Hip Muscle Strength in Males With and Without Chronic Mid-Portion Achilles Tendinopathy:
A Cross-Sectional Study

Master Thesis

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"ONDERGETEKENDE

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SAMENVATTING

Doelstelling De primaire doelstelling van deze studie was het onderzoeken van verschillen in kracht van de heupmusculatuur tussen patiënten met Achilles tendinopathie (ATP) en gematchte asymptomatische controles.

Methode De kracht van de heupabductoren, -exorotatoren en -extensoren werd gemeten bij een groep mannen met chronische mid-portion ATP en een groep gematchte asymptomatische controles. Isometrische kracht werd gemeten met een handheld dynamometer. De functionele kracht van de heupmusculatuur werd beoordeeld met de single leg squat. Daarnaast vulden de patiënten de Victorian Institue of Sport Assessment – Achilles vragenlijst in om de klinische ernst van hun symptomen te bepalen.

Resultaten In totaal werden 11 patiënten met ATP (mediane leeftijd 52 jaar, interquartile range [IQR] 42-53) en 11 asymptomatische controles (mediane leeftijd 49 jaar, IQR 40-54) geïncludeerd. De patiënten met ATP hadden 30,8% minder isometrische abductiekracht ($p = 0.016$), 40% minder exorotatiekracht ($p = 0.013$), en 36,8% minder extensiekracht ($p = 0.050$) vergeleken met de controle groep. Er werden geen significante verschillen gevonden in functionele kracht tussen beide groepen.

Conclusie De resultaten tonen aan dat mannelijke patiënten met chronische mid-portion ATP significant minder isometrische kracht van hun heupabductoren en –exorotatoren hebben dan gematchte asymptomatische controles. Er werden geen verschillen gevonden in functionele kracht van de heupmusculatuur.

Klinische relevantie Verminderde kracht van de heupmusculatuur bij patiënten met ATP kan leiden tot veranderde biomechanica van de onderste extremiteit, hetgeen een verhoogde belasting van de Achillespees tot gevolg kan hebben. Verder onderzoek naar de exacte relatie tussen kracht van de heupmusculatuur en ATP, en mogelijke implicaties voor revalidatie is nodig.

ABSTRACT

Aim The primary aim of this study was to investigate differences in hip muscle strength between patients with Achilles tendinopathy (ATP) and asymptomatic controls.

Methods Strength of the hip abductors, external rotators, and extensors was measured in a group of males with chronic mid-portion ATP and a group of matched asymptomatic controls. Isometric strength was measured using a hand-held dynamometer. Functional strength of the hip musculature was measured with the single-leg squat. Besides strength measures, patients with ATP completed the Victorian Institute of Sport Assessment – Achilles to determine clinical severity of their symptoms.

Results A total of 11 subjects with ATP (median age 52 years, interquartile range [IQR] 42-53) and 11 asymptomatic controls (median age 49 years, IQR 40-54) were included. Subjects with ATP demonstrated 30.8% less isometric abduction strength (p = 0.016), 40% less external rotation strength (p = 0.013), and 36.8% less hip extension strength (p = 0.050) when compared to the asymptomatic controls. No significant differences were found in functional strength between groups.

Conclusion Our results indicate that male patients presenting with chronic mid-portion ATP demonstrate significantly less isometric strength of their hip abductors and external rotators compared with matched asymptomatic controls. No differences in functional hip muscle strength were found.

Clinical Relevance Decreased hip muscle strength in patients with ATP may cause altered lower extremity biomechanics, resulting in increased Achilles tendon loading. Further research investigating the exact relationship between hip muscle strength and ATP, and the possible implications for rehabilitation programs is warranted.

Keywords: *Achilles Tendon, Tendinopathy, Muscle Strength, Hip*

INTRODUCTION

Achilles tendinopathy (ATP) is a clinical syndrome of the Achilles tendon, that is characterized by pain, swelling, and impaired performance.[1,2] The diagnosis may include, but is not restricted to histopathological changes of the tendon.[2] Most ATPs are localized in the mid-portion of the tendon, typically 2-7 centimeters proximal to the calcaneal insertion.[2,3]

Incidence of ATP is highest in sports that involve running and jumping, with an annual incidence of 7-9% in runners.[4,5] The injury is most prevalent in middle-aged men (21-60 years of age).[6-8]. Management of ATP in athletes is considered difficult,[9,10] and ultimately, the injury may cause considerable limitations in sport participation.

Conservative treatment is the primary choice in ATP, typically for a period of 3-6 months.[3,11,12] Within this period, eccentric calf muscle loading is considered the most effective treatment strategy, but other physiotherapeutic modalities may also be effective.[12,13] However, in 24-45% of patients with ATP conservative management is not successful, and for these patients surgical debridement of the tendon might be necessary.[5,14,15]

There may be multiple reasons why conservative management is not successful. Different aetiological factors, such as age, foot type, decreased lower extremity flexibility, and (excessive) training load may play a role.[16-18] Another reason may be that isolated strengthening of the calf muscle-tendon unit does not adequately restore function, indicating that rehabilitation of ATP possibly should also focus on restoring the function of the kinetic chain.[3,19,20] The kinetic chain is described as a system of multiple body segments that move in a coordinated and sequent manner in order to optimize position and velocity of the distal segment.[21] Of the many factors that are required for proper kinetic chain function, proximal muscle strength is considered to be essential.[21] Failure to absorb external forces through structures of the kinetic chain is thought to cause excessive tendon loading during sport activities.[22] Therefore, proximal muscle weakness might theoretically place large demands on the distal Achilles tendon, but empirical evidence for this theory is still lacking.

Despite a lack of studies investigating kinetic chain function in relation to ATP, there is growing evidence that kinetic chain dysfunction, and particularly decreased hip muscle strength, is involved in several other lower extremity injuries. Research has shown that patients with patellofemoral pain syndrome (PFPS)[23-25] and anterior cruciate ligament rupture[26] demonstrate decreased hip muscle strength compared to non-injured subjects. Moreover, patients with an ankle inversion sprain show less hip muscle strength in their injured limb compared to their non-injured limb.[27]

Decreased strength of the hip abductors and external rotators, on the one hand, has been demonstrated to cause increased femoral adduction and internal rotation, and excessive knee valgus angles.[28,29] These pathomechanics could potentially place the line of weight bearing on the medial side of the subtalar joint,[29] and consequently result in a whipping action of the Achilles tendon due to altered gastrocnemius length and excessive

foot pronation.[7,30] Strength deficits of the hip extensors, on the other hand, may result in an altered push-off phase during running: hip extensors are considered the prime forward movers of the body during running,[31] and decreased strength of this muscle group might consequently increase forces in the distal parts of the kinetic chain.[32] Altogether, these deteriorated mechanics may contribute to permanently increased stress in the Achilles tendon during loading, which could be an explanation for the limited effectiveness of conservative management in some patients with ATP.

Whilst decreased hip muscle strength seems to play an important role in several lower extremity injuries, this has scarcely been demonstrated for ATP. Azevedo and colleagues[33] have studied neuromuscular function of the gluteus medius muscle in patients with ATP. They found significantly lower electromyographic activity of this muscle during walking in patients with ATP when compared with asymptomatic controls. However, no muscle strength was assessed in this study. To date, no other studies can be found that have studied hip muscle strength in patients with ATP. Therefore, the primary aim of our study was to investigate differences in hip muscle strength between patients with ATP and matched asymptomatic controls. The secondary aims were to investigate differences in hip muscle strength between the injured and the non-injured limb, and to investigate the association between hip muscle strength and clinical severity of symptoms of ATP. It was hypothesized that patients with ATP would demonstrate significantly less hip abduction, external rotation, and extension strength in their injured limb when compared to asymptomatic controls and to their non-injured limb. Moreover, it was expected that strength of these muscle groups and clinical severity are negatively associated.

METHODS

Study design

A cross-sectional case-control study with two different groups was conducted. One group consisted of patients with chronic mid-portion ATP (ATPG), while the other group consisted of matched asymptomatic controls (CG). Matching was based on age (± 5 years), sport type, and training frequency categorized in three groups (i.e. < 3 hours per week, 3-7 hours per week, and > 7 hours per week). Written informed consent was obtained from all subjects prior to participation. The study protocol was approved by the institutional review board of the University Medical Center Utrecht (registration number 14-112), and was in accordance with the Declaration of Helsinki.

Subjects

A convenience sample of patients with chronic mid-portion ATP was recruited between February and June 2014, using several strategies. Primarily, patients were recruited through direct referrals from sports physicians at Papendal Sports Medical Center, and general practitioners in the surrounding region. Additionally, patients were requested for participation through mailings and advertisements at local sport clubs. Control subjects were recruited through e-mail / personal contact with employees at the Papendal National Olympic Training Center and the University Medical Center Utrecht, and mailings to local sport clubs.

Potential subjects were initially contacted by telephone or e-mail by the principal investigator (BH), in order to determine their eligibility. Subjects were eligible for inclusion if they were males, 21-60 years of age,[8] and if they participated in a sport that involved running and/or jumping. Subjects from the ATPG had a clinical diagnosis of unilateral mid-portion ATP,[2] with a duration of symptoms of at least three months. Potential subjects were excluded if they had a diagnosis of insertional ATP, bilateral mid-portion ATP, (history of) Achilles tendon rupture, other injuries of the lower extremity during the past 12 months, or if they had a neurological or systemic disease. If a subject was eligible for inclusion, an appointment was made for examination. During this examination, the diagnosis of mid-portion ATP was confirmed by the investigator, using two clinical tests that have been shown to be reliable and accurate for detecting mid-portion ATP: 1) subjective self-reported pain on 2-6 cm proximal to the calcaneal insertion, 2) pain on palpation by the examiner.[34] Subsequently, all measurements were performed by the same investigator, who was not blinded to group status (i.e. ATPG or CG).

Sample size calculation

Sample size calculation was performed using G*Power 3.1.5,[35] assuming 1-β = 0.80 and α (two-sided) = 0.05. Assuming a strength difference of 21%, which has been demonstrated in patients with PFPS,[23] a minimum of 12 subjects for each group was required.

Procedures

All measurements were performed for the injured limb for subjects in the ATPG, and for the corresponding limb of the asymptomatic controls. The non-injured limb of subjects from the ATPG was also measured for comparison between the injured and non-injured limb.

Isometric strength

Isometric strength measurements were performed with a Microfet 2 hand-held dynamometer (HHD; HOGGAN Health Industries, Inc, Salt Lake City, Utah, United States), which has been shown to be a reliable method for measuring hip muscle strength.[36,37] The dynamometer is able to measure force through a load-cell, and the force is displayed in Newton (range 3.6-660 N). For all measurements, subjects were asked to give a maximal isometric effort in the test direction (i.e. abduction, external rotation, and extension), and hold for 5 seconds. Before the actual test, subjects performed two trial repetitions. Subsequently, three test repetitions were performed, separated by 30 seconds of rest.[38] Strength values were recorded on a sheet, and the peak value of each test was used for data analysis.

Hip abduction strength was measured with the subject in side lying on an examination table.[37] The contralateral leg was flexed approximately 30° at the hip and knee, in order to enhance stability and comfort. The test leg was placed in 0° of flexion, and 10° of abduction with the knee fully extended. A strap was placed over the iliac crest and attached to the underside of the table. The HHD was placed on the lateral side of the femur, 5 cm proximal to the lateral femoral condyle. It was secured by a second strap, which was also attached to the underside of the table.

For strength testing of the hip external rotators, subjects were sitting on an examination table, with the hips and knees flexed to 90°, and the feet off the ground. [24] A strap was used for stabilization of the ipsilateral thigh, and subjects placed their arms behind their back. The HHD was placed 5 cm proximal to the medial malleolus, and it was secured by a strap that was fixated on the table base.

Strength of the hip extensors was measured with the subject lying prone on an examination table, with the hip in neutral position and the knee flexed to 90°.[38] A strap was placed at the height of the iliac crest, in order to stabilize the pelvis. The HHD was placed 5cm proximal to the popliteal fossa at the posterior thigh.

Functional strength

Functional strength was assessed using the single leg squat. This has been shown to be a reliable method to identify decreased hip muscle strength.[39]
The test was performed as described by Crossley *et al*[39] Subjects were assessed barefoot and in their underwear. They were asked to stand on one leg on a 20 cm box, with their arms fold across their chest. Then they were asked to squat down until 60° of knee flexion was achieved and push themselves up again. Squats were performed at a rate of approximately one squat per two seconds, and the depth of the squat was determined with a goniometer. Prior to the actual test, the procedure and technique were demonstrated by the investigator,

and subjects were allowed three trial repetitions. The actual test was performed directly after practicing, and comprised five consecutive test repetitions. These test repetitions were recorded with a video camera, that was placed approximately two meters in front of the subject at the height of the subject's pelvis. All videos were stored on a DVD in a coded manner, and were used for data analysis (i.e. rating of performance).

Rating was performed on a three-point ordinal scale ("good", "fair", and "poor"), according to the criteria determined by Crossley *et al*[39] These criteria were 1) overall impression for the five trials, 2) posture of the trunk over the pelvis, 3) posture of the pelvis, 4) hip joint posture and movement, and 5) knee joint posture and movement (Appendix I provides a detailed description of the criteria and all specific requirements). A criterion was satisfied, when all requirements for that criterion were met. The performance of the single leg squat was rated as "poor", if a subject did not satisfy at least one criterion for all test repetitions (i.e. not all requirements for any of the criteria were met). If a subject met all requirements for one, two, or three criteria for all test repetitions, the performance was rated as "fair". The performance on the single leg squat was rated as "good", in case a subject satisfied all requirements for at least four out of five criteria for all test repetitions.

Clinical severity of ATP

Clinical severity of ATP was measured with the Victorian Institute for Sport Assessment – Achilles (VISA-A) questionnaire, which has been shown to be a valid and reliable tool for this purpose.[40] It consists of eight questions covering the domains of pain, function in daily activity, and sport activity. Results range from 0-100, where 100 equals a perfect asymptomatic score. The VISA-A score was used to investigate the association between hip muscle strength and clinical severity of symptoms.

Additional variables

Several variables that were thought to influence the primary and secondary study outcomes were also recorded during the examination. Ankle dorsiflexion range of motion (ROM) was measured with the weight-bearing lunge test,[41] while dorsiflexion ROM of the first metatarsophalangeal joint was measured with a standard goniometer.[42] Additionally, hip joint ROM values were recorded for extension and internal rotation according to previously reported methods.[43,44] Finally, treatment (yes/no) and use of (pain) medication (yes/no) were recorded for subjects from the ATPG.

Statistical analysis

Data verification was performed by an independent physiotherapist, who did only have access to the encrypted data. After data input was verified, normality of the data was checked visually with Q-Q-plots and statistically using the Shapiro-Wilk test. Descriptive statistics were calculated for demographic and anthropometric variables, and differences between groups and between the injured and non-injured limb were investigated using the Wilcoxon signed rank test.

Before further analysis, peak isometric strength measures were normalized to body weight. The Wilcoxon signed rank test was used to compare isometric strength of the abductors, external rotators, and extensors between patients and asymptomatic controls, and for comparison between the injured and non-injured limb in subjects from the ATPG. Differences in functional strength, as measured with the single leg squat, were investigated with the McNemar-Bowker test. Spearman's rank correlation coefficients were used to investigate the association between isometric strength and clinical severity (VISA-A score).

All statistical analyses were performed with IBM SPSS Statistics 22.0 (IBM Corp., Armonk, New York, United States) with statistical significance set at $\alpha = 0.05$.

RESULTS

A total of 11 subjects were included in both groups. There were no significant between-group differences in demographic and anthropometric characteristics (Table 1; $p > 0.1$). Furthermore, there were no differences between the injured and the non-injured limb, except for hip internal rotation ROM ($p = 0.017$). The duration of symptoms for subjects from the ATPG was approximately 17 months, and the median VISA-A score was 60.

Isometric strength values are reported in Table 2. Subjects from the ATPG showed significantly less isometric strength in their hip abductors and external rotators compared with subjects from the CG ($p < 0.02$). The highest difference was found for external rotation (40%), while the difference for the hip abductors was 30.8%. Differences in isometric hip extensor strength showed a trend towards significance (36.8%, $p = 0.05$). No significant differences in isometric strength between the injured and the non-injured limb were found ($p > 0.8$).

Functional strength, as measured with the single leg squat, did not significantly differ between both groups, or between the injured and non-injured limb (Table 3).

Figure 1A-C shows the association between isometric strength measurements and clinical severity of symptoms. Spearman's rank correlation coefficients of 0.20, 0.18, and 0.09 respectively for abduction, external rotation, and extension were found ($p > 0.5$).

Table 1 Demographic and anthropometric characteristics of the study population

	ATPG injured side (n = 11)	ATPG non-injured side (n = 11)	*p*-value †	CG (n = 11)	*p*-value ‡
Age (y)*	52.0 (42.0-53.0)			49.0 (40.0-54.0)	0.501
Height (cm)*	188.0 (181.0-192.0)			180.0 (179.0-186.0)	0.153
Weight (kg)*	80.0 (75.0-89.5)			77.0 (69.0-89.0)	0.182
Sport type (n)					
- Running	8			8	
- Soccer	1			1	
- Volleyball	1			1	
- Tennis	1			1	
Training frequency (n)					
- < 3 hours / week	4			4	
- 3-7 hours / week	6			6	
- > 7 hours / week	1			1	
Sports experience (y)*	34.0 (20.0-40.0)			40.0 (20.0-40.0)	0.838
Ankle dorsiflexion ROM (cm)*	12.0 (8.5-15.0)	12.0 (10.5-14.6)	0.959	13.5 (9.0-14.5)	0.894
First MTPJ dorsiflexion ROM (°)*	56.0 (18.0-60.0)	54.0 (18.0-62.0)	0.441	54.0 (50.0-58.0)	0.423
Hip extension ROM (°)*	18.0 (10.0-23.0)	15.0 (14.0-24.0)	0.811	18.0 (14.0-22.0)	0.506
Hip internal rotation ROM (°)*	22.0 (14.0-30.0)	30.0 (18.0-37.0)	0.017	22.0 (20.0-25.0)	0.593
Injured side (left/right)	4/7				
Duration of symptoms	17.0 (17.0-23.0)				
VISA-A score	60 (48-79)				
Current treatment (yes/no)	7/4				
Use of pain medication (yes/no)	11/0				

* Data are reported as median (lower bound – upper bound IQR)

† *p*-values for differences between the injured and non-injured limb

‡ *p*-values for differences between the ATPG and CG

ATPG = Achilles tendinopathy group; CG = control group; ROM = range of motion; MTPJ = metatarsophalangeal joint; VISA-A = Victorian Institute of Sport Assessment – Achilles; IQR = interquartile range

Table 2 Isometric strength values of hip abductors, external rotators, and extensors for patients with Achilles tendinopathy and asymptomatic controls

	ATPG injured side (n =11)		ATPG non-injured side (n = 11)		p-value †	CG (n = 11)		p-value ‡
	Strength values (N)	% BW (N/kg)	Strength values (N)	% BW (N/kg)		Strength values (N)	% BW (N/kg)	
Hip abduction*	222.9 (178.8-291.4)	2.7 (2.3-3.2)	243.8 (180.1-290.9)	2.5 (2.3-3.2)	1.000	295.6 (252.2-378.6)	3.9 (3.3-5.0)	0.016
Hip external rotation*	116.5 (69.8-126.8)	1.2 (0.9-1.6)	120.5 (78.7-127.2)	1.2 (0.7-1.7)	1.000	136.1 (129.4-191.3)	2.0 (1.6-2.3)	0.013
Hip extension*	119.6 (83.2-144.1)	1.2 (1.0-1.6)	134.3 (81.4-157.9)	1.4 (1.0-1.8)	0.859	146.3 (121.0-177.9)	1.9 (1.5-2.4)	0.050

* Data are reported as median (lower bound – upper bound IQR)

† p-values for differences in % BW between the injured and non-injured limb

‡ p-values for differences in % BW between the ATPG and CG

ATPG = Achilles tendinopathy group; CG = control group; BW = body weight; IQR = interquartile range

Table 3 Performance on the single-leg squat for patients with Achilles tendinopathy and asymptomatic controls (rating according to Crossley et al[39])

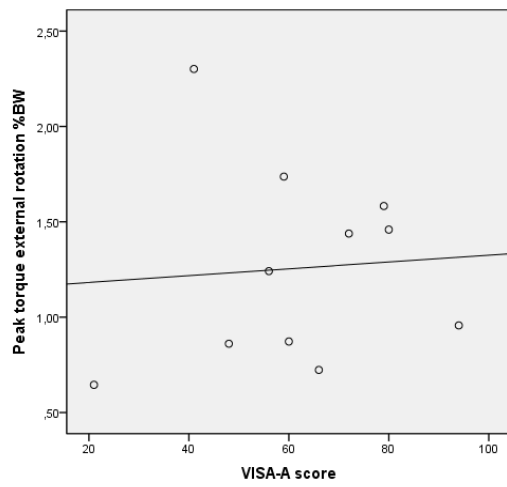|	ATPG injured side (n = 11)	ATPG non-injured side (n = 11)	p-value †	CG (n = 11)	p-value ‡
Good (n)	0	0	0.317	2	0.446
Fair (n)	4	6		5	
Poor (n)	7	5		4	

† p-value for difference between the injured and the non-injured limb (McNemar-Bowker test)
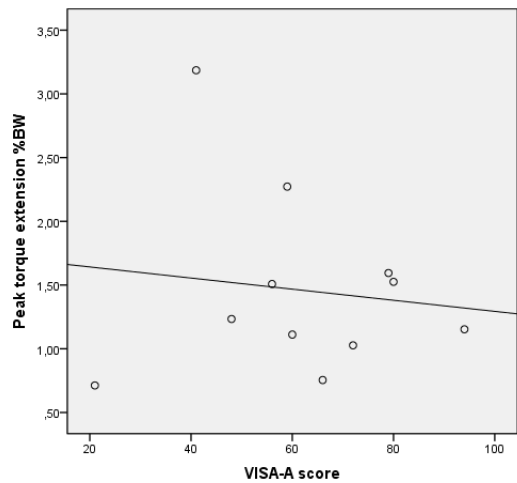‡ p-value for difference between the ATPG and CG (McNemar-Bowker test)
ATPG = Achilles tendinopathy group; CG = control group
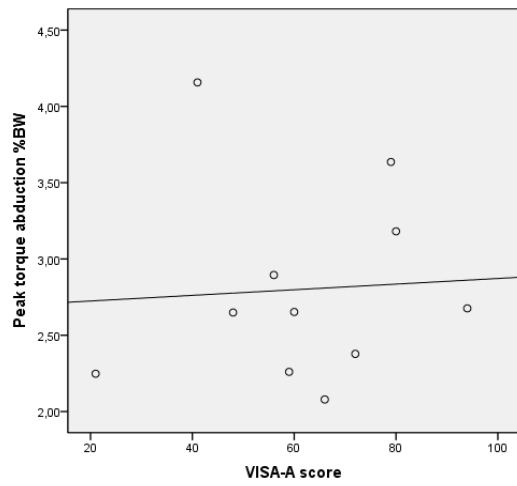
Figure 1A-C Association between clinical severity of Achilles tendinopathy and (A) isometric hip abduction strength, (B) isometric hip external rotation strength, and (C) isometric hip extension strength

DISCUSSION

The primary aim of this study was to investigate differences in hip muscle strength between patients with ATP and asymptomatic controls. Our results show that males with chronic mid-portion ATP have significantly less isometric strength in their hip abductors and external rotators, compared to their asymptomatic counterparts. When corrected for body weight, these differences ranged from 30.8-40%. Differences in isometric hip extensor strength showed a trend towards significance. Functional hip muscle strength, as measured with the single leg squat, did not significantly differ between groups. Moreover, no significant differences were found for isometric or functional strength between the injured and the non-injured limb in patients with ATP. Our results showed no significant association between isometric strength of the injured limb and clinical severity of symptoms.

The results of the current study support the findings of Azevedo and colleagues,[33] who found decreased electromyographic activity of the gluteus medius in patients with ATP. They concluded that patients with ATP show altered neuromuscular control of the hip musculature. Our study demonstrated decreased isometric hip muscle strength, which – together with appropriate neuromuscular control – is considered essential for proper kinetic chain function. However, isometric measurements only provide insight in isolated hip muscle function, which is different from sport specific movement. Therefore, we also included a measure of functional strength, which was the single leg squat. In this way, we attempted to challenge the neuromuscular control of the hip musculature. Our results did not demonstrate significant differences in functional strength between both groups, which is contrary to the findings of Azevedo et al[33] However, although it has been shown to be a reliable tool for identifying hip muscle dysfunction,[39] the single leg squat also assesses strength and coordination of other muscle groups of the lower extremity and trunk. Additionally, as many of the asymptomatic subjects did also not achieve a good score on the single leg squat, a definitive conclusion on differences in functional hip muscle strength based on our findings should be made with caution. We used video analysis according to the criteria of Crossley et al[39] to assess the performance on the single leg squat. Even though this rating method has been shown to be reliable for clinical use,[39] it was our experience that visual observation using 2-dimensional video images is difficult. This is consistent with other authors that have used video observation in their study.[45] The usage of additional resources, such as reflective markers or electromyographic measurements, might have objectified our rating method. Furthermore, electromyographic measurements might have been of added value in determining the exact activation patterns of the hip musculature during the squat.

Our findings correspond to findings in patients with PFPS, in which isometric strength differences of 21-36% were reported for the hip abductors and external rotators.[23,24] It has been shown that these strength deficits are associated with altered lower extremity biomechanics,[46] resulting in increased femoral adduction and internal rotation, and potentially leading to excessive pronation of the foot. Whilst these pathomechanics have been frequently proposed as a cause of several knee injuries,[46] studies investigating lower extremity biomechanics in relation to ATP are scarce. Kulig et al[47] retrospectively

investigated the takeoff phase of the saut de chat in dancers with a history of ATP, and they found significantly greater peak hip adduction and internal rotation angles compared with healthy controls. Additionally, a recent study in runners demonstrated that subjects with a history of ATP showed a relative increased internal rotation of the femur compared to subjects with no history of ATP.[48] It was suggested that this internal rotation may alter gastrocnemius length, and thereby increase stress on the Achilles tendon. Decreased strength of the hip abductors and external rotators, as demonstrated in our study, may be an explanation for these altered lower limb biomechanics in subjects with ATP, but further research is needed to confirm this.

It has been shown that strength differences of up to 15.5-26.7% naturally exist between healthy individuals.[49] However, these differences are particularly associated with age.[49,50] As subjects in our study were matched on age (± 5 years), it is unlikely that age could account for the strength differences that were found. Therefore, it might be concluded that the strength differences demonstrated in this study are clinically important, and that they may support the theory that hip muscle weakness plays a significant role in the persistence of ATP. It has been shown that hip muscle strengthening can improve pain and function,[51,52] and lower extremity biomechanics in patients with PFPS.[53] Addition of these exercises is therefore promoted in current rehabilitation programs for PFPS. Although our results do not allow a comprehensive treatment recommendation, it could be hypothesized that hip muscle strengthening may also be of added value in the management of patients with chronic ATP, in particular those who do not respond to conventional treatment strategies. Future research exploring the exact relationship and possible role for hip strengthening in patients with ATP is therefore warranted.

Our study has several limitations. Firstly, the cross-sectional design makes it impossible to determine if the strength differences are a cause or an effect of the injury. The patients with ATP had a median duration of symptoms of 17 months, and the strength differences that were observed might therefore be rather a result of disuse and altered motor patterns than a cause of the injury.[24] The fact that strength of the non-injured limb did not significantly differ from the injured limb further questions a causal relationship. Secondly, although our sample size was based on the primary study aim, we also investigated the association between isometric strength and severity of symptoms. It could be that our relatively small sample does not provide sufficient power to accurately demonstrate this association, and therefore, conclusions should be interpreted with caution. A third limitation might be that the investigator was not blinded to group status (i.e. ATPG or CG) during the examination. This may have influenced the outcome of the strength measurements, although we tried to prevent this by using external straps for fixation of the HHD.

CONCLUSION

The current study showed that male patients presenting with chronic mid-portion ATP demonstrate significant weakness (30.8-40%) in their hip abductors and external rotators compared to matched asymptomatic controls. Differences in hip extensor strength showed a trend towards significance. Our study showed no significant differences in functional strength, and no significant difference between the injured and non-injured limb. Finally, no significant association was found between hip muscle strength and clinical severity of symptoms. Based on the cross-sectional nature of this study, it is unknown if the strength differences that are reported are a cause or a result of the injury. Future prospective research is needed to determine this relationship. Moreover, additional biomechanical studies are needed to explore the underlying injury mechanism and the possible implications for rehabilitation.

ACKNOWLEDGMENT

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APPENDIX I

Clinical rating criteria for performance on the single leg squat according to Crossley *et al*[39]

	Criterion	To be rated "good"
(1)	Overall impression across the 5 trials	
	Ability to maintain balance	Participant does not loose balance
	Perturbations of the person	Movement is performed smoothly
	Depth of the squat	The squat is performed to at least 60° of knee flexion
	Speed of the squat	Squat is performed at approximately 1 per 2 seconds
(2)	Trunk posture	
	Trunk/thoracic lateral deviation or shift	No trunk/thoracic lateral deviation or shift
	Trunk/thoracic rotation	No trunk/thoracic rotation
	Trunk/thoracic lateral flexion	No trunk/thoracic lateral flexion
	Trunk/thoracic forward flexion	No trunk/thoracic forward flexion
(3)	The pelvis "in space"	
	Pelvic shunt or lateral deviation	No pelvic shunt or lateral deviation
	Pelvic rotation	No pelvic rotation
	Pelvic tilt (take note of depth of squat)	No pelvic tilt
(4)	Hip joint	
	Hip adduction	No hip adduction
	Hip (femoral) internal rotation	No hip (femoral) internal rotation
(5)	Knee joint	
	Apparent knee valgus	No apparent knee valgus
	Knee position relative to foot position	Center of the knee remains over the center of the foot

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