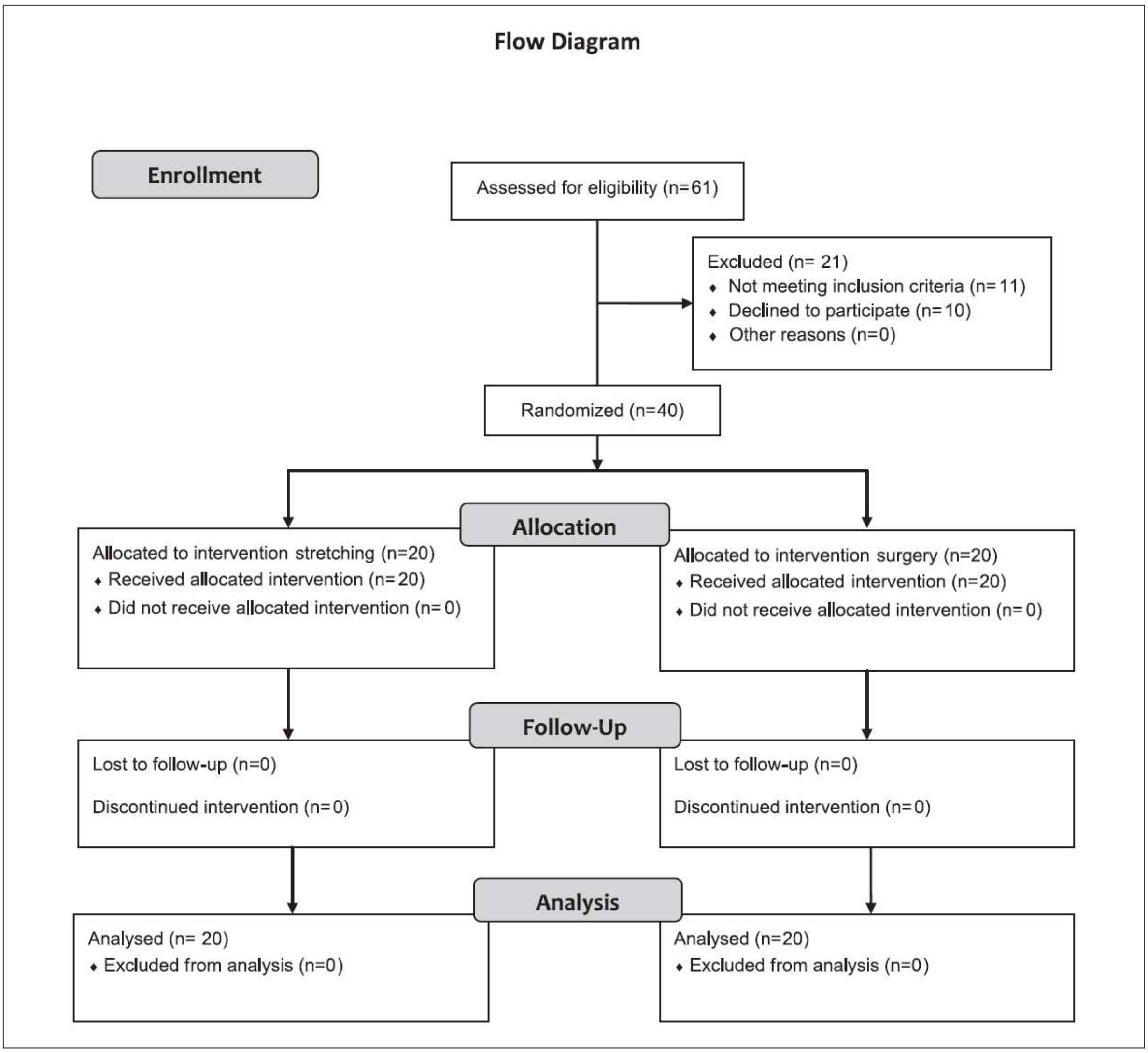

Figure 1. Flow chart describing all patients considered for inclusion in the study.

needed, the patients were allowed to use crutches during the first 2 weeks after surgery. Sutures were removed 2 weeks after surgery.

Outcomes

The primary outcome was the American Orthopaedic Foot & Ankle Society (AOFAS) ankle hindfoot scale at 1-year follow-up. The scale ranges from 0 to 100, where 100 represents an individual with no symptoms or disability. It consists of one part answered by the patient and one part answered by the surgeon. The AOFAS ankle hindfoot score at 3 months was a secondary outcome.

Visual analogue scale (VAS) score for pain at 3 and 12 months was another secondary outcome. As the condition of plantar heel pain is associated with a great variance of pain throughout the day, we defined it as "the worst pain you have experienced in your foot within the last 24 hours." The scale ranges from 0 to 10 points, where 0 represents *no pain* and 10 represents the *worst pain you can imagine*. A standardized metric scale was used for scoring. The Short Form–36 (SF-36) health survey at 12 months was another secondary clinical outcome.

Ankle dorsiflexion was determined using a device that measured the ankle's range of motion that has been previously tested and found to be valid, reliable, and responsive

Figure 2. The level of the proximal medial gastrocnemius recession is illustrated.

in detecting isolated gastrocnemius contractures (IGCs).[25] An electric goniometer, Biometrics SG150 (Units 25-26, Biometrics Ltd, Newport, UK), with an accuracy of ±2 degrees and a repeatability of 1 degree was used. The device was calibrated before every new participant. Force was applied directly beneath the head of the second metatarsal until the end range of dorsiflexion with a dynamometer (Hoggan microFET2 dynamometer; Hogan Health Industries, Salt Lake City, UT).

Achilles performance was evaluated by a test battery consisting of 6 independent tests. Three tests were jump tests, 2 were strength tests, and 1 was an endurance test.[36] We examined all operated feet, and analyses of feet diagnosed with plantar fasciitis from the nonoperative group were used for comparison. Eleven parameters from these 6 tests were used for analysis. The Musclelab (Ergotest Technology, Porsgrunn, Norway) measurement system was used. The system consisted of a data collection unit, a jump mat with an infrared beam field used for the jump tests, and a linear encoder used for the strength and endurance tests.

For all feet allocated to surgery, plantar pressure during gait was evaluated at baseline and at 12 months postsurgery. We used the Tekscan HR mat (Tekscan Inc, South Boston, MA) with Tekscan research software. The system was calibrated before every single measurement. Patients were instructed to walk at their normal pace. A minimum of 5 recordings were obtained for each leg. For analysis, we used average peak pressure of the forefoot through stance, peak heel pressure, and heel off as percentage of stance.

Statistical Analysis

A power analysis was performed prior to the study. It was based on the smallest clinical significant difference in the main outcome of AOFAS score of 10 points. A standard deviation of 10 was estimated based on a similar study.[4] With a power of 80 and level of significance of 5%, 16 patients were needed in each group. We chose to include 40 patients to compensate for possible loss to follow-up. Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) software, version 21.0 for Windows (SPSS Inc, Chicago, IL). Nonparametric data are presented as medians with ranges. Wilcoxon tests were used for statistical analyses, and differences were considered statistically significant if $P \leq .05$. Parametric data are presented as means with standard deviations. *t*-Tests were used for statistical analyses, and differences were considered statistically significant if $P \leq 005$.

Results

Demographic data such as age, body mass index, duration of symptoms, and sex were comparable between the groups at baseline (Table 1). No between-group differences in AOFAS, VAS pain, or SF-36 scores were observed at baseline (Table 2). Significant improvements in AOFAS ankle-hindfoot and VAS pain scores were observed for the operative group from baseline to both 3-month and 1-year follow-up. For the nonoperative group, no such change was observed (Table 2). The operative group scored significantly better than the nonoperative group for both scores at both 3-month and 1-year follow-up. The SF-36 scores increased from baseline to 1-year follow-up for all 8 parameters for the operative group but only for 2 parameters in the nonoperative group. The operative group had significantly better SF-36 scores than the nonoperative group at 1-year follow-up (Table 2).

For the operated feet ($n = 28$ feet), a significant increase in ankle dorsiflexion with the knee extended was observed between baseline and 12-month follow-up ($P < .001$), while no changes were observed for ankle dorsiflexion with the knee flexed at baseline versus 12 months after surgery ($P = .646$; Table 3). The Achilles test battery revealed no between-group differences at 12-month follow-up for any of the tests (Table 4). Pedobarography demonstrated an increased fore- and hindfoot pressure through stance, while heel-off was unchanged (Table 3).

No major complications were observed, but 3 patients experienced prolonged swelling or pain at the operative site. In 2 of these patients, the pain resolved, whereas 1 patient complained of persistent pain in the popliteal fossa 1 year after surgery. Even though the heel pain resolved, this patient was dissatisfied due to persistent pain in the

Table 1. Baseline Demographic Data of Study Participants.

	Operative Group	Stretching Group	*P* Value
Age, y	46 (29-68)	45 (22-63)	.655
Symptoms, mo	31 (12-252)	33 (12-396)	.796
Body mass index, kg/m^2	27.8 (20.1-49.8)	26.8 (20.2-35.3)	.262
Sex, female:male	15:5	16:4	.705

Table 2. Clinical Outcomes for Both Groups at Baseline and at All Follow-ups.[a]

Outcome	Group	Baseline	3 Months	12 Months	*P* Value
AOFAS	Operative	59.5 (42-76)	85.5 (64-100)	88 (50-100)	<.001
	Nonoperative	52.5 (37-73)	66.5 (36-85)	65.5 (31-88)	.138
P		.357	<.001	<.001	
VAS	Operative	7.6 (3.9-10)	3.3 (0-8.1)	2.8 (0-8.1)	<.001
	Nonoperative	7.1 (1.5-9.5)	6.9 (2.1-10)	7.4 (0.2-9.3)	.968
P		.137	.003	.001	
SF-36					
Physical function	Operative	65 (40-95)		90 (55-100)	<.001
	Nonoperative	55 (25-95)		63 (15-100)	.252
P		.341		.007	
Role personality	Operative	0 (0-75)		100 (0-100)	<.001
	Nonoperative	0 (0-100)		0 (0-100)	.491
P		.259		.014	
Bodily pain	Operative	31 (0-62)		52 (20-100)	<.001
	Nonoperative	32 (0-84)		32 (0-100)	.032
P		.524		.027	
General health	Operative	67 (20-97)		77 (20-100)	.002
	Nonoperative	62 (5-100)		56 (15-100)	.556
P		.725		.036	
Vitality	Operative	45 (0-95)		68 (5-95)	.026
	Nonoperative	43 (5-95)		50 (5-100)	.066
P		.369		.029	
Social function	Operative	75 (25-100)		100 (25-100)	.001
	Nonoperative	56 (0-100)		75 (0-100)	.472
P		.296		.006	
Role emotional	Operative	50 (0-100)		100 (0-100)	.031
	Nonoperative	17 (0-100)		100 (0-100)	.036
P		.312		.046	
Mental health	Operative	74 (44-100)		84 (44-100)	.024
	Nonoperative	64 (28-100)		70 (24-100)	.965
P		.190		.008	

Abbreviations: AOFAS, American Orthopaedic Foot & Ankle Society ankle-hindfoot score; SF-36, Short Form–36; VAS, visual analogue scale for pain.
[a]Median (range) values are presented. Statistics presenting *P* values for change from baseline to 12-month follow-up, as well as between-group differences at baseline and all follow-ups.

popliteal fossa. In addition, 1 patient experienced increased cramping in the calf. Her heel pain, however, resolved.

Discussion

The results from this study show that patients with chronic plantar heel pain who were operated with a PMGR and performed stretching exercises had less pain and better functional outcomes compared with patients treated with stretching exercises alone at 1-year follow-up. The functional tests showed increased ankle dorsiflexion and plantar pressure after surgery. No between-group differences were observed for any of the tests focusing on Achilles function at 12-month follow-up. The main limitation of this study is that neither the patients were blinded for group-affiliation nor was the investigator blinded for evaluating clinical

Table 3. Ankle Dorsiflexion and Pedobarographic Data.[a]

	Before Surgery			12-Month Follow-up			
Outcome	Median	Min	Max	Median	Min	Max	*P* Value
Ankle dorsiflexion with stretched knee, degrees	6	−3	15	10.5	0	23	<.001
Ankle dorsiflexion with flexed knee, degrees	22.5	8	36	25	10	39	.646
Difference stretched vs flexed knee, degrees	16.5	7	27	12	5	22	.004
Average peak plantar pressure forefoot, KPa	536	306	780	642	384	885	<.001
Peak heel pressure, KPa	393	207	582	451	246	634	<.001
Time of heel-off/total time of stance, %	71	54	87	71	57	81	.227

Abbreviation: KPa, kilopascal.
[a]The table presents biomechanical outcome data at baseline as well as at 12-month follow-up. Median values with range are presented.

outcomes for the chosen treatment at follow-up. In addition, a follow-up time of 12 months is too short draw conclusions about the long-term effects of the operative procedure. There is no objective way to make the diagnosis of plantar heel pain. It is also known that other conditions could mimic this condition.[23] From the literature, it seems that the typical history of pain at first step in the morning, pain on palpation of the proximal plantar fascia insertion, and increased pain when stretching the plantar fascia are accepted as diagnostic criteria.[22,23] We followed these diagnostic criteria to establish the diagnosis, but the lack of objective diagnostic tools must be acknowledged as a weakness of this study.

Several nonoperative treatment protocols have been described for treating plantar heel pain.[22,23] If nonoperative measures fail, operative treatment can be an option and is advocated by several authors.[4,22] However, no treatment protocol, neither conservative nor operative, has proven to be beneficial in terms of pain relief and restoring function in the long term.[22] This challenges the implementation of a randomized controlled trial as no gold standard of treatment exists for comparison. Two recent reviews concluded that stretching exercises of the Achilles and plantar structures of the foot are safe and have an effect at least in the acute phase.[9,37] Patients from both groups were instructed in the same stretching exercise protocol. We realize that the selected choice of treatment for the control group could be debated.

The choice of clinical outcomes could also be debated. The AOFAS ankle hindfoot score is, as all other scores, not validated for this condition. It is, however, the far most used outcome in other comparable studies, making it suitable in terms of understanding and interpreting the results.[19] A review of the use of clinical outcome measurement tools in foot and ankle research concluded that the 3 most frequently used scores are the AOFAS scale (55.9%), VAS pain (22.9%), and the SF-36 health survey (13.7%).[19]

The strengths of this study are that it is prospective and randomized. It describes several aspects of clinical, biomechanical, and functional outcomes following gastrocnemius recession not previously described in the literature. For the evaluation of biomechanical changes, we have used validated outcomes of an objective nature. The investigator for these outcomes was also blinded to which treatment the patients had received. There were no dropouts, and complete data for all participants are presented.

The AOFAS score significantly increased from baseline to 3-month and 12-month follow-up for the PMGR group. No such change was observed in the nonoperative group. We consider an improvement of 28.5 points as excellent. However, an AOFAS greater than 90 is usually considered an excellent result, and a median score from the operative group at 1-year follow-up of 88 reflects that not all patients fully recover, although they improve. Monteagudo et al,[28] who published the only level III study on this topic, reported an AOFAS at 1 year of 90 for patients treated with PMGR, compared with 66 in the group who underwent plantar fasciotomy. We also found nearly similar results as Monteagudo et al[28] on the AOFAS 3 months postsurgery. They reported a score of 85, and we found our patients' score to be 85.5, indicating that the patients recover quickly after surgery.

For the VAS pain score, a reduction in pain was observed in the operative group but not in the nonoperative group at both 3- and 12-month follow-up. However, even operatively treated, the patients were not pain free 1 year after surgery (median VAS pain, 2.8). Better VAS pain scores have been reported in other studies at 12-month follow-up.[24,28] Monteagudo et al[28] and Maskill et al[24] reported VAS pain scores of 0.9 and 2, respectively. The difference could possibly be explained by the way the VAS is monitored. We have chosen to define this as worst pain within the last 24 hours, as we believe this best reflects the true nature of plantar heel pain conditions. How this was measured is not

Table 4. Results From Achilles Test Battery.[a]

Test	Parameter	Unit	Group	No. of Feet	Baseline	12 Months	*P* Value
Counter movement jump	Max height	cm	Operative	24	4.81 (1.77-12.56)	3.70 (1.25-12.71)	.038
			Nonoperative	31	4.71 (1.62-16.07)	5.15 (1.30-18.46)	.405
	Statistics	*P* value			.905	.191	
Hopping	Frequency	Jumps/s	Operative	28	1.84 (1.04-2.36)	1.85 (0.87-2.28)	.949
			Nonoperative	31	1.95 (0.53-2.25)	1.94 (1.17-2.19)	.984
	Statistics	*P* value			.179	.727	
	Plyometric quotient	Contact time/ flight time	Operative	28	2.50 (1.16-4.21)	2.73 (1.01-4.43)	.362
			Nonoperative	31	2.76 (1.50-5.30)	2.68 (0.75-4.73)	.337
	Statistics	*P* value			.179	.988	
Drop counter movement jump	Effect	w/kg	Operative	27	4.94 (2.43-20.21)	4.55 (1.60-12.18)	.026
			Nonoperative	30	6.06 (1.69-15.74)	5.25 (1.73-12.99)	.007
	Statistics	*P* value			.204	.441	
	Max height	cm	Operative	27	4.29 (1.74-19.04)	4.06 (1.02-12.09)	.025
			Nonoperative	30	5.44 (1.06-13.93)	4.60 (1.15-11.11)	.003
	Statistics	*P* value			.322	.484	
Concentric toe raise	Concentric 23 kg	Watt	Operative	23	232 (55-1093)	198 (75-729)	.171
			Nonoperative	30	176 (82-587)	161 (94-1214)	.258
	Statistics	*P* value			.076	.332	
	Concentric 33 kg	Watt	Operative	23	195 (62-631)	171 (73-581)	.260
			Nonoperative	29	173 (69-492)	154 (57-1143)	.922
	Statistics	*P* value			.072	.182	
Eccentric-concentric toe raise	Eccentric-concentric 23 kg	Watt	Operative	21	313 (171-738)	287 (126-779)	.170
			Nonoperative	26	256 (137-420)	264 (127-702)	.101
	Statistics	*P* value			.026	.357	
	Eccentric-concentric 33 kg	Watt	Operative	20	258 (162-749)	287 (184-775)	.970
			Nonoperative	25	231 (126-553)	265 (133-590)	.054
	Statistics	*P* value			.042	.110	
Toe-raise endurance	Number of toe raises	Number	Operative	28	23 (11-51)	26 (15-62)	.029
			Nonoperative	28	24 (7-48)	24 (6-46)	.656
	Statistics	*P* value			.831	.426	
	Total work	Joule	Operative	28	1496 (421-3624)	1478 (270-5305)	.657
			Nonoperative	28	1218 (325-2603)	1388 (388-2691)	.873
	Statistics	*P* value			.258	.376	

[a]Results from 6 tests for Achilles performance at baseline and 12-month follow-up. Median values with range are presented. The table presents between-group statistics and statistics for 12-month follow-up compared with baseline data.

clearly defined in other studies.[24,28] It could also reflect the same as for the AOFAS score; the pain is reduced but not completely absent.

General health was evaluated with the SF-36, and as for the VAS pain and AOFAS scale, higher scores were observed in the operative compared with the nonoperative group at 12 months. An increase from baseline was also observed for all 8 parameters of the score for the operative group but only for 2 parameters in the nonoperative group. The SF-36 has not been reported in comparable studies.

Several operative approaches for lengthening the gastrocnemius have been described.[8,13] Recently, the PMGR, involving only the medial head of the gastrocnemius in the popliteal crease, was introduced (Figure 2).[1,5,28] The PMGR is reported to have a low complication rate, fast recovery, and reduced incidence of postoperative calf weakness.[1,5,28,37] However, a more distal recession is supposed to have a greater impact on ankle dorsiflexion than a more proximal recession.[35] The Strayer procedure has been described to increase ankle dorsiflexion as much as 18 degrees.[33] The PMGR's ability to increase dorsiflexion has been described in only 1 clinical study.[25] In the present study, ankle dorsiflexion with an extended knee joint increased from a baseline level of median 6 degrees to 10.5 degrees at 12-month follow-up in patients operated with the PMGR technique. This increase was less than previously demonstrated in cadaver and clinical studies.[25,35] Although recognizing the PMGR's limited ability to increase ankle dorsiflexion compared with other gastrocnemius recession techniques, we do not know if this influences the clinical outcome, as no study comparing clinical outcomes after the different operative methods for gastrocnemius recession have been published.

The performance of the Achilles muscle-tendon complex on the operated legs and the affected legs from the control group was comparable at 1-year follow-up. However, when comparing performance at baseline with 1-year follow-up, the operative group had a decrease in performance for 2 of the jump tests, while the result for the toe-raise endurance test improved. To our knowledge, only 2 previous retrospective studies have used outcomes based on functional tests validated for describing Achilles function.[26,29] Both studies evaluated function in patients who underwent a Strayer recession for Achilles tendinopathy, and the results showed a tendency for weakness of the operated limb. The obvious limitation of both studies is that there was no preoperative evaluation. It is believed that a more distal recession, for instance, the Strayer procedure, would affect function more than the proximal recession, but no study has compared this. A safe conclusion regarding the PMGR's impact on Achilles performance is difficult to make. Although it seems that the changes are small from baseline and that the groups are comparable at follow-up, the decreased performance for 2 of the jump tests in the operative group could be a true reflection of minor weakening of the muscle due to the operative lengthening.

In the present study, we examined 20 patients (28 feet) with pedobarography before and 12 months after surgery. The results showed an increase in both forefoot and heel peak plantar pressure, and heel-off was unchanged after surgery. This is not in compliance with previous cadaver studies, case reports, and theoretical outlines.[2,7] An explanation could be that patients with IGC can develop gait strategies to reduce painful foot loading such as increased ankle plantarflexion, reduced peak ankle plantarflexion moment, or increased knee flexion during stance.[3,11,20,30-32] Subsequently, it could be theorized that plantar pressure increases after operative correction of the gastrocnemius contracture, as pain resolves. Another explanation may be that neither kinematic studies nor pedobarography can fully record the impact of increased dorsiflexion through the triple joint complex in patients with IGC. Substantial dorsiflexion could be achieved by pronation of the hindfoot.[38] IGC has previously been connected to development of tibialis posterior insufficiency and flatfoot.[13,16] It is possible that the increased strain on the plantar structures of the foot in patients with IGC occurs through this detrimental pronation of the foot and therefore could not be measured by plantar pressure measurements or kinematic studies. As ankle dorsiflexion improves after surgery and pain resolves, the increased peak plantar pressure could reflect an unrecordable normalization of gait mechanics in the ankle and subtalar joint.

We conclude that the PMGR combined with postoperative stretching exercises improved foot function, pain, and general health outcomes for patients with chronic plantar heel pain compared with stretching exercises alone. Ankle dorsiflexion increased, and the function of the Achilles complex seemed to be affected to only a minor degree. A study with longer follow-up should be conducted to see how these effects persist in the long term. We believe the PMGR should be the preferred treatment for chronic cases of plantar heel pain that is nonresponsive to nonoperative treatment.

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AOFAS ankle-hindfoot scale

Pain (40 points)	
None	40
Mild, occasional	30
Moderate, daily	20
Severe, almost always present	0
Function (50 points)	
Activity limitations, support requirement	10
No limitations, no support	7
No limitation of daily activities, limitation of recreational activities, no support	
Limited daily and recreational activities, use of cane	4
Severe limitation of daily and recreational activities, walker, crutches, wheelchair, brace	0
Maximum walking distance (blocks)	
Greater than 6	5
4–6	4
1–3	2
Less than 1	0
Walking surfaces	
No difficulty on any surface	5
Some difficulty on uneven terrain, stairs, inclines, ladders	3
Severe difficulty on uneven terrain, stairs, inclines, ladders	0
Gait abnormality	
None, slight	8
Obvious	4
Marked	0
Sagital motion (flexion plus extension)	
Normal or mild restriction (30° or more)	8
Moderate restriction (15°–29°)	4
Severe restriction (< 15°)	0
Hindfoot motion (inversion plus eversion)	
Normal or mild restriction (75–100% normal)	6
Moderate restriction (825–74% normal)	3
Marked restriction (< 25% normal)	0
Ankle-hindfoot stability (anterioposterior, varus-valgus)	
Stable	8
Definitely unstable	0
Alignment (10 points)	
Good, plantigrade foot, ankle-hindfoot well aligned	10
Fair, plantigrade foot, some degree of ankle-hindfoot malalignment observed no symptoms	5
Poor, nonplantigrade foot, severe malalignment, symptoms	0

SF-36 SPØRRESKJEMA OM HELSE

INSTRUKSJON: Dette spørreskjemaet handler om hvordan du ser på din egen helse. Disse opplysningene vil hjelpe oss til å få vite hvordan du har det og hvordan du er i stand til å gjennomføre dine daglige gjøremål.

Hvert spørsmål skal besvares ved å sette en ring rundt det tallet som passer best for deg. Hvis du er usikker på hva du skal svare, vennligst svar så godt du kan.

1. Stort sett, vil du si din helse er:

(sett ring rundt ett tall)

Utmerket	1
Meget god	2
God	3
Nokså god	4
Dårlig	5

2. <u>Sammenliknet med for ett år siden</u>, hvordan vil du si at din helse stort sett er <u>nå</u>?

(sett ring rundt ett tall)

Mye bedre nå enn for ett år siden	1
Litt bedre nå enn for ett år siden	2
Omtrent den samme som for ett år siden	3
Litt dårligere nå enn for ett år siden	4
Mye dårligere nå enn for ett år siden	5

3. De neste sporsmålene handler om aktiviteter som du kanskje utforer i lopet av en vanlig dag. Er din helse slik at den begrenser deg i utforelsen av disse aktivitetene nå? Hvis ja, hvor mye?

(sett ring rundt ett tall på hver linje)

AKTIVITETER	Ja, begrenser meg mye	Ja, begrenser meg litt	Nei, begrenser meg ikke i det hele tatt
a. Anstrengende aktiviteter som å lope, lofte tunge gjenstander, delta i anstrengende idrett	1	2	3
b. Moderate aktiviteter som å flytte et bord, stovsuge, gå en tur eller drive med hagearbeid	1	2	3
c. Lofte eller bære en handlekurv	1	2	3
d. Gå opp trappen flere etasjer	1	2	3
e. Gå opp trappen en etasje	1	2	3
f. Bøye deg eller sitte på huk	1	2	3
g. Gå mer enn to kilometer	1	2	3
h. Gå noen hundre meter	1	2	3
i. Gå hundre meter	1	2	3
j. Vaske deg eller kle på deg	1	2	3

4. I lopet av de siste 4 ukene, har du hatt noen av folgende problemer i ditt arbeid eller i andre dine daglige gjoremål på grunn av din fysiske helse?

(sett ring rundt ett tall på hver linje)

	JA	NEI
a. Du har måttet **redusere tiden** du har brukt på arbeid eller på andre gjoremål	1	2
b. Du har **utrettet mindre** enn du hadde onsket	1	2
c. Du har vært hindret i å utfore **visse typer** arbeid eller gjoremål	1	2
d. Du har hatt **problemer** med å gjennomfore arbeidet eller andre gjoremål (for eksempel fordi det krevde ekstra anstrengelser)	1	2

5. I løpet av de siste 4 ukene, har du hatt noen av følgende problemer i ditt arbeid eller i andre dine daglige gjøremål på grunn av følelsesmessige problemer (som for eksempel å være deprimert eller engstelig)?

(sett ring rundt ett tall på hver linje)

	JA	NEI
a. Du har måttet **redusere tiden** du har brukt på arbeid eller på andre gjøremål	1	2
b. Du har **utrettet mindre** enn du hadde ønsket	1	2
c. Du har utført arbeidet eller andre gjøremål **mindre grundig** enn vanlig	1	2

6. I løpet av de siste 4 ukene, i hvilken grad har din fysiske helse eller følelsesmessig problemer hatt innvirkning på din vanlige sosiale omgang med familie, venner, naboer eller foreninger?

(sett ring rundt ett tall)

Ikke i det hele tatt	1
Litt	2
En del	3
Mye	4
Svært mye	5

7. Hvor sterke kroppslige smerter har du hatt i løpet av de siste 4 ukene?

(sett ring rundt ett tall)

Ingen	1
Meget svake	2
Svake	3
Moderate	4
Sterke	5
Meget sterke	6

8. I løpet av de siste 4 ukene, hvor mye har smerter påvirket ditt vanlige arbeid (gjelder både arbeid utenfor hjemmet og husarbeid)?

(sett ring rundt ett tall)

Ikke i det hele tatt	1
Litt	2
En del	3
Mye	4
Svært mye	5

9. De neste spørsmålene handler om hvordan du har følt deg og hvordan du har hatt det de siste 4 ukene. For hvert spørsmål, vennligst velg det svaralternativet som best beskriver hvordan du har hatt det. Hvor ofte i løpet av de siste 4 ukene har du:

(sett ring rundt ett tall på hver linje)

	Hele tiden	Nesten hele tiden	Mye av tiden	En del av tiden	Litt av tiden	Ikke i det hele tatt
a. Følt deg full av tiltakslyst	1	2	3	4	5	6
b. Følt deg veldig nervøs?	1	2	3	4	5	6
c. Vært så langt nede at ingenting har kunnet muntre deg opp?	1	2	3	4	5	6
d. Følt deg rolig og harmonisk?	1	2	3	4	5	6
e. Hatt mye overskudd?	1	2	3	4	5	6
f. Følt deg nedfor og trist?	1	2	3	4	5	6
g. Følt deg sliten?	1	2	3	4	5	6
h. Følt deg glad?	1	2	3	4	5	6
i. Følt deg trett?	1	2	3	4	5	6

10. I løpet av de siste 4 ukene, hvor mye av tiden har din fysiske helse eller følelsesmessige problemer påvirket din sosiale omgang (som det å besøke venner, slektninger osv.)?

(sett ring rundt ett tall)

Hele tiden	1
Nesten hele tiden	2
En del av tiden	3
Litt av tiden	4
Ikke i det hele tatt	5

11. Hvor RIKTIG eller GAL er hver av de følgende påstander for deg?

(sett ring rundt ett tall på hver linje)

	Helt riktig	Delvis riktig	Vet ikke	Delvis gal	Helt gal
a. Det virker som jeg blir syk litt lettere enn andre	1	2	3	4	5
b. Jeg er like frisk som de fleste jeg kjenner	1	2	3	4	5
c. Jeg tror at helsen min vil forverres	1	2	3	4	5
d. Jeg har utmerket helse	1	2	3	4	5