Jonas Grønli
Mikkel Holt
Even Lindaas

Risk Factors for Achilles Tendon Overuse Injuries in Runners

Bachelor's thesis in Human Movement Science
Supervisor: Karin Roeleveld
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Abstract

Purpose**:* Multiple studies have investigated Achilles tendon overuse injuries and how they work, but questions are yet to be answered regarding how and why they develop. We wanted to investigate the strength of evidence regarding intrinsic and extrinsic risk factors linked to Achilles tendon overuse injuries for running athletes. ***Research methods**:* A literature search was conducted in SPORTDiscus and PubMed to identify risk factors for Achilles tendon overuse injuries. Eight relevant articles were included in the analysis as main articles and ten for the use as support literature. ***Results: Significant results showing an increased risk factor were age; running experience; weekly running distance; training pace; soft surface; previous ATOI; pronation max; breaking force; lateral force; vertical force. Decreased risk; high competition pace; plantar and dorsal torque; arch index; propulsive force. ***Conclusion:*** Main findings of this review: reoccurring ATOIs looks to be the only variable with clear effect. Training load, pace and soft surface also seem to have a negative effect, but more research is needed. Several other risk factors may also be linked to ATOIs in running athletes, yet many of their effects remain ambiguous.

Hensikt: Flere studier har undersøkt overbelastningsskader knyttet til akillessenen og deres natur, men det er fortsatt uklart hvordan og hvorfor slike belastningsskader oppstår. Vi ønsket å undersøke indre og ytre risikofaktorer knyttet til akillesskader hos løpere. **Metode:** Et systematisk litteratursøk i SPORTDiscus og PubMed ble gjennomført for å finne artikler knyttet til akillesskader. Åtte artikler ble inkludert i analysen som originalartikler. **Resultat:** Signifikante risikofaktorer som ga økt risiko for skade var: Alder, erfaring, løpt distanse per uke, løpshastighet på trening, løping på mykt underlag, tidligere akillesskader, maksimal pronasjon, bremsekraft, lateral kraft, vertikal kraft. Signifikante risikofaktorer som ga redusert risiko: Høy konkurransefart, plantar-/dorsalt dreiemoment, fotbueindeks, fremdriftskraft. **Konklusjon:** Hovedfunn i studiet; tidligere akillesskader ser ut til å være den eneste variabelen med klar effekt. Treningsbelastning, fart og mykt underlag ser også ut til å ha en negativ effekt, men mer forskning trengs. Flere andre risikofaktorer kunne også knyttes til akillesskader i løpere, men mange av effektene deres er tvetydige.

Key words: Achilles, Running; Injury; Tendinopathy

1. Introduction

There has been an increase in the occurrence of Achilles tendon (AT) overuse injuries, particularly in different areas of sports (1). An escalation in sporting activities over the past few decades has contributed to a notable increase in both the frequency and occurrence of Achilles tendon overuse injuries (ATOIs) and complete ruptures (1). ATOIs are most common in sports associated with running and jumping (1). The annual incidence of ATOIs in elite level runners was reported at approximately 7-9% (1). Lower-limb injuries are frequently encountered in running athletes, with chronic ATOIs standing out as particularly prevalent and severe in terms of their impact on training and racing time (2).

Several different terms are used regarding ATOIs, such as Achilles Tendinopathy, Tendinitis and Tendinosis. While tendinopathy is a wide term related to tendon injuries, even including complete rupture, the two other terms are more specific. *Tendinitis* involves inflammation, following micro-tears (3). The tears are acute deformations in the tendon, but tendinitis is still considered an overuse injury. This is because a tendon should be able to sustain a larger force then the muscle itself. When an acute damage to the tendon occurs, it is likely that a deformation or weakening of the tendon had appeared prior to the tear. *Tendinosis* could be the reason for such weakening of the tendon. Tendinosis is a response to chronic overuse, and it involves degeneration in the tendon's collagen (3). These degenerations in the collagen fibers affects the tendon's maximal loadbearing, weakening the tendon (3). There are different theories to which of the two that usually occurs first, but we do know that development of one of the two is related to development of the other (3).

ATOIs are frustrating for athletes, as they tend to have a long recovery time and high tendency for reoccurrence (4). ATOIs manifest in two primary locations within the AT: the mid-portion, where the cross-sectional area is smallest, and the insertion point onto the calcaneus (5). The mid-portion of the AT is a critical site where collagen fibers from the soleus, medial gastrocnemius, and lateral gastrocnemius converge (6). This region experiences substantial stress during running and other weight-bearing activities, making it prone to overuse injuries such as tendinopathies (1). Achilles tendinopathy is the most common running-associated tendinopathy, with an injury rate per 1000km of 0.0159. Mid-portion tendinopathy was twice as common as insertional tendinopathy (7).

Understanding the functional anatomy of the AT is crucial in understanding the aspects of risk factors leading to tendinopathy. The AT is the strongest and thickest tendon in the human body and connects the triceps surae (m. gastrocnemius and m. soleus) to the calcaneus (1,6). The AT originates at the middle of the calf merging with the gastrocnemius proximally and is connected to the soleus almost to its lower end and insertion on the calcaneus (6). The gastrocnemius is a fusiform, two-headed muscle, located superficially on the dorsal part of the lower leg. Both heads cross the knee joint (6). The medial head of the gastrocnemius originates from the popliteal surface of the femur. The lateral head originates from the lateral femoral condyle (6). The soleus is located deep to the gastrocnemius and originates from the tibia, a fibrous arch between the tibia and the fibula, and from the fibula itself (6). As opposed to the gastrocnemius muscle, the soleus does not cross the knee joint, meaning it only acts on the ankle joint (6).

Numerous extrinsic and intrinsic risk factors have been identified concerning running related ATOIs. Intrinsic factors refer to characteristics inherent to the athlete, such as anthropometric and biomechanical aspects, while extrinsic factors refer to external influences, such as equipment and training variables. Intrinsic factors include a range of biomechanical considerations, such as foot structure, gait mechanics, tendon properties, muscle strength and flexibility. Variations in these individual characteristics can impact the load distribution and stress placed on the AT during running, potentially predisposing athletes to injury. For instance, abnormalities in foot alignment or muscle imbalances may increase strain on the AT, leading to overuse injuries. Extrinsic factors, on the other hand, involve environmental or external elements that can contribute to ATOIs. These may include factors such as footwear characteristics, training intensity, terrain surfaces, and coaching techniques. Improper footwear, inadequate training progression, and running volume without adequate recovery are examples of extrinsic factors that can heighten the risk of ATOIs by subjecting the tendon to excessive or repetitive stress.

1.1 Objective

The objective of this review was to synthesize existing evidence and assess the strength of intrinsic and extrinsic risk factors associated with the development of ATOIs in running athletes. Specifically, we aimed to identify factors that showed a significant occurrence in individuals with ATOIs. The review sought to highlight key factors that may contribute to the onset or development of these injuries in running athletes. Additionally, the review aimed to identify areas where further research is needed to improve our understanding of ATOI mechanisms.

2. Methods

2.1 Search strategy, parameters, and criteria

The review was conducted according to the preferred reporting items for systematic reviews (PRISMA) guidelines (8). The search strategy aimed to identify studies that accurately reported different risk factors for ATOIs. A search was made in the databases of SPORTDiscus and PubMed with Boolean operators ("AND", "OR", "NOT") connecting the terms linked to the Achilles tendon injuries. The search was completed using the following keyword strings: *("Achilles" OR "Achilles tendon") AND ("Injury" OR "Tendinopathy" OR "Tendonitis") AND ("Running" OR "Runners") AND ("Risk Factors").* A total of 125 articles were identified of which 21 were duplicates. Based on the title and abstract, 77 articles were excluded. The exclusion criteria were: Not injury-related; Not Achilles-related; No runners; Animals; Surgery; Rehabilitation; Prevention; Rupture; Few participants; Change of direction in abstract. Articles that had a lack of findings/evidence, as well as reviews and articles where the full text was unavailable were removed in the full text selection. 8 main articles were left for inclusion in the final review. We have also included the use of support litterature to help us with converting and illustrating results, as well as to provide further explanation of various aspects. The support litterature was found through the original search and the use of PubMed and Google Scholar.

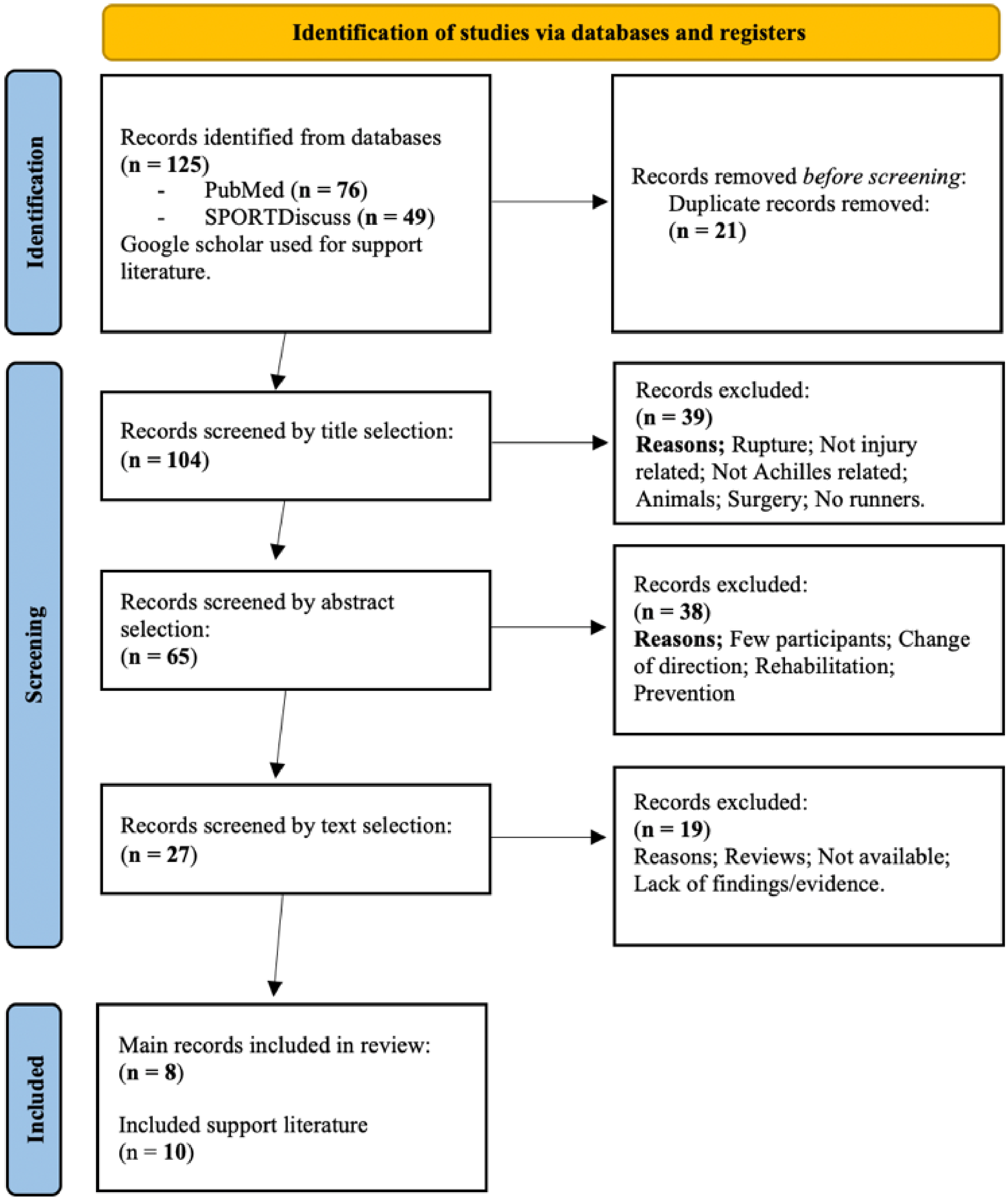

Figure 1: PRISMA flow-chart of the systematic review.

2.2 Analysis and interpretation

ORs/means and percentages were converted to effect size (ES) by using converters from Campbell Collaboration (9) and Psychometrica (10). ESs with 95 % confidence limits were calculated from means and standard deviations. All results are summarized as ESs in the results. Factors that were assessed in more than one study were averaged. If more than two studies were used, the number of studies is given as ‘n’ in brackets. Microsoft Excel was used to make tables and charts to sort and present the results. The most prominent and important values were presented in table 2. A negative ES indicates that increasing the variable of interest may be detrimental to an athlete in terms of ATOIs, while a positive ES indicates that the variable may be protective. An ES smaller than ±0.2 was considered nonsignificant, ±0.2–0.6 was considered small, ±0.6–1.0 moderate, ±1.0–2.0 large, and greater than ±2.0 very large.

3. Results

In total, 60 different risk factors were identified from the main articles. 25 risk factors were eliminated from further analysis, as they were deemed irrelevant to our aim, and/or non-significant, or if results could not be converted into ES. Of the remaining 35 risk factors, 13 were reported in two or more main articles. When averaged, six risk factors showed a very strong significance (3 increased risk, 3 protective), seven risk factors showed a strong significance (3 increased risk, 4 protective) and eight risk factors showed a moderate significance (4 increased risk, 4 protective). The remaining 14 risk factors showed a small significance or no significance at all (9 increased risk, 5 protective). Table 1 presents an overview of the findings and main descriptives of our main articles. All risk factors are presented in Table 2 with average ES and 95% CI.

Table 1: Summary of the eight main articles, with short descriptions of study design, population, and the most important findings. Anthropometric/biomechanical results are not included in this, as they were only reported in one article each. They could be found in Table 2. Main articles are given roman numerals for reference in the text.

Article	Study design	n	Age	% male	Population	Main findings (ES with 95% CI)
McCrory et.al (I)	Cross-sectional case-control - participants were divided into control group (non-injured), and injured group. Two screening sessions were completed. In the first, a questionnaire regarding running history and anthropometric and isokinetic strength measurements were collected. In the second session, rearfoot motion and kinetic analysis were done.	89	34,5 ± 1,2 (CG) 38,4 ± 1,8 (IG)	n/a	Recreational and competitive running athletes, 31 of whom had a history of Achilles Tendinitis.	Age (ES = -2,71 ± 0,59), Running Experience (ES = -2,149 ± 0,538), Weekly Running Distance (ES = -1,835 ± 0,513), Training Pace (ES = -3,125 ± 0,63), Competition Pace (ES = 2,644 ± 0,58)
Reule et.al (II)	Cross-sectional case-control study - participants answered a questionnaire on anthopometry, injury history and running performance. Following this, the STA of both feet were measured, using an ultrasonic pulse-echo-based measurement system.	307	39 ± 17	71,0	Long-distance running athletes, 95 of whom had a history of ATOIs.	Age (ES = -0,67 ± 0,25), Weight (ES = -0,29 ± 0,24), Weekly Running Distance (-0,62 ± 0,25)
Wezenbeek et.al (III)	Prospective cohort study - baseline measurements were made both before and after physical activity. A questionnaire was also answered. Injury status was registered regularly over the two following years, as well as weekly sports participation and time at risk.	250	18 ± 0,8	45,2	First-year students at Ghent University with no history of ATOIs.	Weight (ES = 0,35 ± 0,40), BMI (ES = 0,28 ± 0,40)
Lagas et.al (IV)	Prospective cohort study - participants completed four questionnaires. The first one at baseline (time of registration for running event), asked questions related to demographics, training habits, lifestyle, RRI history for the last 12 months and current RRI status. The rest were completed two weeks prior to the running event, one day, and one month after the running event. The follow-up questionnaires focused on the RRI status.	1929	41,9 ± 12,1	52,9	Running athletes recruited through registration for different running events in Netherlands (5-42km).	Sex (male) (ES = -0,18 ±0,27), Age (ES = -0,27 ± 0,20), BMI (ES = -0,07 ± 0,20), Running Experience (ES = 0 ± 0,01), Weekly Running Distance (ES = 0 ± 0,01), Running on Hard Surface (ES = 0,15 ± 0,30), 5k (ES = -0,09 ± 0,59), 10k (ES = 0,22 ± 0,24), Half-marathon (ES = 0,03 ± 0,27), Marathon (ES = -0,17 ± 0,08), ATOIs in previous 12 months (ES = -1,01 ± 0,26)
Chen et.al (V)	Prospective cohort study - participants completed four questionnaires. The first one at baseline (time of registration for running event), concerning demographics, training, registered running events and previous/current RRI. The rest were done one month prior, one week prior and one month after the running event, registering information on new-onset injuries.	3379	43.1 ± 12.2	63,1	Running athletes recruited through registration for different running events in Netherlands (10-42km), who responded to at least one follow-up or ad hoc questionnaire.	Sex (male) (ES = -0,36 ± 0,22), Age (ES = -0,08 ± 0,17), Weight (ES = -0,10 ± 0,17), Running Experience (ES = -0,01 ± 0,01), Running on Hard Surface (ES = 0,10 ± 0,22), 10k (ES = 0,38 ± 0,24), Half-marathon (ES = 0,25 ± 0,30), Marathon (ES = -0,35 ±0,31), ATOIs in the previous 12 months (ES = -1,05 ± 0,22)
Mahieu et.al (VI)	Prospective cohort study - Participants answered a questionnaire and underwent a physical screening at baseline. The questionnaire asked questions about training habits, medical and injury history of the past two years. All participants went through six weeks of basic millitary training, during which ATOI were registered continously.	69	18,0 ± 1,5	100	Male officer cadets from the Belgian Royal Military Academy.	Weight (ES = -0,17 ± 0,67), BMI (ES = -0,60 ± 0,68)
Skypala et.al (VII)	Prospective cohort study - A group of healthy runners were followed for one year. A questionnaire and baseline measurements were made. The participants reported injury status weekly, and new measurements were done at the end of the one year period.	103	36,89 ± 8,45 (CG) 35,45 ± 8,86 (IG)	44,6	Recreational, low-volume running athletes (< 51 km/week), recruited through advertising in social media.	Age (ES = 0,17 ± 0,45), BMI (ES = 0,23 ± 0,44), Training pace (ES = -0,37 ± 0,44),
Knobloch et.al (VIII)	Retrospective survey - Participants answered a questionnaire about injuries and training habits.	291	42 ± 9	85,2	Master running athletes who responded to a questionnaire in a German running newsletter.	Weight (ES = 0,10 ± 0,44), Running on hard surface (ES = 0,41 ± 0,35), Running on soft surface (ES = -1,27 ± 1,22), 1500-3000m (ES = -0,51 ± 0,46), 5k (ES = -0,32 ± 0,02)

n= number of participants, ES = Effect Size, CI = Confidence Interval, CG = Control Group, IG = Injured Group, STA = SubTalar joint Axis, ATOI = Achilles Tendon Overuse Injury, BMI = Body Mass Index, RRI = Running-Related Injuries

Table 2: Risk factors with average ES with 95% CI. The articles that have been used to collect results are displayed with roman numerals accordingly to Table 1.

Demographics	**ES (95%CI)**	**n**	**Articles**
Sex (male)	-0,27 ± 0,25	2	*IV, V*
Age (years) *	-0,71 ± 0,33	5	*I, II, IV, V, VII*
Weight (+)	-0,02 ± 0,39	5	*II, III, V, VI, VII*
BMI (+)	-0,04 ± 0,43	4	*III, IV, VI, VII*
Training/competition			
Running experience (+) *	-0,72 ± 0,19	3	*I, IV, V*
Running distace per week (+) *	-0,82 ± 0,26	3	*I, II, IV*
Training pace (+) **	-1,75 ± 0,54	2	*I, VII*
Competition pace (+) ***	2,64 ± 0,0,58	1	*I*
Running on hard surface (+)	0,22 ± 0,29	3	*IV, V, VIII*
Running on soft surface (+) **	-1,27 ± 1,22	1	*VIII*
1500 - 3000 meters	-0,51 ± 0,46	1	*VIII*
5 kilometers	-0,21 ± 0,31	2	*IV, VIII*
10 kilometers	0,30 ± 0,24	2	*IV, V*
Half marathon	0,14 ± 0,28	2	*IV, V*
Marathon	-0,26 ± 0,20	2	*IV, V*
ATOIs in the previous 12 months (yes) **	-1,03 ± 0,24	2	*IV, V*
Anthropometrics/Biomechanics			
Passive DF ROM (+)	0,41 ± 0,44	1	*I*
Passive PF ROM (+) **	1,82 ± 0,51	1	*I*
DF torque @180 deg/s (+) **	1,83 ± 0,51	1	*I*
PF torque @180 deg/s (+) ***	2,57 ± 0,58	1	*I*
PF torque @30 deg/s Right foot (+) *	0,78 ± 0,45	1	*VI*
PF Torque @30 deg/s Left foot (+) *	0,77 ± 0,45	1	*VI*
Arch index (+) ***	3,37 ± 0,66	1	*I*
Pronation ROM (+)	-0,37 ± 0,44	1	*I*
Pronation max (+) *	-0,76 ± 0,45	1	*I*
Time to pronation max (+) **	1,72 ± 0,50	1	*I*
EV ROM (+)	-0,45 ± 0,16	1	*I*
EV max (+) *	0,96 ± 0,46	1	*I*
Time to EV max (+) **	1,54 ± 0,49	1	*I*
Peak vertical force (+)***	-3,72 ± 0,65	1	*I*
Max propulsive force (+) *	0,87 ± 0,45	1	*I*
Max braking force (+) ***	-2,86 ± 0,61	1	*I*
Max medial force (+)	0,11 ± 0,44	1	*I*
Max lateral force (+) ***	-3,34 ± 0,66	1	*I*
Max knee flexion (+)	-0,49 ± 0,45	1	*VII*

ES = Effect Size, CI = Confidence Interval, n = number of articles, BMI = Body Mass Index, ATOI = Achilles Tendon Overuse Injuries, DF = Dorsiflexion, ROM = Range Of Motion, PF = Plantar Flexion, EV = Evertion, (+) = increased

* = moderate significance (ES = ± 0.6-1.0), ** = strong significance (ES = ±1.0-2.0), *** = very strong significance (>±2.0)

4. Discussion

35 different risk factors have been identified in relation to ATOIs. 6 risk factors were identified as largely significant risk factors for developing ATOIs, while 7 were identified as largely significant protective factors for developing ATOIs. Several other factors showed small and moderately significant risk for developing or protecting from ATOIs. Risk factors were divided into three different main categories; Demographic, training- and competition related, and anthropometric- and biomechanical risk factors.

4.1 Demographics

Male sex was reported to have a small, but significant correlation with increased risk of ATOIs (ES = -0,27 ± 0,25). Study III was the only study to report females to be significantly at increased risk (p = 0,019) of developing ATOIs (11). Study III was also the only study to report sex as a risk factor by considering the amount of activity performed. It was concluded that females were more at risk of developing ATOIs if they were to perform the same amount of exercise as males (11). Activity level is something that needs to be taken into consideration when comparing two different groups. Study II reported that male participants were more at risk, as well as reporting a 30% higher weekly milage compared to female participants (12). Males running more than females may be an explanation to why males are more at risk, which is a concept supported by other articles (13). Overall, results regarding sex remained unclear, as both positive and negative effects have been found.

Age as a possible risk factor was investigated in five studies. There was a moderate significance on average (ES = -0,71 ± 0,33), which was greatly affected by the results of Study I (ES = -2,71 ± 0,59) (14). It is unclear why this study showed such a strong effect of older age. Study II also reported a significant effect of increased age (ES = -0,67 ± 0,25) (12). Most of our studies had an average age in the 30s or lower 40s. Study III and VI only included younger participants with minimal variation in age and were therefore excluded from these calculations. Findings related to collagen synthesis in elderly humans indirectly support old age as a risk factor for ATOIs (15). Elderly humans are more exposed to a weakening of the collagen synthesis in association with inactivity over shorter periods (15). Less collagen being synthesized means that the body would not be able to heal and recover a damaged tendon as quickly as at a younger age (15). This can be related to a degenerated tendon in a case of tendinosis, or the microtears in a tendinitis case (3). However, participants in their 40s and 50s from our original articles might not be considered elderly, but body function does gradually decrease with age.

Weight and BMI as a possible risk factor were investigated by studies II, (only weight) III, IV (only BMI), V (only weight), VI and VII. The studies reported conflicting results, and an average ES near zero for both weight and BMI means that the effect of these risk factors remains unclear.

4.2 Training and competition related results

Five studies investigated risk factors related to the participants' training habits. Running experience and weekly running distance were included in three studies. Study I was the only one to report years of running experience as a significant discriminator between injured and non-injured subjects (ES = -2,15 ± 0,54) (14). Overall, a moderate significance was found regarding running experience and the risk of developing ATOIs (ES = -0,64 ± 0,18). One might expect novice runners to be more injury prone than more experienced runners, however more experienced runners are likely to have a higher training volume, leading to increased risk of injury (12,14). We did not find any studies that reported the relation between training volume and running experience, and the risk of developing ATOIs. Weekly mileage was reported as a significant discriminator in studies I and II, and overall showed a moderate significance (ES = -0,82 ± 0,26) (12,14). This is according to our expectations, as a higher weekly mileage means a higher load on the tendons, which leads to increased injury risk.

Training pace and competition pace were reported to have strong and very strong relations to ATOIs. Study I reported data on both training and competition pace, while study VII reported only on training pace. Athletes that avoid easy runs and primarily trains close to competition pace seems to be at increased risk of developing ATOIs (ES = -1,75 ± 0,54) (14,16). However, athletes with lower competition pace were reported to be at strongly increased risk (14). Why this is the case remains unclear, but one theory is that athletes with lower competition pace tend to participate in longer competitions, which was shown to increase risk of ATOIs in study.

Three studies looked at the participants' habits related to running surface. Study IV and V asked whether they performed more than 80 % of their training on paved roads (5,17). Study VIII reported the participants' most preferred surface including asphalt, forest trails, mountain and sand, also including data on soft surface (7). Running on hard surfaces showed slightly promising results, while running on soft surfaces, such as sand, was a large risk factor for developing ATOIs (7). Running on soft surfaces may lead to increased strain on the AT, which could cause damage to the tendon.

The primary races of participants were investigated by studies IV, V and VIII. Study IV and V reported data on the biggest range of distances and reported marathon as a primary distance to be a significant risk factor (ES = -0,26 ± 0,20) (5,17). In general, longer preferred distance tended to overall give slightly increased risk (5,17). This lines up well with our finding regarding competition pace, where lower competition pace showed increased risk of ATOIs (14). Interestingly, study VIII reported results on distances where the shortest reported distance where the only risk factor reporting statistically significance (7). This may be due to a bigger portion of training being performed at very high speed, which puts more force on the AT, which could lead to increased risk of injury.

Possibilities of reoccurring ATOI symptoms were investigated in studies IV and V. The two studies are similar and report equivalent results of onset of ATOI. Being one of the most outstanding risk factors with a narrow CI, previous symptoms of ATOIs is an interesting risk factor. In Study IV, symptoms in the previous 12 months were found to be the strongest risk factor related to occurring symptoms in the follow-up period (17). In study V, the rate of which ATOI-symptoms could be considered reoccurring was 31% (5). Tendinosis involves degenerating of the fibers, which weakens the tendon, since the fibers do not work as well in the intended direction (3). As a consequence of tendinopathy, individuals tend to make adaptations to their biomechanics (18). Change in biomechanics might further damage the AT if it cannot endure the changes in its load. If the AT cannot tolerate the biomechanical load this might be a reason why ATOIs have a tendency of reappearing in the same tendon. Change in biomechanical load on the AT could be caused by adaption of muscle activity in the triceps surae. An example of this could be larger muscle activity in the lateral part of the triceps surae (18), as a compensation for the opposite in the medial part. Such adaptions over time could lead to strengthening and weakening of respectively the lateral and the medial head of the gastrocnemius (18). This could lead to a bigger pull on the lateral part of the tendon, and an overuse injury could be easier to incur.

4.3 Anthropometrics and biomechanics

PF and DF ROM were both investigated by Study I. While results were unclear regarding DF ROM (ES = 0,41 ± 0,44), a high PF ROM showed a clear protective effect (ES = 1,82 ± 0,51) (14). A high PF ROM might be related to good muscular strength in a plantar flexion movement, which also showed a large protective effect on the development of ATOIs (14).

Study I showed that isokinetic muscular strength in plantar flexion (PF) and dorsal flexion (DF) was a significant differentiator between the injury and control group (14). Torque was measured at 180 degrees per second. The control group showed on average a higher peak torque than the injury group (14). Study VI also shows a significant effect on plantar flexion peak torque in both legs at 30 degrees per second (19). Study VI only included data on plantar flexion but differentiated between right and left leg. All the data showed a significant value, with a high PF torque at 180 deg/s being a very strong protective factor (19). The fact that 180 deg/s has the greatest significance is interesting, as the actual speed of a plantar flexion when running is closer to 180 deg/s than 30deg/s (14). We know the possible load a tendon can endure, is closely related to the strength of the tendon. The strength of the tendon is also known to adapt in relation to the muscle activity (20). The results of large significance between PF torque and development of AT does therefore make sense.

In study I, arch index was measured by dividing the foot length into three parts and dividing the area of the midfoot by the area of the whole footprint (14). There was a significant difference between the two groups, with the injured group having the biggest arch, but the results of both groups were still within what is considered a normal arch index (21). It is worth noting that the variation between the two groups, regarding how much of the total footprint is part of the midfoot, was only 2% (14). Being a small study, with only 89 participants, this leaves room for possible bias. Unbalanced muscle activity is also a likely risk factor in development of ATOIs. The lateral overweight in force would lead to an exaggerated pronation (18). Such pronation would lead to a smaller arch and therefore oppose the arch index related results from Study I.

Study I investigated the effect of pronation and eversion. High pronation and eversion ROM showed slightly negative effects, although results were unclear, especially regarding the pronation ROM (14). High maximum pronation showed a moderately significant result, whereas a higher pronation resulted in a bigger risk for the development of ATOI (14). Exaggerated pronation could be a consequence of unbalanced strength ratio between the two gastrocnemii heads, which is known to be a possible risk in development of ATOIs (18). A high maximum eversion showed a positive effect on the development of ATOIs (14). Study I only mentioned eversion in a table and left it out of the discussion, making the effect unclear (14). A longer time to both maximal pronation and maximal eversion was shown to have a strong significance were protective of developing ATOIs (14). Rapid pronation and eversion may put a larger force on the tendon, which may cause microtears resulting in injury.

Study I conducted several measurements of the effect of different kinetic forces on the AT. High vertical force, high braking force and high lateral force all showed a very strong significant effect, increasing the risk of developing ATOIs (14). High propulsive force was slightly protective (ES = 0,87 ± 0,45), while medial force had an unclear effect(14). A high propulsive force may be related to good muscular strength in the triceps surae, especially in relation to PF, which also showed significantly protective effects (14,19).

Knee flexion was investigated by Study VII as a possible risk factor, but results were unclear (ES = -0,49 ± 0,45) (16). A small significance towards a negative effect is noted. Other studies found similar results, pointing towards a negative effect of high maximal knee flexion during stance (18).

Study II did extensive research on the role of the Subtalar joint Axis (STA), and its effect on developing ATOIs. The article only provided one small significant risk factor, but with a very large CI (deviation angle, ES= -0,35 ± 1,84) (12). Apart from this, no results were significant, and results regarding STA were excluded from further analysis.

Study III did extensive research on vascular and structural response to activity related to ATOIs but did not find any major significant results related to these topics. The study reported a significant result on increased blood flow after exercise, but we were not able to calculate any effect size from the numbers in the article (22). No other findings in the study were significant, and we decided to eliminate all results regarding vascular and structural response from further analysis.

4.4 Limitations

Several studies have used questionnaires as sources of information. While questionnaires are easy to perform in large populations, results may be incorrect as participants may give inaccurate answers, due to limited response options or misunderstandings. Many of our findings were limited to only one study, giving a narrow foundation for conclusions. A broader range of background information would have enabled us to answer our research questions more conclusively.

5. Conclusion

We have investigated multiple intrinsic and extrinsic risk factors related to ATOIs. Previous ATOIs were the only risk factor that had a clear negative effect. High weekly mileage, high training pace and running on soft surfaces seems to have a negative effect, but more research is needed to back these findings. Good plantar flexion strength seems to have a positive effect, but more research is needed on this topic to conclusively say so. More research is needed regarding biomechanical factors and their relation to ATOIs. Many risk factors are still uncertain, and their effects remain ambiguous.

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