Iikka Lantto

ACUTE ACHILLES TENDON RUPTURE

Epidemiology and Treatment
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Abstract

The Achilles tendon is the strongest and largest of human tendons, and its proper function is essential for normal gait. Most acute Achilles tendon injuries occur during sports, particularly in ball games.

The purposes of this study were (1) to examine the incidence of total Achilles tendon rupture (ATR) over a 33-year period in the city of Oulu and to investigate its changes with respect to age, sex, and injury mechanism. (2) to compare ≥10-year outcomes of two postoperative regimens after ATR repair: early weightbearing with early mobilization versus early weightbearing with early immobilization in tension, (3) to compare clinical outcome and calf muscle strength recovery after conservative treatment or open surgical repair of acute ATR, followed by identical accelerated rehabilitation programs.

The overall incidence per 100 000 person years increased from 2.1 in 1979 to 21.5 in 2011. The incidence increased in all age groups. The incidence of sports-related ruptures increased during the second 11-year period, whereas the incidence of non-sports-related ruptures increased steadily over the entire study period.

Early mobilization and immobilization in tension after ATR repair resulted in similar clinical outcomes and isokinetic strengths. Regardless of patient satisfaction with the operative treatment, calf muscle strength did not recover normally, even at the 10-year follow-up.

Surgery and conservative treatment of acute ATR resulted in similar Achilles tendon performance score after 18 months, but surgery restored calf muscle strength earlier. Surgery also resulted in better health-related quality of life in the domains of physical functioning and bodily pain. Conservative treatment with a functional protocol is recommended for a large majority of patients. However, patients with high physical expectations could still benefit from operative treatment.

In conclusion, the incidence of ATR is rising, postoperative immobilization and early mobilization result in similar long-term results in terms of the Achilles tendon performance score and calf muscle function, and conservative treatment with a functional protocol is the preferred treatment for the majority of patients.

Keywords: achilles tendon rupture, conservative treatment, epidemiology, long-term result, operative treatment
Lantto, Ikka, Akuutti akillesjänteen repeämä. Esiintyvyys ja hoito
Oulun yliopiston tutkijakoulu; Oulun yliopisto, Lääketieteellinen tiedekunta; Medical Research
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Oulun yliopisto, PL 8000, 90014 Oulun yliopisto

Tiivistelmä

Akillesjänne on ihmisen suurin ja vahvin jänne ja sen kunnollinen toiminta on edellytys normaalille kävelylle. Suurin osa akillesjänteen repeämistä syntyy urheilussa, erityisesti pallopeleissä.


Asiassanat: akillesjänteen repeämä, epidemiologia, konservatiivinen hoito, operatiivinen hoito, pitkäaikaistulokset
To my family
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Oulu, May 2016

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<td>American Orthopedic Foot and Ankle Society</td>
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<td>AT</td>
<td>Achilles tendon</td>
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<td>ATR</td>
<td>Achilles tendon rupture</td>
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List of original publications

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1 Introduction

The “poster child” for an acute Achilles tendon rupture (ATR) injury is the approximately 40-year-old “weekend warrior” who participates in a sports activity in his spare time. He will feel like somebody has kicked his Achilles tendon (AT) when he reaches for the ball. He will feel that his ankle is not working properly, and a palpable gap may be present in his AT at about 4 cm above the heel bone. Diagnosis can usually be made clinically and is easily confirmed by ultrasound (US).

The first report of an occurrence of ATR was by Christensen, who reported 57 ATRs among 70 000 patients treated in an orthopedic department between the years 1936 and 1954 (Christensen 1954). Nillius et al. (1976) reported increasing incidence of ATRs from Malmö, Sweden from 1950 to 1973. Since then, growing evidence has confirmed that the ATR has become a more common tendon rupture (Ganestam et al. 2015, Leppilahti et al. 1996). This is probably because Scandinavian countries have publicly funded health care systems and reliable medical records, so we have played a leading role in epidemiological studies concerning ATRs. Previously published data from Oulu showed that the incidence of ATRs in our city with about 200 000 inhabitants increased from 2/100 00 to 18/100 000 between years 1979 and 1994 (Leppilahti et al. 1996). This paper is commonly cited in the international literature as an example of growing incidence. Little is known of the changes in epidemiology that have occurred during the last two decades.

At the same time as this increase in the number of patients suffering ATRs, the discussion of optimal ATR treatment continues. In the first decades of the 1900s, the general development of surgical techniques improved the results of operative treatment of ATRs. Even though some studies reported good outcomes for nonoperative treatment and some papers reported severe surgery-related complications, operative treatment became established as the gold standard, especially in physically active patients, during 80s and 90s. Most commonly, an ATR is operated on by a simple, open end-to-end operation, which can be strengthened by one or two fascia flaps. The recent literature has not shown advantages of performing fascia augmentation in short-term follow-up (Pajala et al. 2009), and any advantages of minimally invasive techniques are also unclear (Khan et al. 2005). Postoperative treatment has gradually changed from prolonged cast immobilization into functional bracing procedures that allow early weight bearing.
Historically, nonoperative treatment has included different kind of bandages or casts for varying periods, normally between 6 and 9 weeks. In the beginning of the 20th century, the famous American physician Dr. C.H. Mayo treated his own ATR by putting a large cork under his shoe heel, and the injury healed in three months (Lipscomb & Weiner 1956). Functional treatment protocols are becoming more common as well in current nonoperative treatments. Modern functional protocols have decreased the re-rupture, and most studies show functional outcomes that are comparable to operative treatments (Soroceanu et al. 2012). Nonoperative treatments avoid surgery-related complications, and their good patient satisfaction and functional outcomes have made nonoperative treatments the most preferred treatment type for ATRs, at least in Scandinavian countries (Ganestam et al. 2015, Huttunen et al. 2014, Mattila et al. 2013,). However, despite numerous prospective randomized trials comparing surgery with nonoperative treatment, several issues, especially the recovery of calf muscle strength and long-term results, remain unaddressed.

The main goal of the present study is to compare the results of surgery to those of conservative treatment for ATRs, and to assess the long-term outcomes of surgically treated patients. We also wanted to determine if the ATR incidence has continued to increase in Oulu since 1994.
2 Review of the literature

2.1 Anatomy and biomechanics of the Achilles tendon

The AT consists of the tendons of the gastrocnemius and soleus muscles. The purpose of the AT is to transmit the power of these muscles to the heel bone and to produce knee flexion, tibiotalar flexion, and subtalar inversion. The length of the AT fibers varies from 11–26 cm in the gastrocnemius part and from 3–11 cm in fibers from soleus (Cummins et al. 1946). The cross sectional area of the AT varies from 0.8 cm² to 1.4 cm² along the course of the tendon (O’Brien 1992) and depends on the cumulative training load (Rosager et al. 2002). The biomechanical loading in the AT can increase to 9 kN during running (Komi et al. 1992), and the tensile strength of the tendon is about 50 N/mm in vitro (Jozsa & Kannus 1997), which makes the normal tendon theoretically capable of supporting weights up to 1000 kg. The AT is therefore the largest and the strongest of the human tendons.

The AT is circular in shape at its midpoint, and it is wider at the osteotendinous junction on the heel bone. The tendon fibers turn rotationally so that those fibers from posterior gastrocnemius rotate anterolateral, whereas the anterior soleus tendon fibers run posteromedial (Cummins et al. 1946, Stein et al. 2000). The AT is not simply straight in its micro architecture as the collagen fibers and fibrils of the tendon assume a wavy configuration when the tendon is unstretched. If the tendon is stretched by 2%, this wavy configuration disappears; more than 4% stretching causes irreversible changes. Stretching to more than 8% causes macroscopic failure and tendon rupture (O’Brien 1992).

Fibroblasts are the dominant cells in the AT, but major part of the AT consists of extracellular matrix. The dry weight of collagen content of the AT is about 70% (Jozsa et al. 1989b), and most of the collagen is type I collagen. A small amount of type II collagen is found in the osteotendinous junction and types III, IV, and V are found in the endotenon (Jozsa & Kannus 1997). Collagen turnover is relatively slow, ranging from 50–100 days (Curwin & Stanish 1984). Metabolism can speed up after injury, but immobilization decreases collagen synthesis and increases its degradation, thereby reducing tendon strength (Karpakka et al. 1991).

Over the years, the tensile strength of the healthy AT decreases, reaching about 40% of its value by the age of 70 years when compared to 30 years
Repeated microtraumas that cause histological changes in the AT and in type III collagen content are significantly increased upon rupture (Kannus & Jozsa 1991, Pajala et al. 2002). Biomechanical factors, like an underpronating foot and an ankle type linked with poor shock absorption, will increase the strain on the AT and may result in AT overuse injuries and ATR (Kvist 1991, Leppilahti et al. 1998). A study by Davis et al. (1991) on military recruits reported that black people had an increased risk for ATR when compared with caucasians and that this higher risk could not be explained by differences in sports training alone.

Some drugs, especially fluoroquinolones, increase the risk for ATR (Sode 2007). Some investigations have suggested that statins, given to treat hypercholesterolemia, might also have some effect on tendons (Beri et al. 2009, Marie et al. 2008), and studies using animal models have reported decreases in the biomechanical strength of the AT with statin use (de Oliveira 2015). The exact mechanism underlying the effect of these drugs on the occurrence of ATR remains to be established. Anabolic hormone abuse leads to dysplasia of collagen fibrils, reducing the tensile strength of the AT and increasing the risk for ATR (Laseter & Russel 1991). Oral and locally injected corticosteroids are generally considered as a risk factor for ATRs (Claessen et al. 2014, Spoendlin et al. 2015, van Sterkenburg & van Dijk. 2011), even if the corticosteroids are not injected just next to the tendon (Turmo-Garuz et al. 2014). Pre-existing intratendinous diseases (e.g., rheumatoid nodule, gout affection, xanthoma, and tumors) are uncommon causes for ATR (Kannus & Jozsa 1991).
Fig. 1. Anatomy of Achilles tendon according to Jean-Baptiste Sarlandière.

2.2 Acute ATR

2.2.1 Diagnosis

ATR is an injury mostly associated with young and healthy active individuals. It occurs during a sudden forced ankle dorsiflexion, mostly during sports exercises or by stepping in a hole.

The majority of ATRs occur 2–6 cm above the heel bone (Fox et al. 1975), possibly because the vascularity of the tendon is decreased in that area, as shown in an angiographic study (Lagergren & Lindholm 1959). The typical patient history and symptoms make clinical diagnosis of ATR usually easy. One quarter of these patients typically has had previous AT problems, 56 % during the 3 months preceding the rupture. The patients with previous AT symptoms are
younger and more often competitive athletes and often have had a sports-related injury mechanism (Leppilahti et al. 1996).

Typically, a patient undergoing an ATR will feel a sudden pain and a snap in the lower calf – a feeling as if somebody has kicked the AT. A palpable gap in the ruptured area can be found in about 70% of patients, and in about 80% if tested under anesthesia (Maffulli 1998).

Some clinical tests can help improve the diagnostic accuracy. The Thompson test is easy and accurate for diagnosing a complete ATR (Cuttica et al. 2015, Maffulli 1998). This test is done by squeezing the calf of the affected leg, which is placed at a 90-degree angle on a chair, while the opposite leg remains standing. The absence of ankle plantar flexion is suggestive of a complete ATR and is termed a "positive" Thompson test (Thompson & Doherty 1962).

The O’Brien test involves insertion of a 25-gauge needle 10 cm proximal to the superior border of the calcaneus, such that it penetrates the AT. The ankle is then alternated with passive dorsiflexion and plantar flexion movements. The absence of needle movement means a positive test result and indicates an ATR (O’Brien 1984). The Copeland test is done with the patient in a prone position and the knee is flexed 90 degrees. A sphygmomanometer cuff is applied around the calf muscle and inflated to approximately 100 mmHg, with the ankle plantar flexed. Passive dorsiflexion of the ankle will cause no change in the pressure in the case of a ruptured AT, but a healthy tendon will cause a rise of about 140 mmHg. The opposite leg may be used as a control, for comparison purposes (Copeland 1990). However, the sensitivity of these two tests is only slightly better than clinical evaluation (Maffulli 1998).

Even if ATR diagnosis is mostly based on clinical examination, technical devices can be used to support the diagnosis. X-ray was used in ATR diagnosis for several decades. Kager described the appearance of the “Kager triangle” – the normal triangular pre-Achilles fat pad – on lateral x-rays, which has been regarded as diagnostic for ATR (Kager 1939). Electromyography (EMG) has also been used for diagnosis, especially for partial ruptures (Ljungqvist 1968). At present, US is the gold standard for confirming rupture and for determining the appropriate treatment option (Amlang et al. 2011, Thermann et al. 1989). In conservative treatment, US can also be used to monitor the healing processes (Walz et al. 1993). It is inexpensive and readily available, but its results are also highly investigator dependent. AT injuries can also be diagnosed confidently by magnetic resonance imaging (MRI) (Keene et al. 1989), but its availability is
limited compared to US. In differential diagnosis between partial and complete tears, MRI is superior to US (Kayser et al. 2005).

### 2.2.2 Epidemiology

The incidence of ATRs has been studied quite appreciably in northern European countries over the last 3 decades (Ganestam et al. 2015, Houshian et al. 1998, Leppilahti et al. 1996, Levi 1997, Mattila et al. 2014, Möller et al. 1996, Nillius et al. 1976, Nyyssönen et al. 2008, Rantanen et al. 1993, Wählby 1978). Studies have also been conducted in Scotland (Clayton & Court-Brown 2008, Maffulli et al. 1999) Canada (Scott et al. 2014, Suchak et al. 2005), Slovenia (Cretnik et al. 2010), New Zealand (Gwynne-Jones et al. 2011), and the United States (Raikin et al. 2013, White et al. 2007). The study populations of these previous studies are heterogenic, containing patients from very different backgrounds, and the studies have included both acute and chronic ATRs from the year 1936 (Christensen 1954) to 2013 (Ganestam et al. 2015). This has resulted in wide variation in the reports of the overall incidence per 100 000 person-years in these different studies, from 2.1/100 000 (Leppilahti et al. 1996) to 37.3/100 000 (Houshian et al. 1998).

Almost all the studies assessing changes in epidemiology have shown an increasing incidence. This increasing incidence is also reflected in more recent studies, which report a higher overall incidence than reported in the older studies. A previous study from our Oulu University hospital showed an increasing incidence over a 16 year period from 1979 to 1994. The incidence increased from 2/100 000 in 1979 to 18/100 000 person-years in 1994 (Leppilahti et al. 1996). The total incidence in Finland between 1987 and 1999 has been reported as 11.2/100 000, but this study examined only operatively treated ruptures (Nyyssönen et al. 2008). The longest time period and the largest study population in these previous studies is that from the National Patient Registry of Denmark, which ran from 1994 to 2013 and included 33 160 ATRs. It showed a clear increase in the incidence from 27.0 in 1994 to 31.2/100 000/person-years in 2013 (Ganestam et al. 2015). The Finnish data show an increasing incidence during the 80s and 90s, but whether the incidence has continued to grow after the year 2000 remains unclear.

In all the epidemiological studies, the majority of ATRs are sports related. The ATR typically occurs during sports that require sudden acceleration and jumping, such as badminton, volleyball, soccer, and basketball, but considerable
national differences are evident (Houshian et al. 1998, Jozsa et al. 1989, Leppilahti et al. 1996, Raikin et al. 2013, Suchak et al. 2005). Previous studies have shown that about 25% of ATRs are non-sports related (Jozsa et al. 1989, Leitner et al. 1991), but the specific changes in the incidence of sports-related ruptures are unclear. The median age at the time of the injury, reported in previous studies, has been quite similar, from 42 to 47 years (Ganestam et al. 2015, Houshian et al. 1998, Huttunen et al. 2014, Leppilahti et al. 1996, Nyyssönen et al. 2008, Raikin et al. 2013). Another common factor in these previous studies is that ATR is 2 to 6 times more common in men than in women; even greater differences have been proposed by Maffulli et al. (1999).

The seasonal variation of ATRs is controversial. Two studies one in Finland and another one in Canada found no statistically significant seasonal variation in the incidence (Nyyssönen et al. 2008, Suchak et al. 2005), whereas Scott et al. found an increase in the number of cases in spring in terms of sports-related ruptures (Scott 2013). Contrary to these findings, Ganestam et al. (2015) found a higher incidence during the fall, with a peak incidence in September.

2.3 Treatment of acute ATR

ATRs can be treated operatively (open or percutaneous) or nonoperatively. Historically, ATR has been treated nonoperatively with different kinds of bandages or braces for varying periods (Wills et al. 1986). As early as the 1920s, surgery was proposed as the treatment of choice in the French literature (Quenu & Stoianovitch 1929). Studies favoring surgery (Arner & Lindholm 1959, Christenssen 1954) made operative treatment more popular, despite reports of good results with conservative treatment (Gillies & Chalmers 1970, Lea & Smith 1968). An editorial appearing in the Lancet in 1973 raised doubts regarding the superiority of operative treatment compared to conservative treatment. Nevertheless, operative treatment became frequent, especially among active young patients, and the conservatively treated patients were mostly elderly patients or patients with high operation-related risks.

Different kinds of percutaneous techniques have been described since 1977, when Ma & Griffith (1977) reported their results for 18 patients treated with percutaneous sutures. However, percutaneous techniques have not challenged open operative techniques as the most commonly used treatment. During the past few years, several high quality studies have been published, including systematic reviews and meta-analyses comparing operative and nonoperative treatments.

2.3.1 Conservative treatment

The most common conservative treatment method has traditionally been a below-the-knee cast for 6–10 weeks, starting with plantar flexion and changing the cast to a normal position, usually with no or only partial weight bearing. The use of a rigid cast in nonoperative treatment has decreased and functional treatment has increased in the last decade. Experimental studies have shown that immobilization of a muscle in a shortened position is deleterious and causes more histological changes, whereas immobilization in a stretched position markedly delays the development of atrophy (Hurme et al. 1990, Rantanen et al. 1999).

Functional treatment consists of braces and casts worn for varying times. Patients are normally encouraged to weight bear, starting at weeks 0–3, depending on the protocol. Usually, some range-of-motion (ROM) exercises are also possible for the tibiotalar joint. McComis et al. (1997) reported good results with a functional nonoperative treatment as early as 1997 with a limited (15 patients) sample size.

Wallace et al. (2011) had treated 946 patients with a functional conservative protocol in a prospective study and observed a re-rupture rate (2.8 %) similar or even smaller than that published for operative treatments. Functional bracing showed a lower re-rupture rate than was observed with cast immobilization in a meta-analysis (Khan et al. 2005). Möller et al. reported a high re-rupture rate (11/53) following conservative treatment in their randomized trial in 2001, but other subsequent randomized trials reported lower re-rupture rates following nonoperative treatment (Keating et al. 2011, Nilsson-Helander et al. 2010, Olsson et al. 2013, Schepull et al. 2012, Twaddle et al. 2007, Willits et al. 2010). Concerns have been raised regarding the rare complication of significant lengthening of the AT, especially during functional conservative treatment (Schepull et al. 2012). Therefore Hufner et al. (2006) suggested repeated US controls in the first week in their conservative treatment protocol.

On the other hand, Costa et al. (2006) found no evidence of tendon lengthening or a higher re-rupture rate when early mobilization with weight bearing was compared with traditional plaster cast immobilization.
2.3.2 Operative treatment

Numerous variations in surgical techniques are available for the treatment of ATRs (Wong et al. 2002). Generally, these techniques can be divided into open or percutaneous techniques. Techniques with external fixation and tendon suturation with fibrin glue have also been described, with very good outcomes (Hohendorf et al. 2008, Nada et al. 1985). In most cases, surgery means simple end-to-end suturation, augmentation with one or two gastrocnemius-soleus fascia flaps, or local tendon augmentation. Cadaver studies have shown that augmentation increases the gap resistance by as much as 29% when compared with simple sutures in AT repair (Gerdes et al. 1992, Lee et al. 2008). Two randomized clinical studies that compared augmentation and non-augmentation operative techniques (Pajala et al. 2009, Tezeren et al. 2006) reported no differences between augmentation and non-augmentation in terms of AT performance score or isokinetic strengths after 12 to 24 months of follow-up. However, Pajala et al. (2009) found a more marked tendon elongation in the non-augmented group, and tendon elongation was significantly correlated with strength deficits at 12 months postoperatively. By contrast, one prospective and two retrospective studies have found no differences between augmentation and non-augmentation in short-term follow-up (Aktas et al. 2007, Jessing & Hansen 1975, Nyyssönen et al. 2003).

Marked variation is also evident in the percutaneous techniques. The most frequently used techniques are variations of the protocol described by Ma & Griffith in 1977 (Wong et al. 2002). Percutaneous techniques are often associated with lower postoperative infection, but they have a greater occurrence of sural nerve problems when compared to open techniques (Buchgraber et al. 1997, Cretnik et al. 2005). Two randomized controlled studies that compared percutaneous and open techniques in a total of 94 patients (Lim et al. 2001, Schroeder et al. 1997) reported that the pooled data showed a tendency for a lower overall rate of complications (especially infections) in the percutaneous group. A meta-analysis of retrospectively and prospectively collected data also showed similar results, but other complication rates were relatively high in the percutaneous group, particularly when percutaneous operations were combined with functional postoperative treatment (Wong et al. 2002).
Postoperative treatment

After surgery ATR is usually treated with cast immobilization or some kind of functional brace allowing more or less ankle movement. Functional postoperative treatment became common in the 1990s. Current evidence now indicates that early functional treatment with early weight bearing after ATR repair does not increase the re-rupture rate and results in better patient satisfaction in the short-term follow up period (Cetti et al. 1994, Costa et al. 2006, Kangas et al. 2003, Maffulli et al. 2003, Metz et al. 2011, Schepull et al. 2013). Early mobilization with weight bearing may decrease the adverse effects related to cast immobilization but does not affect the long-term clinical outcome or isokinetic calf muscle strength (Barfod et al. 2014, Kangas et al. 2003, Young et al. 2014). Several meta-analyses have shown that early functional treatment protocols, when compared with postoperative immobilization, lead to a greater number of excellent ratings in subjective responses and a faster return to prior employment and sporting activities, but no difference in complication rates (Maffulli et al. 2003, McCormack & Bovard 2015, Suchak et al. 2006, van der Eng et al. 2013). Variations in functional treatment protocols are large and the efficacies of different rehabilitation protocols are unclear (Kearney et al. 2012). However, postoperative early weight bearing, combined with early ankle motion exercises, appears to lead to better results when compared with early ankle motion exercises alone (Huang et al. 2015).

2.3.3 High-quality evidence of operative vs. conservative treatment

Outcome measures

Analysis of different treatment methods in surgery obviously requires a reliable system for comparing results. Concerning ATR, no consensus has been reached on any single measuring system. Scores can be divided into generic health outcome measures, like the 36-item questionnaire (SF-36), or disease and region-specific outcome measures, like the American Orthopedic Foot and Ankle Society (AOFAS) ankle-hindfoot score. Several different scoring systems have been used in meta-analysis in recent years, including the short musculoskeletal scoring system (Keating et al. 2011), musculoskeletal functional assessment instrument (Twaddle et al. 2007), the Achilles tendon total rupture score (ATRS) (Nilsson-Helander et al. 2010, Olsson et al. 2010, Schepull et al. 2012), the Leppilahti
score (Metz et al. 2008, Willits et al. 2010), the Foot and Ankle outcome score, and the EQ-5D (a standardized instrument for use as a measure of health outcomes) (Olsson et al. 2013). Among these scores, the ATRS and Leppilahti score are specific for ATR.

Our study group has been using the Leppilahti score since it was published 1998. This score consists of subjective factors (pain, stiffness, muscle weakness, footwear restriction, and subjective outcome) and objective factors (active ROM of the ankle and the isokinetic calf muscle strength score) (Appendix 1). The meta-analysis conducted by Kearney et al. in 2012 reported 4 generic quality-of-life outcome measures and 17 region-specific outcome measures being used to assess ATR outcomes. The AOFAS ankle-hindfoot score was the most frequently used. The ATRS is the only formally validated score for ATRs; however, its ceiling effect remains unclear (Kearney et al. 2012).

Strength recovery after an ATR has been assessed by a simple heel raise test or by isometric or isokinetic strength measurements. Isokinetic measurements are considered more physiological than are isometric measurements, especially relative to gait. A large variety of isokinetic tests is available, but the peak torque (PT) is the most frequently reported value, and it is normally reported regardless of the angle in the ROM at which it occurs (Mullaney et al. 2006). The PT shows a good correlation with calf muscle volume (Rosso et al. 2015). Reporting the differences between the affected and non-affected leg as percentage deficits is advisable, especially in long-term studies, because the absolute values can also decrease due to aging if the study period extends over several years.

The average torque and total work have also proven to be reliable methods for measuring the torque of the plantar flexors and outcomes after an ATR (Chester et al. 2003). The clinical importance of small strength deficits are unclear, but one study reported persistent impairment and a 30 % strength deficit, resulting in gait adaptations observed in a two-year follow-up (Don et al. 2007). Work differences in plantar flexion also reflect the strength capabilities of the calf and have been used to show the differences between the affected and non-affected legs (Pajala et al. 2009). Our unpublished data showed good to excellent interclass correlation values for work displacement (appendix 2).
Randomized controlled trials (RCTs) comparing surgery and conservative treatment

Studies comparing open operative and nonoperative treatments have been published since the 1970s (Gillies & Chalmers 1970, Inglis et al. 1976, Jacobs et al. 1978). The first randomized controlled study was launched in 1973, when Nistor started his study in Göteborg. That study, which included 105 patients, was published in 1981. Like most subsequent studies on the same subject, it reported more re-ruptures in the nonoperative group and more surgery-related complications in the operative group. Nistor concluded that “non-surgical treatment offers advantages over surgical treatment” (Nistor 1981).

After Nistor’s work, 11 high-level RCTs comparing operative treatment with nonoperative treatment were published (Cetti et al. 1993, Keating et al. 2011, Majewski et al. 2000, Möller et al. 2001, Nilsson-Helander et al. 2010, Olsson et al. 2013, Schepull et al. 2012, Schroeder et al. 1997, Thermann et al. 1995, Twaddle et al. 2007, Willits et al. 2010). The study by Möller (2001) was the last trial included in the meta-analyses of Bhandari et al. (2002) and Khan et al. (2005). These meta-analyses did not use precisely the same trials; however, both concluded that operative treatment reduces the risk of re-rupture, but is associated with a significantly higher risk of infection. Khan et al. (2005) also found that functional postoperative treatment reduces the overall complication rate; however, this result was based on two studies (Petersen et al. 1992, Saleh et al. 2002) with a total combined number of only 90 patients. In the same year, Wong et al. (2002) published a quantitative review of retrospective and prospective studies and recommended open repair and early mobilization, with a general complication rate of 6.7%.

After these meta-analyses, three high-quality RCTs were published, which were included in the meta-analyses of Jiang et al. (2012), Soroceanu et al. (2012), and Wilkins et al. (2012). Although 291 new patients were included, the conclusions remained practically unchanged. The functional outcomes or returning of strength showed no significant differences, but the return to work was slightly quicker in the operatively treated patients. Soroceanu et al. (2012) found that nonoperative treatment, including early ROM, led to equivalent results when compared with open operative treatment in terms of re-rupture rate, and concluded that “conservative treatment should be considered at centers using functional rehabilitation.”
In their quantitative review, Wong et al. (2002) found that the quality of articles has improved and the rate of complications has decreased over time. A recent systematic review by Holm et al. (2015) included only studies published in the last ten years (Keating et al. 2011, Metz et al. 2008, Nilsson-Helander et al. 2010, Olsson et al. 2013, Schepull et al. 2012, Twaddle et al. 2007, Willits et al. 2010) and summarized data from 584 patients. The majority of these patients had been treated using functional protocols. One study (Metz et al. 2008) compared nonoperative treatment to minimally invasive surgery, whereas the other studies used open end-to-end sutures. No statistically significant differences were found for patient satisfaction, pain, or re-ruptures, although two studies (Nilsson-Helander et al. 2012, Olsson et al. 2013) found a difference of 2–4% vs. 10–12% favoring operative treatment. Studies measuring different functional tests found some slight differences favoring surgery, but the clinical importance of these findings is unclear. The authors suggested that subtle differences between groups could mean that rehabilitation is more important than the actual initial treatment.

In 2009, when we started to collect patients for our prospective randomized study comparing operative vs. nonoperative treatments, studies with good strength measurements were lacking. Since then, four randomized studies that include strength measurements have been published. All reported results favored surgery at least in the short term (Keating et al. 2011, Nilsson-Helander et al. 2010, Olsson et al. 2013, Willits et al. 2010). The effects of accelerated postoperative rehabilitation on calf muscle strength are unclear, and only one study has been published so far (Willits et al. 2010).
Table 1. Meta-analyses of randomized studies.

<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>Bhandari</th>
<th>Khan</th>
<th>Jiang</th>
<th>Soroceanu</th>
<th>Wilkins</th>
<th>Holm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coombs</td>
<td>1981</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nistor</td>
<td>1981</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Cetti</td>
<td>1993</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Thermann</td>
<td>1995</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schroeder</td>
<td>1997</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Majewski</td>
<td>2000</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Möller</td>
<td>2001</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Twaddle</td>
<td>2007</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metz</td>
<td>2008</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Willits</td>
<td>2010</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nilsson-Helander</td>
<td>2010</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Keating</td>
<td>2011</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schepull</td>
<td>2012</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Olsson</td>
<td>2013</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Coombs 1981 was excluded because of inadequate reporting of results
Thermann 1995 because of inadequate randomization
Majewski 2000 because of discontinuation of treatment group

Table 2. Randomized controlled studies, operative vs. nonoperative treatment.

<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>Oper/cons</th>
<th>Re-rup.</th>
<th>Re-rup. %</th>
<th>Comp.</th>
<th>Comp. %</th>
<th>Strenght favor</th>
<th>Recom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nistor</td>
<td>1981</td>
<td>45/60</td>
<td>2/5</td>
<td>4.4/8.3</td>
<td>29/2</td>
<td>64/3</td>
<td>cons</td>
<td>cons</td>
</tr>
<tr>
<td>Cetti</td>
<td>1993</td>
<td>56/55</td>
<td>3/7</td>
<td>5.3/12.7</td>
<td>17/5</td>
<td>30/9</td>
<td>0</td>
<td>oper</td>
</tr>
<tr>
<td>Schroeder</td>
<td>1997</td>
<td>13/15</td>
<td>0/0</td>
<td>0.0/0.0</td>
<td>2/0</td>
<td>15/0</td>
<td>0</td>
<td>?</td>
</tr>
<tr>
<td>Möller</td>
<td>2001</td>
<td>59/53</td>
<td>1/11</td>
<td>1.7/20.8</td>
<td>10/2</td>
<td>17/4</td>
<td>0</td>
<td>oper</td>
</tr>
<tr>
<td>Twaddle</td>
<td>2007</td>
<td>25/25</td>
<td>2/1</td>
<td>10/4.5</td>
<td>0/0</td>
<td>0/0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Willits</td>
<td>2010</td>
<td>72/72</td>
<td>2/3</td>
<td>2.8/4.2</td>
<td>11/3</td>
<td>15/4</td>
<td>oper 24 m</td>
<td>cons</td>
</tr>
<tr>
<td>Nilsson-Helander</td>
<td>2010</td>
<td>49/48</td>
<td>2/6</td>
<td>4.4/12</td>
<td>18/0</td>
<td>36/0</td>
<td>oper 6 m, 12 m</td>
<td>0</td>
</tr>
<tr>
<td>Keating</td>
<td>2011</td>
<td>39/41</td>
<td>2/4</td>
<td>5.4/10</td>
<td>3/2</td>
<td>8/5</td>
<td>oper 3 m</td>
<td>cons</td>
</tr>
<tr>
<td>Schepull</td>
<td>2012</td>
<td>15/15</td>
<td>0/1</td>
<td>0.0/6.7</td>
<td>0/4</td>
<td>0/26</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Olsson</td>
<td>2013</td>
<td>49/51</td>
<td>1/5</td>
<td>2.0/10</td>
<td>21/4</td>
<td>42/8</td>
<td>oper 12 m</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>422/435</td>
<td>15/43</td>
<td>3.6/10</td>
<td>111/20</td>
<td>26/4.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Coombs 1981 was excluded because of inadequate reporting of results
Thermann 1995 because of inadequate randomization
Majewski 2000 because of discontinuation of treatment group

2.4 Long-term results of acute Achilles tendon ruptures

Only a few long-term follow-up studies after ATR have been conducted (Bevoni et al. 2014, Hohendorff et al. 2008, Horstmann et al. 2012, Rosso et al. 2013,
Rosso et al. 2015, Zwipp et al. 1989). These studies have included patients treated operatively, nonoperatively, minimally invasively, and with fibrin glue. Only Bevoni et al. (2014) had a prospectively-designed study but no control group. 66 patients included in the trial underwent identical surgical technique with functional postoperative treatment and the length of follow-up was 3 years. They found good results in terms of AOFAS and Leppilahti scores and no significant difference with respect to isokinetic strength when compared to the uninjured side. However, the study by Porter et al. (2014), operatively treated patients with almost 3 years of follow-up time, demonstrated plantar flexion deficits of the involved ankle ranging from 12–18 % for PT.

With a significantly longer follow-up, Horstman et al. (2012) found smaller ankle ROM, heel height during heel-raise tests, and calf circumference on the injured than on the contralateral side. Additionally, the total work in isokinetic testing during a plantar flexion exercise at 180°/sec was 14.9 % lower in the injured compared to the contralateral leg after 10 years. Rosso et al. (2015) compared operative and conservative treatment in their retrospective study with 7 years of follow-up and found no difference in ATRS score, muscle volume, or AT length between operatively and conservatively treated patients. The AT was 18 mm longer in the affected leg, while the PT was 13 % higher in the untreated leg (Rosso et al. 2013 and 2015). Zwipp et al. (1989) reported no strength parameters, but 90 % of the patients had excellent or good functional scores after simple end-to-end suture in 10 years of follow-up.

In conclusion, the previous studies reported in the literature have shown that ATR results in significant impairment of the leg for several years after treatment. The weakness of these previous studies is that they have very heterogenic patient populations, no randomization, and the results related to strength are conflicting.
3  **Aims of the present study**

The specific aims of this thesis were:

1. To assess changes in the epidemiology and injury mechanisms of acute ATR in the city of Oulu. The main goal was to determine whether the incidence of ATR has continued to increase since the year 2000, and to investigate changes in epidemiology of sports and non-sports related injuries over the past three decades.

2. To assess long-term functional results and calf muscle recovery in RCT, comparing early functional treatment versus cast immobilization in tension after ATR repair.

3. To compare nonoperative and operative treatment of acute ATR with similar functional postoperative rehabilitation protocols in RCT. The main points of interest were the functional result, detailed assessment of calf muscle recovery, RAND 36-item health survey scores, and the effect of patient age on the results.
4 Materials and methods

4.1 Epidemiology (I)

All closed ATRs in adult patients in the city of Oulu (Oulu University Hospital, Oulu Deaconess Institute, Terveystalo Oulu, Mehiläinen Oulu, Oulu Military Hospital) between 1.1.1979 and 31.12.2011 were included in the study. Data were collected retrospectively from patient records until 1995, and since 1996 from electronic medical records.

Demographic data, mechanism of injury, treatment method, and complications were obtained from the medical records of each patient. The data collected from years 1979–1994 and published previously (Leppilahti et al. 1996) were re-assessed. 81 % of patients received operative treatments (429 cases), including suturing with augmentation (n = 214), suturing without augmentation (n = 203), and percutaneous suture techniques (n = 12). Non-operative treatments (99 cases) included a cast (n = 53) and functional bracing (n = 46).

The total number of inhabitants and the age and sex distribution in the population of Oulu over the study period was obtained from the Statistics Finland website (Statistics Finland website, 2013).

The crude and gender specific incidences of ATRs were calculated per 100 000 person-years in Oulu inhabitants from 1979–2011. Age specific incidences were calculated using 10-year intervals. The changes in incidence were assessed in 10-year periods in each age group. Patients were also divided into two age groups, under and over 40 years, because previous data suggested that degenerative changes in the AT are more common on people older than 35 years. Additionally, incidences in non-sports and sports-related injuries were calculated.

4.2 Long-term results of early functional treatment versus cast immobilization in tension after ATR repair (II)

Study II was a long-term follow-up of a previously published RCT comparing early postoperative mobilization (group 1) with early immobilization with cast (group 2) in tension after surgical treatment of ATR (Kangas et al. 2003, 2007). The inclusion criteria were complete acute ATR and age between 18 and 60 years. The exclusion criteria were a delay of 1 week or more in treatment after the rupture, systemic corticosteroid treatment and local corticosteroid injection(s)
around the AT for 6 months before the rupture, previous ATR on the opposite side, living outside the country, and diabetes mellitus.

In total, 107 patients were screened for eligibility for the trial at Oulu University Hospital between July 1995 and July 1998. Of these, 57 patients met one or more exclusion criteria and 23 eligible patients refused to participate. The primary study group consisted of 50 patients (47 men and 3 women, mean age 36 years, range 21–55 years). The mean age at the time of injury, body mass index (BMI), and activity level (competitive athlete, recreational athlete, or nonathletic) was recorded (Table 3). All patients were treated operatively using an identical surgical technique proposed by Silfverskiöld (1941). Postoperative treatment was randomized either to early mobilization or immobilization with cast.

### Table 3. Demographic data on the Achilles Tendon Rupture patients in study II.

<table>
<thead>
<tr>
<th>Property</th>
<th>Group 1 (Early mobilization)</th>
<th>Group 2 (Cast immobilization)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men/women</td>
<td>17/2</td>
<td>17/1</td>
<td>0.59</td>
</tr>
<tr>
<td>Mean age (SD)</td>
<td>36 (9)</td>
<td>34 (7)</td>
<td>0.61</td>
</tr>
<tr>
<td>Activity level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Competitive athlete</td>
<td>4</td>
<td>1</td>
<td>0.86</td>
</tr>
<tr>
<td>Recreational athlete</td>
<td>11</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Nonathlete</td>
<td>4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>BMI (SD)</td>
<td>26 (2.8)</td>
<td>26 (4.2)</td>
<td>0.8</td>
</tr>
</tbody>
</table>

### 4.2.1 Postoperative management

The postoperative treatment was not known at the time of the operation. The patients were randomized on the first postoperative day to either early mobilization or immobilization in tension, using 25/25 randomly mixed sealed envelopes. The patients in the early motion group (group 1) received a below-knee dorsal brace (3M Soft cast®) for 6 weeks. The brace allowed active free plantar flexion of the ankle, but dorsiflexion was restricted to neutral. The patients in the immobilization group (group 2) received a below-knee plaster cast (3M Scotchcast®) with the ankle at a 90 degree angle for 6 weeks. Full weight bearing was allowed after 3 weeks in both groups. Patients in both groups were instructed to perform postoperative exercises according to a standard rehabilitation regimen (Kangas et al. 2003).
4.2.2 Outcome Measures

Forty-eight patients (96%) from the original study were contacted after minimum of 10 years of follow-up. Thirty-seven patients (19 in group 1 and 18 in group 2) were re-examined in 2008, after an average of 11 (SD 0.9) years of follow-up (Fig. 2). The primary outcome measure was the Leppilahti score (Appendix 1) at the 11-year follow-up. Secondary outcomes included the isokinetic and isometric strengths of the calf muscles. Complications and potential reoperations were also recorded. Patients visited the outpatient clinic 3, 6, and 14 months and 11 years after surgery. The clinical observers were not blinded to the postoperative treatment group.

Fig. 2. Flow chart of Early Functional Treatment versus Cast Immobilization in tension.
A physiotherapist performed all strength measurements using a computer-based isokinetic dynamometer (appendix 2). After the isokinetic tests, the maximal isometric plantar flexion strength was measured with the ankle in the neutral position. The PT, average work, and isometric strength results were measured for both legs.

The groups were compared using the unaffected ankle as a reference. The relative deficit (\((\text{unaffected} - \text{affected side}) / \text{unaffected side} \times 100\%\)) in PT, average work, and isometric strength were calculated. The injured and non-injured sides were compared using absolute values of PT and average work. The average work (measured in joules) was defined as the sum of the total area under all the torque-angular displacement (time) plots and was measured as the mean of the five best repetitions of the test. Additionally, for the 11-year control, the repetition with the highest plantar flexion PT value was selected, and work-displacement curves (−15 degrees to 35 degrees) for both calves were calculated to assess the work deficits for each 10-degree interval over the ROM of the ankle joint.

4.3 RCT comparing surgery with conservative treatment (III)

All patients with acute ATR treated at Oulu University Hospital between April 2009 and November 2013 were screened for trial eligibility. The inclusion criteria were complete acute ATR and age between 18 and 65 years. The exclusion criteria were a delay of \( \geq 1 \) week between the rupture and treatment, local corticosteroid injection(s) around the AT within 6 months before the rupture, previous surgery on the lower leg, previous ATR on the opposite side, open ATR, pregnancy, skin problems over the area of the AT, living outside the area, diabetes mellitus, or a persistent gap between the ruptured tendon ends in passive plantar flexion as assessed by US.

Two investigators examined all eligible patients and assigned them to interventions. Total ATR was diagnosed if a clear gap was palpable in the AT and the Thompson’s test was positive. A radiologist confirmed the diagnosis by US examination of the AT within 2 days after the injury. The radiologist also assessed whether the tendon ends could be reduced in passive plantar flexion of the ankle joint with the knee extended. A total of 258 patients were screened for trial eligibility; 124 patients were excluded and 74 eligible patients refused to participate. Thus, the study group comprised 60 patients, including 53 men and 7 women, with a mean age of 39.3 years (range 27–60 years) (Fig. 3).
4.3.1 Conservative Treatment

Non-surgical treatment started with a non-weight bearing full equinus cast for the first week. After 1 week, the cast was changed to an orthosis (Vacoped®). The ankle was positioned at 30° plantar flexion for weeks 2 to 3, 15° plantar flexion for weeks 4 to 5, and free movement from 0° to 30° plantar flexion for weeks 6 to 7. Full weight bearing was directed and encouraged during the orthosis immobilization. After week 7, a 1-cm heel raise was used for 1 month.
and swimming exercises were recommended at 2 months; jogging began at 3 months. Sports involving sudden acceleration and jumping were allowed after 6 months.

### 4.3.2 Surgical Treatment

Surgery was performed within 7 days of the injury. Four surgeons were involved in the operations. One surgeon operated on 29 patients and three surgeons each operated on one patient. The Krackow locking loop technique (two non-absorbable sutures and smaller apposition sutures) was used in all patients (Krackow 1986). After surgery, the patients received a full equinus cast for 1 week, without weight bearing. The postoperative treatment was identical to the conservative treatment protocol.

### 4.3.3 Outcome Measures

The primary outcome measure was the Leppilahti score at the 18-month follow-up. Secondary outcomes included calf muscle isokinetic strengths measured at 3, 6, and 18 months after the injury and the health-related quality of life (HRQoL) measured by the RAND 36-item health survey at 18 months (Aalto et al. 1999). Complications and potential re-operations were also recorded. The assessors of the outcomes were not systematically blinded to the treatment method.

Strength measurements were performed by an experienced physiotherapist and an exercise physiologist (appendix 2). Peak plantar flexion torque at an angular velocity of 60 degrees/s was recorded for each leg, based on the best repetition. Torque deficits over the ankle joint’s ROM were assessed by recording PT values at specific angles (0°, 10°, and 20°), based on five repetitions for both calves.

The effect of age on the Leppilahti score, PT, and re-rupture rate was the only pre-planned subgroup analysis.

### 4.4 Ethics (I, II, III)

The ethical committee of Oulu University Hospital approved all study protocols (I–III) and re-examination of the patients (II). All patients in study II and III received oral and written information about the trial and provided informed consent to participate.
4.5 **Statistical methods (I, II, III)**

Summary measurements are presented as means ± SDs or medians with interquartile range, unless otherwise stated. Simple between-group comparisons were analyzed by the Student t-test (continuous variables) and the chi-squared or Fisher exact test (categorical variables).

Repeated-measures data were analyzed using a linear mixed model (LMM) in which patients were set as random effects and the correlation between measurements was taken into account by testing different covariance patterns. The best pattern was chosen according to the Akaike information criteria. P-values reported as the result of LMM analyses were as follows: $P_{time}$, overall change over time; $P_{group}$, average difference between groups; and $P_{time 3 \ group}$. Two-tailed p-values and 95 % confidence intervals (CIs) are presented. A p-value < 0.05 was considered significant.

In study II, mixed sealed envelopes were used for randomization. In study III, a biostatistician generated a random allocation sequence using computer software. A randomly varying block size (4, 6, or 8) was used, each block having an equal number of surgically and conservatively treated patients. To control the possible confounding effect of age, the randomization was performed separately in two age groups ($\leq 35$ and $> 35$ years) with the ratio of 1/3 (n = 20) and 2/3 (n = 40), respectively.

The sample size (study III) was calculated using the Leppilahti score. The clinically significant difference was set at 10 points, standard deviation 10, alpha 0.05, and beta 0.10, resulting in 17 patients in each group. To compensate for an estimated dropout rate of 30 %, a total of 60 patients were to be enrolled in the study.
5 Results

5.1 Epidemiology (I)

Between 1979 and 2011, 515 patients (456 male, 59 female) experienced 528 ATRs in Oulu. The mean age at the time of rupture was 43 years (SD 13, range 19–90) for all patients; 42 years (SD 13, range 19–79) for men and 46 years (SD 15, range 23–90) for women. The ruptures were sports-related in 371 (70 %) cases and non-sports-related in 157 (30 %) cases. The sports that were most frequently associated with ruptures were badminton (113 ruptures), volleyball (70 ruptures), and football (59 ruptures), comprising 65 % of all sports-related ruptures.

The overall incidence per 100 000 person-years increased from 2.1 (95 % CI 0.3 to 7.7) in 1979 to 21.5 (95 % CI 14.6 to 30.6) in 2011. The peak annual overall incidence was 26.6/100 000 person-years in 2007 (Fig. 4). Among men, the incidence increased from 4.5 to 39.5/100 000 person-years from 1979 to 2011. Among women, the incidence rose from 0 to 4.1 from 1979 to 2011 (Fig. 4). The incidence increased in all age groups (Fig. 5). A biphasic pattern became obvious in males when the age-specific incidences were divided into sex-specific incidences (Fig. 6).
Fig. 4. The incidence of Achilles tendon ruptures from 1979 to 2011 (The time series was smoothed by calculating a 3-year moving average for each year).

Fig. 5. The age-specific incidence of Achilles tendon ruptures.
Fig. 6. Age- and sex-specific incidence of Achilles tendon ruptures.

The incidences of sport- and non-sport-related ATRs are shown in figure 7. The patients with non-sports-related ruptures were significantly older (mean age, 53.4 years) and more frequently women (50 %) compared to those with sports-related ruptures (mean age, 38.3 years, 26.9 % women; p < 0.001 for both; Fig. 8 and Fig. 9). The incidence of ATRs increased over time in all age groups, for both sports-related and non-sports-related groups (Fig. 8 and Fig. 9). In non-sports related injuries (Fig. 8), the age-specific incidence increased during both the second and third 11-year periods, particularly among individuals aged 60–69 years. In sports-related ruptures (Fig. 9), the age-specific incidence increased sharply during the second 11-year period, but it only increased slightly during the third 11-year period. The peak incidence also shifted towards a younger age group during the second 11-year period.
Fig. 7. The incidence of sport- and non-sport-related Achilles tendon ruptures.

Fig. 8. The age-specific incidence of non-sport-related Achilles tendon ruptures for each 11-year period.
5.2 Early functional treatment (group 1) versus cast immobilization (group 2) after ATR repair (II)

5.2.1 Leppilahti Score

The mean Leppilahti score was 92.9 (SD 5.6) in group 1 vs. 93.6 (SD 7.2) in group 2 ($p = 0.68$). The result in group 1 was classified as excellent for 16 (84 %) and good for 3 (16 %) patients, whereas it was excellent in 14 (78 %) and good in 4 (22 %) patients in group 2 (Fig. 10). No statistically significant difference was found between the groups in terms of pain, stiffness, subjective calf muscle weakness, footwear restrictions, ROM of the ankle joint, and subjective results. The subjective results at 11 years of follow-up were identical in both groups; 90 % were very satisfied and 10 % satisfied.
5.2.2 Isokinetic and isometric calf muscle strength

The mean isokinetic plantar flexion PT deficits or average work deficits in plantar flexion showed no differences between the groups with any angular velocity at any time point. The mean work upon plantar flexion did not differ at any of 5 angular displacements (−15 to 35 degrees) between the groups (Fig. 11).

The isokinetic muscle strength of either ankle did not change substantially between 14 months and 11 years. The mean isokinetic plantar flexion strengths showed differences of up to 5.9% in PT and differences of 8.9% in average work between the injured and non-injured side at the 11-year follow-up (p < 0.001 group, Fig. 12).

The mean isometric plantar flexion strength deficit between the injured and non-injured sides in the early motion group diminished from 15.9% to 1.7% between 14 months and 11 years, whereas this deficit in the cast group diminished from 8.5% to 3.1% in the same time interval (p_{time} = 0.001). The mean relative isometric plantar flexion deficit was 2.4% when comparing the injured vs. non-injured sides at the 11-year follow-up.

Fig. 10. Leppilahti score at follow-up: early motion versus cast immobilization in tension.
The work deficit for 10-degree intervals ranged from 4.6 % at (−15 degree to −5 degree) dorsiflexion to 14.9 % (25 degree to 35 degree) plantar flexion for the injured side at the 11-year follow-up, but the interaction between angular displacement and ankles was not statistically significant (p = 0.098, Fig. 12).

Fig. 11. The median (error bars represent the 25th and 75th percentiles) peak work in plantar flexion measured in 10 intervals at the 11-year follow-up between groups.
Fig. 12. The median (error bars represent the 25th and 75th percentiles) peak work in plantar flexion measured in 10 intervals at 11.1-year follow-up. Whole study population: operated versus healthy leg.

5.2.3 Complications / Re-operations

One deep infection and three re-ruptures occurred at a mean of 5 months (range, 3–7 months) after the primary operation. In group 1, one patient had a re-rupture and one patient had bi-lateral ATRs at 1.5 years after the primary ATR. In group 2, one patient had a re-rupture and the same patient had bi-lateral ATRs at 2 years after the primary ATR. In addition, one patient had a re-rupture plus a deep infection, required two microvascular reconstructions, and the AT was lost.

5.3 A prospective randomized trial comparing surgery and conservative treatment (III)

5.3.1 Leppilahti score

At the 18-month follow-up, the mean Leppilahti scores were 79.5 (SD 10.3) and 75.7 (SD 11.2) for surgically and conservatively treated patients, respectively.
(mean difference 3.8 points, 95% CI -1.9 to 9.5, p = 0.19). The results were excellent for 8 surgical patients (28%), good for 11 surgical patients (38%), and fair for 10 surgical patients (34%). For conservatively treated patients, scores were excellent for 4 (14%), good for 15 (55%), fair for 6 (21%), and poor for 3 (11%). The groups did not differ in terms of pain, stiffness, subjective calf muscle weakness, footwear restrictions, ankle joint ROM, or subjective results.

5.3.2 Isokinetic calf muscle strength

At the 3-month follow-up, both groups achieved similar mean PT results, but at 6 months, the advantage for surgically treated patients was 24% (mean difference 14.8 Nm, 95% CI 2.7 to 29.9, p = 0.017). The difference between the study groups decreased to 14% at 18 months follow-up; the average PT for the surgical group was 110.3 Nm vs. 96.5 Nm in the conservatively treated group (mean difference 13.6 Nm, 95% CI 2.0 to 25.1, p = 0.022) (Fig. 13).

Angle-specific PT curves at the 18-month follow-up had an almost similar shape, but surgically treated patients achieved 9.8% to 17.9% higher values throughout the ankle ROM (Fig. 14).

Fig. 13. Median peak torque values (error bars represent the 25th and 75th percentiles) for plantar flexion of the affected and healthy legs measured at 3, 6, and 18 months.
5.3.3 RAND 36-Item health survey

The RAND 36-item health survey indicated better results for surgically treated patients in the domains of physical functioning and bodily pain (Table 5).

Table 4. RAND 36-item health survey scores at the 18-month follow-up.

<table>
<thead>
<tr>
<th>Domain</th>
<th>Surgery (^1) n = 32</th>
<th>Conservative (^1) n = 28</th>
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<td>General health</td>
<td>83 (12)</td>
<td>76 (21)</td>
<td>0.12</td>
</tr>
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</tr>
<tr>
<td>Social functioning</td>
<td>95 (11)</td>
<td>94 (13)</td>
<td>&gt; 0.9</td>
</tr>
<tr>
<td>Vitality</td>
<td>78 (14)</td>
<td>78 (18)</td>
<td>&gt; 0.9</td>
</tr>
<tr>
<td>Bodily pain</td>
<td>87 (15)</td>
<td>74 (27)</td>
<td>0.037</td>
</tr>
<tr>
<td>Role functioning/physical</td>
<td>97 (11)</td>
<td>89 (26)</td>
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<tr>
<td>Role functioning/emotional</td>
<td>95 (17)</td>
<td>91 (23)</td>
<td>0.56</td>
</tr>
</tbody>
</table>

\(^1\) Values are presented as mean (standard deviation), \(^2\) Student’s t-test comparing the two groups.
5.3.4 Age

In patients $\leq$ 35 years of age, the Leppilahti scores in surgically and conservatively treated patients were 81.3 (SD 11.7) and 76.0 (SD 9.9) (mean difference 5.3 points, 95 % CI -4.4 to 14.9, $p = 0.27$) and the average PTs were 108.0 (SD 21.9) Nm vs. 99.2 (SD 19.0) Nm (mean difference 9.7 Nm, 95 % CI -8.7 to 27.9, $p = 0.29$), respectively. In patients $>$ 35 years of age, the Leppilahti scores were 78.2 (SD 9.3) and 75.6 (SD 12.1) (mean difference 2.7 points, 95 % CI -4.7 to 10.1, $p = 0.47$) and the average PTs were 111.1 (SD 23.0) vs. 94.9 (SD 26.7) (mean difference 16.2 Nm, 95 % CI -0.46 to 32.9, $p = 0.056$), respectively, in surgically and conservatively treated patients.

5.3.5 Complications

Four (14 %) re-ruptures occurred in the conservatively treated group and one (3 %) re-rupture occurred in the surgical group. In the conservatively treated group, three re-ruptures occurred during immobilization and one partial re-rupture occurred 4 months after the primary injury. One patient in the surgery group had a deep wound infection, which was treated by debridement and antibiotics. Patient age had no effect on the rate of re-rupture.
6 Discussion

6.1 General considerations

Our studies have several strengths. In the epidemiological study, we had available the comprehensive patient data from all hospitals in the Oulu area. All hospitals provided reliable patient data, and electronic patient records were available after 1996. In addition, we included the tendon ruptures with delayed diagnoses – which are rare – that were treated in our hospital. To our knowledge, this is the first study to report an increasing incidence of ATRs due to non-sports-related injuries. Studies II and III included a prospective, randomized design and homogenous groups of patients. The number of patients lost to follow-up was low. One surgeon treated almost all the patients in both studies, the same physiotherapist performed all the muscle strength measurements, and the same isokinetic dynamometer was used throughout the whole follow-up.

Our study also had some limitations. Study I was retrospective, and its demographic data were collected from routine medical records. It is possible that, during the 1970s and 1980s, patient records may not have been as comprehensive, and the operation statistics and outpatient visits may have not been as accurate, as those currently available. On the other hand, during the early years of the study, treatment was mostly operative and data about operations were comprehensively recorded.

Because of our free communal healthcare system, it is unlikely that patients with acute ATR did not seek treatment from local hospitals. Since the 1980s, the introduction of ultrasound and MRI may have improved diagnostics; however, equivalent reports of this dramatic increases in the incidence of ATR have not been published in the last decades. The diagnosis of ATR has always relied on clinical examination; better imaging techniques are unlikely to explain the rise in incidence. In addition, recent studies have shown no difference in diagnostic accuracy between clinical examination and MRI (Garras et al. 2012). Furthermore, our series may have missed some patients with ATR that temporarily lived outside our Hospital’s catchment area; however, we assumed that this would be a very small number of patients and that this omission would not significantly affect our results.
A limitation of study II and III is that the clinical observers who performed the isokinetic strength tests were not systematically blinded to the treatment modality. Many eligible patients also refused to participate in the studies.

In study II, the period between the follow-up visits was long. Therefore, we could not determine the exact time frame of isometric strength recovery. In study III, the subgroup analysis assessing the effect of age on calf muscle strength may be underpowered, so a larger number of patients is needed to confirm these results. All patients received identical rehabilitation instructions after immobilization, but we could not monitor the compliance of the patients with their exercise program.

### 6.2 Epidemiology (I)

This study showed that the incidence of ATR has increased in all age groups over the 33-year study period. We observed that the peak incidence occurred in the 30–39 year age group; in a previous study from Oulu, the peak occurred in the 40–49 year age group, which suggested that current ruptures tend to occur at a younger age. The age- and sex-specific incidences also increased, indicating a change in the epidemiology of ATRs. Sports-related injuries remained the most common etiology, but the incidence of non-sports-related ruptures has increased more rapidly than that of sports-related ruptures.

The results of this study supported results from earlier investigations, which reported increases in the incidence of ATRs in western countries. The main reason for the tremendous increase in ATRs in the late 1980s was probably the increase in the popularity of ball games in Oulu. The building of three sports halls in the city of Oulu in the late 1980s allowed middle-aged residents to take part in recreational ball games to an increased extent. The incidence of sports-related ruptures increased sharply from 1979 to 1999, but it remained nearly constant over the last 11-year period of this study. On average, 73–83 % of ATRs occur during sports that require sudden acceleration and jumping (Gwynne-Jones et al. 2011, Levi 1997, Suchak et al. 2005). About 75 % of the ATRs occur during recreational sports; 8–20 % occurred during professional sports; and about 10–12 % were non-sports-related ruptures (Leppilahti et al. 1996).

We found that the incidence of non-sports-related ruptures has particularly increased since the 1990s. In our series, non-sports-related ruptures occurred three times more frequently than previously reported (Leppilahti et al. 1996). In contrast to sports-related ruptures, the incidence of non-sports-related ruptures has
increased steadily, even during last 11-year period of our study. Previous studies have reported that most patients with low energy ruptures exhibited degenerative changes in the AT (Kannus & Jozsa, 1991). The basic etiology of these changes is known to be multi-factorial (Järvinen et al. 2005), but aging is considered a strong factor. Therefore, the reason for the increase in the age-specific incidence of non-sports-related ruptures over time is unclear. Non-traumatic ATRs, sometimes bilateral, can be caused by some medications, including fluoroquinolone and systemic steroids. However, the use of these medications is unlikely to have increased in our population over the studied time period. Some investigations have suggested that statins, given to treat hypercholesterolemia, might have some effect on tendons. (Beri et al. 2009, Marie et al. 2008) In animal models, a decreased biomechanical strength of the AT has been reported with statin use (de Oliveira 2015), but this association is controversial, and a potential biological mechanism is unclear. Nevertheless, the use of statins has grown rapidly over the last 15 years: about 15 % of the Finland’s population now uses statins. The use of pronation-support shoes and insoles has also increased significantly over the last two decades. These could have an effect on hindfoot alignment, which is reported to be a factor in developing AT disorders (Waldecker et al. 2012).

6.3 Early functional treatment versus cast immobilization in tension after ATR repair (II)

Our results show that early mobilization and immobilization after surgical treatment of ATR results in similar clinical outcomes and isokinetic strengths after 11 years of follow-up. We also found that isokinetic strength changed minimally between 1 and 11 years, compared to the unaffected ankle, with a mean deficit of 5 % in PT and a mean deficit of 8 % in average work still present after 11 years. On the contrary, isometric plantar flexion strength recovered significantly and only a 2 % difference was noted after 11 years of follow-up. The shape of the work-displacement curves in the affected and unaffected ankle was almost identical, but a deficit of about 10 % was present in the operated ankle over the whole ROM at the 11-year follow-up.

Our study confirms the results of earlier studies with short-term follow-ups, showing that the post-operative treatment protocol after AT repair does not affect the long-term clinical outcome or isokinetic calf muscle strength (Barfod et al. 2014, Kangas et al. 2003, Young et al. 2014). Early functional treatment with

We found that isokinetic strength changed minimally after 1 year, whereas isometric strength recovered even 1 year later, and only a minimal deficit remained at the last follow-up. A previous study using isometric strength as the outcome reported up to 14.9 % deficits in men and 20.1 % deficits in women after three years of follow-up (Leppilahti et al. 1996). Mullaney et al. (2006) reported 34 % and 20 % deficits at 20 degrees and 10 degrees of plantar flexion, respectively, but only 6 % deficit at neutral flexion, at an average of 1.8 years postoperatively. Pajala et al. (2009) reported a mean 10 % deficit in relative isometric strength for the simple repair group and 2 % for the augmented repair group at the 12-month follow-up. Therefore, isometric calf muscle strength may take several years to recover. Different time frames for isokinetic and isometric strength recovery should be considered when planning further ATR studies.

Furthermore, rehabilitation protocols after ATR should probably be sufficiently aggressive during the first year after ATR to minimize strength deficits. Several previous short-term to midterm studies of mixed operative techniques and conservative treatment have shown 11 % to 17 % plantar flexion strength deficits between the injured and uninjured ankles after ATR (Bevoni et al. 2014, Leppilahti et al. 2000, Pajala et al. 2009, Rosso et al. 2013, Young et al. 2014). Horstmann et al. (2012) reported on long-term results of AT repair and found plantar flexion strength 6 % lower than in the uninjured leg. Our study showed that 5 % to 8 % deficits in isokinetic strength are still present after 11 years, despite good functional scores. However, the work-displacement curves may represent isolated calf muscle strength better than PT or average work, and showed deficits of up to 15 % at 25 degrees to 35 degrees plantar flexion for the injured leg. Although ordinary patients may not notice a strength deficit of up to 15 % in plantar flexion, it may cause notable impairment for elite athletes. The perceptual deficit that causes clinically significant impairment is not known and further studies are needed.
6.4 RCT comparing surgery and conservative treatment in acute ATRs (III)

Our results support those of earlier studies reporting that surgical and conservative treatment of acute Achilles tendon ruptures results in similar Achilles tendon performance scores. Surgery, however, leads to faster and better recovery of isokinetic calf muscle strength. Surgically treated patients resulted up to 24% higher results both in peak torque and angle-specific peak torque at 6 months. At 18 months follow-up, the strength difference still favored surgically treated patients, up to 14% in peak torque and 18% in angle specific peak torque. Both techniques failed to restore muscle strength to that of the contralateral side. Patient age failed to have any effect on the clinical scores, calf muscle strength, or re-rupture rate between the treatment methods. The RAND 36-item health survey indicated better results in the domains of physical functioning and bodily pain for surgically treated patients, suggesting that surgery may result in better HRQoL than conservative treatment.

In terms of Achilles tendon performance scores, our results were similar to previous RCTs summarized in systematic reviews and meta-analyses (Holm et al. 2014, Olsson et al. 2013, Soroceanu et al. 2012). However, our re-rupture rate after conservative treatment was higher than in some previous reports. Although not statistically significant due to small number of patients, re-rupture rate in our accelerated functional treatment is probably higher than in surgical treatment. A larger study comparing accelerated rehabilitation with conventional conservative treatment is needed to confirm our results. Nevertheless, in our study re-ruptures were associated with noncompliance; they occurred when the Vacoped® orthosis was off or with proper dorsiflexion injury Vacoped® orthosis on during rehabilitation protocol. A recent meta-analysis suggested equal re-rupture rates for surgical and non-surgical patients (risk difference 1.7%) if functional rehabilitation with early range of motion is performed (Soroceanu et al. 2012). Also van der Eng et al. found no difference in the re-rupture rate or strength differences between the surgically and conservatively treated patients followed by early weight bearing in their meta-analysis (van der Eng et al. 2013)

The recovery of calf muscle strength after surgical and conservative treatment has been controversial in previous studies (Keating et al. 2011, Nilsson-Helander 2010). Several recent studies showed differences favoring surgical treatment at least in short term (Keating et al. 2011, Nilsson-Helander 2010, Olsson 2013). Our study supports these findings and showed up to 24% and 18% difference.
favoring operative treatment at 6 and 18 months, respectively. The clinical relevance for isokinetic strength and patient satisfaction has not been studied in the ankle joint, but isokinetic peak torque has shown good correlation to calf muscle volume (Rosso et al. 2013). Mullaney et al. found that surgically treated patients with isometric plantar flexion strength deficits up to 34% and 20% (at 20 degrees and 10 degrees of plantar flexion, respectively), were unable to perform a decline heel rise, whereas no torque deficits from neutral to dorsiflexion of ankle joints’ range of motion were detected (Mullaney et al. 2006). Despite up to 65% plantar flexion strength deficit at 18 months, patients in our study noticed the strength impairment but it did not affect their recreational activities at 18 months. None of our patients were competitive athlete, which probably explains the high satisfaction rate despite major calf muscle strength impairment. Also Nilsson-Helander et al. (2010) found in their study that objective and subjective results do not always correlate with each other. Nilsson-Helander et al. (2010) stated that these results underscore the importance of using objective strength tests for evaluating outcome as in the present study (Nilsson-Helander 2010).

Optimal rehabilitation protocol in conservative treatment or after surgical repair of acute Achilles tendon rupture remains controversial. Early motion may encourage tendon healing and reorganization of collagen and therefore may be critical for functional rehabilitation. Compared to previous studies with early plantar flexion or early weight bearing, we allowed both early motion and weight bearing (Nilsson-Helander 2010, Olsson 2013, Willits 2010). In contrast to our results, these previous studies reported similar calf muscle strength after conservative treatment and surgery.

Several risk factors, including tendon elongation, have been proposed as the reason for long-term strength deficits (Kangas 2007, Mullaney 2006, Nilsson-Helander 2010). Only Schepull et al. studied tendon elongation between non-operative and surgical treatment, finding that tendon elongation occurred during the first 19 weeks, but they found no difference between surgical and non-surgical treatment (Schepull 2013). It is possible that our expedited rehabilitation protocol that allows early plantar flexion and full weight bearing during orthosis treatment may result in Achilles tendon lengthening and therefore greater strength deficit in conservative treatment. Surgery, however, may protect from tendon lengthening during accelerated rehabilitation and restores calf muscle strength to best possible level after the injury.
Choosing the optimal treatment for the patient with Achilles tendon rupture the decision should be made individually observing patient needs and treatment risks. Despite the treatment method major calf muscle strength deficit persist and therefore, rehabilitation after the conservative or operative treatment may be the most important phase that should be underlined in future studies.

Patient age had no effect on subjective or objective results when comparing treatment methods in patients aged \( \leq 35 \) and \( >35 \) years at the 18-month follow-up. Our results suggest that patients with Achilles tendon rupture do not necessarily need surgery. However, surgical repair may result in better calf muscle strength, that should be considered when treating physically active and demanding patients.

Olsson et al. studied quality of life between conservatively and surgically treated patients using the EQ-5D life quality and Foot and Ankle Outcome Score (FAOS) questionnaires (Olsson 2013). They found no difference between the study groups during 12 months of follow-up. In contrast, we found that surgically treated patients achieved better results in the domains of physical functioning and bodily pain at 18 months. The RAND 36, which produces a profile of functional health and well-being, may be more sensitive than the EQ-5D in capturing impairments after Achilles tendon rupture.

### 6.5 Clinical implications and future studies

In conclusion, our study results suggest that conservative treatment with a functional rehabilitation protocol for Achilles tendon ruptures results in acceptable results. Surgery and non-operative treatment of acute Achilles tendon rupture have similar results in terms of Achilles tendon performance score, but surgery restores calf muscle strength earlier over the entire range of motion of the ankle joint, with 14–18 % strength difference favoring surgery at 18-months, that should be considered when treating physically active and demanding patients. Surgery may also result in better health-related quality of life in the domains of physical functioning and bodily pain compared to conservative treatment.

Because nonoperative treatment has largely replaced surgery in ATR, further studies should address how more aggressive rehabilitation under physiotherapist instruction during the first 6 months might prevent a strength deficit and whether intensive rehabilitation in the healing period leads to increased tendon elongation. Also clinical importance of strength deficit of ankle joint needs to be clarified.

The reason for the increasing incidence of ruptures, particularly in non-sports related injuries, remains unclear. A registry-based study with a large number of
patients might provide sufficient data to compare subgroups, like men vs. women, and the possible effects of a sedentary lifestyle and concomitant medications. Histological and biochemical studies focused on tendon degeneration mechanisms might also elucidate the reasons for the increasing incidence.
7 Conclusion

1. The incidence of Achilles tendon ruptures (ATRs) has increased significantly in the city of Oulu during the whole time period (1979–2011) encompassed by these studies. At least part of this increase can be explained by a growing interest in recreational sports. The incidence in non-sports-related ruptures has also increased steadily during whole period, but the incidence in sport-related ruptures increased mostly during the second decade of study period.

2. Early functional treatment after operative repair of an ATR gives no significant advantage when compared to immobilization in tension, as seen after an 11-year follow-up. The calf muscle isokinetic strength recovers during the first year after the injury, and minimal changes occur thereafter. About 5% to 8% of the isokinetic strength deficits remain between the ankles, but the clinical significance of this difference in strength remains unknown. Isometric strength recovers even after the first year, and only minimal differences remain after long-term follow-up.

3. Nonoperative and operative treatment yields similar results in the Achilles tendon performance score. Surgery, however, leads to faster and better recovery of isokinetic calf muscle strength. The RAND 36-item health survey also indicated better results in the domains of physical functioning and bodily pain for surgically treated patients. Patient age has no effect on the performance scores, strength recovery, or the RAND-36-item health survey results.
References

Aalto AM, Aro AR, Teperi J - 1999 - thl.fi


Appendices

Appendix 1  Leppilahti Score ................................................................. 78
Appendix 2  Strength measurements.................................................. 82
Appendix 1  Leppilahti Score

Pain (15 points)

None 15
Mild, no limitations on recreational activities 10
Moderate, limitations on recreational but not daily activities 5
Severe, limitations on recreational and daily activities 0

Stiffness (15 points)

None 15
Mild, occasional, no limitations on recreational activities 10
Moderate, limitations on recreational but not daily activities 5
Severe, limitations on recreational and daily activities 0

Subjective calf muscle weakness (15 points)

None 15
Mild, no limitations on recreational activities 10
Moderate, limitations on recreational but not daily activities 5
Severe, limitations on recreational and daily activities 0

Footwear restrictions (10 points)

None 10
Mild, most shoes tolerated 5
Moderate, unable to tolerate fashionable shoes, modified shoes tolerated 0

Active range-of-motion difference between ankles (15 points)

Normal (5 deg) 15
Mild (6–10 deg) 10
Moderate (11–15 deg) 5
Severe (16 deg) 0
**Subjective result (15 points)**

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**Isokinetic muscle strength score (15 points)**

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**Maximum possible total** 100

At least 90 points excellent, 75–89 points good, 60–74 points fair and 60 points poor.
Isokinetic Ankle Strength Scale for Scoring

Plantar Flexion and Dorsiflexion Peak Torques of the Ankle at Three Test Speeds (60, 120, and 180 deg/s)

Plantar flexion peak torque 60 deg/s percentage difference (uninjured-injured) (17 points)

- \( \leq 2 \% \) 17
- \( > 2 \leq 5 \% \) 15
- \( > 5 \leq 10 \% \) 13
- \( > 10 \leq 25 \% \) 9
- \( > 25 \leq 50 \% \) 5
- \( > 50 \%) \) 0

Dorsiflexion peak torque 60 deg/s percentage difference (17 points)

- \( \leq 2 \% \) 17
- \( > 2 \leq 5 \% \) 15
- \( > 5 \leq 10 \% \) 13
- \( > 10 \leq 25 \% \) 9
- \( > 25 \leq 50 \% \) 5
- \( > 50 \%) \) 0

Plantar flexion peak torque 120 deg/s percentage difference (17 points)

- \( \leq 2 \% \) 17
- \( > 2 \leq 5 \% \) 15
- \( > 5 \leq 10 \% \) 13
- \( > 10 \leq 25 \% \) 9
- \( > 25 \leq 50 \% \) 5
- \( > 50 \%) \) 0
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<th>Dorsiflexion Peak Torque 180 deg/s</th>
<th>17 Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 2 %</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>&gt; 2 ≤ 5 %</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>&gt; 5 ≤ 10 %</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>&gt; 10 ≤ 25 %</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>&gt; 25 ≤ 50 %</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>&gt; 50 %</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Maximum possible total 102
Appendix 2  Strength measurements

Strength measurements study II

The isokinetic and isometric strength of both ankles were assessed 3, 6, and 14 months and 11 years after surgery. A physiotherapist performed all strength measurements using a computer-based isokinetic dynamometer (Lido Multi-Joint 2, Loredan Biomedical, Inc., West Sacramento, CA). Patients were informed of the measurement procedure. A 10-minute warm-up period of ergometer cycling was included before the test. The test was performed with the patient in the supine position, and the patient was fixed to the testing apparatus with straps around the foot and pelvis, with the knee supported in extension. The extent of ankle motion was from 15 degrees of dorsiflexion to 35 degrees of plantar flexion. Before testing, the patient performed a few submaximal and maximal repetitions of the ankle flexion and extension movements at the isokinetic test velocity. The isokinetic plantar flexion strengths were measured; first at a speed of 60 degrees/s, then at 120 degrees/s, and finally at 180 degrees/s after 2 minutes of rest. Five maximal voluntary muscular torque contractions were required. After the isokinetic tests, the maximal isometric plantar flexion strength was measured with the ankle in the neutral position. The peak torque, average work and isometric strength results were measured for both legs.

The groups were compared using the unaffected ankle as a reference. The relative deficit ([unaffected – affected side]/ unaffected side x 100 %) in peak torque, average work, and isometric strength was calculated. The injured and non-injured sides were compared using absolute values of peak torque and average work. Average work (measured in joules) was defined as the sum of the total area under all of the torque-angular displacement (time) plots and was measured as the mean of the 5 best repetitions of the test. Additionally, for the 11-year control, the repetition with the highest plantar flexion peak torque value was selected and work-displacement curves (~15 degrees to 35 degrees) for both calves were calculated to assess the work deficits for each 10-degree interval over the range-of-motion of the ankle joint.
An experienced physiotherapist and an exercise physiologist performed strength measurements using a computer-based isokinetic dynamometer (Con-Trex biomechanical test and training system, CMV AG Duebendorf, Switzerland). The patients were informed of the measurement procedure before testing. Ergometer cycling was performed during a 10-minute warm-up period with a few submaximal and maximal repetitions of ankle flexion and extension movements at the isokinetic test velocity. During testing, the patient was in the supine position with the knee supported in extension. The extent of ankle motion was from 15° dorsiflexion to 35° plantar flexion. The isokinetic plantar flexion strengths of both ankles were measured at speeds of 60, 120, and 180 degrees/s. Five maximal voluntary muscular torque contractions were required.

Peak plantar flexion torque at an angular velocity of 60 degrees/s was recorded for each leg based on the best repetition. To assess angle specific peak torque deficits over the ankle joint’s range of motion, peak torque values at specific angles (0°, 10°, and 20°) were recorded based on the five repetitions for both calves. Intraclass correlation for angle specific peak torque was high (0.81–0.9 ICC).
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