Three-Dimensional Gait Analysis Following Achilles Tendon Rupture With Nonsurgical Treatment Reveals Long-Term Deficiencies in Muscle Strength and Function

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Background: Precise long-term assessment of movement and physical function following Achilles tendon rupture is required for the development and evaluation of treatment, including different regimens of physical therapy.

Purpose: To assess intermediate-term (<10 years by conventional thinking) objective measures of physical function following Achilles tendon rupture treated nonsurgically and to compare these with self-reported measures of physical function.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: Two to 5 years after Achilles tendon rupture, 9 women and 43 men (mean age, 49.2 years; range, 26-68 years) were assessed by physical examination, performance of 1-legged jumps, and 3-dimensional gait analysis (including calculation of muscle work). Self-reported scores for foot function (Achilles tendon rupture score) and level of physical activity were collected. Twenty age- and sex-matched controls were assessed in the same manner.

Results: Physical examination of patients with the knee extended revealed 11.1° of dorsiflexion on the injured side and 9.2° on the uninjured side ($P = .020$), indicating gastrocnemius muscle lengthening. The 1-legged jump distance was shorter on the injured side (89.5 vs 96.2 cm; $P < .001$). Gait analysis showed higher peak dorsiflexion (14.3° vs 13.3°; $P = .016$) and lower concentric (positive) plantar flexor work (16.6 vs 19.9 J/kg; $P = .001$) in the ankle on the uninjured side. At the same time, eccentric (negative) dorsiflexor work was higher on the injured side (13.2 vs 11.9 J/kg; $P = .010$). Self-perceived foot function and physical activity were lower in patients than in healthy controls (mean Achilles tendon rupture score, 78.6 and 99.8, respectively).

Conclusion: Nonsurgically treated patients with Achilles tendon rupture showed signs of both anatomic and functional lengthening of the tendon. Attenuated muscle strength and function were present during walking as long as 2 to 5 years after rupture, as determined by 3-dimensional gait analysis. More extensive future studies involving patients having both surgical and nonsurgical treatment could provide additional valuable information.

Keywords: Achilles tendon rupture; gait analysis; 1-legged long jump; dorsiflexion; activity level; ATRS

Although the Achilles tendon is the thickest and strongest tendon in the human body, it is also the most frequently ruptured,[8,14] with a reported incidence of between 18 and 37 per 100,000. Ruptures usually occur in middle-aged men during sporting activity, often in association with abrupt repetitive jumping and/or sprinting.[7] The incidence of Achilles tendon rupture (ATR) has risen in recent decades, probably due to increased participation in recreational sports.[4] Tendon injuries heal slowly, and the normal structure and mechanical properties are often not recovered fully.[16,19,23] Residual weakness and impaired function following ATR may interfere with muscle work and physical activities.[2,20,23] Olsson et al[23] found that calf muscle strength remained reduced by 10% to 30% after 2 years with both surgical and nonsurgical treatment, which can be explained in part by elongation of the tendon. Kangas et al[10] report better outcome with less elongation after surgical treatment. However, Mullaney et al[19] reported end-range plantar flexion weakness in a surgically treated group.

Tendon elongation can be assessed as increased dorsiflexion of the ankle on the ruptured side[18] as well as by ultrasonography[13] or radiographic markers.[4,10,18,25] However, the results regarding strength and tendon elongation and the accuracy of dorsiflexion as a measure of elongation are equivocal. The anatomical length of the Achilles tendon after rupture has been studied, but very little is known about the functional length of this tendon during movement.[4,10,25,26,28]

The major outcomes monitored after ATR are the time required for rehabilitation, maximal voluntary strength,

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the patient's experience of function and satisfaction, the incidence of re-rupture, and, finally, resumption of sports activities.[11,20,29] Relatively young surgically treated individuals demonstrated reduced eccentric muscle work during walking and alterations in gait pattern 2 years after rupture.[5] Despite this, patients reported satisfaction and improvement of function during rehabilitation.[5]

Strength deficits involving lowered push-off force during walking can potentially cause long-term deviations in gait that have not yet been examined adequately by 3-dimensional gait analysis (3D GA). Furthermore, available information concerning the long-term strength of the calf muscle and possible influence on more demanding physical performance (eg, jumping) is limited. The treatment goals desired by individuals of different ages and different levels of physical activity vary, and objective and quantitative measurements such as those provided by 3D GA can be useful in planning treatment and rehabilitation. Accordingly, our goal was to employ 3D GA to examine long-term walking patterns and muscle work during walking and jumping in ATR patients treated nonsurgically.

We hypothesized that 3D GA can reveal changes caused by anatomical elongation after ATR in motion (kinematics) and in muscle work (kinetics), and more specifically, that tendon elongation leads to decreased moment in the ankle, delayed motion and power generation during walking, and decreased length on the 1-legged jump. Moreover, we hypothesize that these measurements correlate with self-reported measures of physical function.

MATERIALS AND METHODS

Study Population

This study was preapproved by the regional ethics committee, which applies the standards of the Declaration of Helsinki, and the participants provided their informed consent before inclusion. For this retrospective cross-sectional study, we recruited patients from the databases and orthopaedic clinics of the 2 hospitals in the region. The criteria for inclusion were a diagnosis of ATR confirmed by medical history, including clinical presentation (tendon gap palpation and Thompsons test/Squeeze test) 2 to 5 years earlier. The exclusion criteria were previous or later ATR or any other disease or injury that affected gait.

The medical records were reviewed, and 80 patients fulfilling the inclusion criteria were identified. Seventy-six patients were willing to participate and made a visit to the hospital, where the 3D GA and other tests were performed.

The characteristics of the 52 nonsurgically treated patients studied are documented in Table 1. A majority of patients (n = 32) were immobilized in a cast. Nineteen had a combination of cast and orthosis, and 1 patient was treated with orthosis only. Immobilization time varied between 7 and 9 weeks, and patients were encouraged to bear weight after 4 weeks of treatment. After immobilization, shoes were fitted with a heel lift for 2 months. Forty-six patients were diagnosed and had their treatment initiated within 3 days after injury. In 4 other cases, diagnosis and initiation of treatment occurred within 3 weeks, and in 2 cases, within 8 weeks. Thirty-five (67%) injuries were sports related (8 during soccer, 6 floor ball, 5 badminton, 8 tennis, 3 volleyball, 3 rounders, and 2 other sports), while the remaining 17 (33%) occurred while pushing a car, jumping over a ditch or fence, falling down stairs, dancing, walking, and other activities.

TABLE 1
Patient Characteristics (N = 52)[a]

Parameter	Value
Age, y, mean ± SD (range)	49.2 ± 10.6 (26-68)
Sex, female/male	9 (17)/43 (83)
Time since ATR/injury, y, mean ± SD (range)	3.3 ± 0.9 (2-5)
Injured side, right/left	23 (44)/29 (56)
Injured dominant foot, yes/no	22 (42)/30 (58)
Treatment	
Orthosis	1 (2)
Cast and orthosis	19 (36)
Cast	32 (62)

[a]Values are expressed as n (%) unless otherwise indicated. ATR, Achilles tendon rupture; SD, standard deviation.

A control group of 20 healthy friends and relatives without previous injury or surgery in the lower extremities was recruited for comparison of gait variables. The mean age of these participants, including 7 women and 13 men, was 45.8 years (range, 30.8-65.5 years).

Although most patients in our region were treated nonsurgically, a small group (14 patients) was treated surgically with some variation of suture technique. In this group, 6 were immobilized in a cast, 5 had a combination of cast and orthosis, and 3 were provided with orthosis only. Immobilization time varied between 6 and 8 weeks except for 2 cases. These 2 patients had surgery performed 4 and 8 weeks, respectively, after nonsurgical treatment, since they were considered as not healing. Therefore, their immobilization time increased by 8 and 10 weeks, respectively.

Comparison between the injured and uninjured sides and comparison with the control group as well as the surgically treated group was performed.

Physical Examination

All participants were examined by the same physical therapist. Passive range of motion of the hip, knee, ankle, and subtalar joints was assessed using a goniometer and standardized positions.[22] Maximal passive ankle dorsiflexion was evaluated with the knee fully extended (0°, representing primarily the length of the gastrocnemius muscle) and in 90° of flexion (primarily the length of the soleus muscle). Height and weight were recorded and possible discrepancies in leg length assessed, with the participant supine, by measuring the distance from the anterior superior iliac spine to the medial malleolus.[17]

Three-Dimensional Gait Analysis

Three-dimensional motion analysis provides an objective quantified assessment of dynamic events, such as gait and

Figure 1. Placement of markers for collection of kinematic data.

other movements. Kinematic (movement) data were collected using a system involving 10 digital cameras (Oqus 400; Qualisys Medical AB, Gothenburg, Sweden). For the kinetic (force) information, a Kistler force plate (Kistler, Winterthur Wulflingen, Switzerland) was utilized to obtain the ground reaction force vectors. Fifty-two retroflective markers were secured to specific anatomical locations on each subject in accordance with a combination of the Oxford Foot Model (OFM) and the modified Helen-Heyes Model[3,9,27] (Figure 1). The OFM, a multisegment kinematic model developed to standardize objective foot measurement during gait, provides reproducible intersegmental angles throughout the gait cycle. Participants walked on a 7.20-m walkway at a self-selected speed and temporal spatial, kinematic, and kinetic data were collected during 5 trials.

Muscle work was calculated as the product of angular velocity (kinematics) and joint moment (kinetics) over time using the formula

$$\text{Power (W/kg)} = \text{Angular Velocity (deg/s)} \times \text{Moment (N}\cdot\text{m)}.$$

Concentric muscle contraction (with shortening) produces positive work and is the cumulative sum of power generation. Eccentric muscle contraction (with lengthening) produces negative work and is the cumulative sum of power absorption. These calculations were performed with Visual 3D software (C Motion Inc, Germantown, Maryland, USA).

We determined reproducibility by having the physical therapist reassess 6 of the control participants 2 weeks later without knowing the previous assessments.

One-Legged Jump for Distance

The validated 1-legged jump for distance, requiring takeoff from and landing on the same foot, was chosen as an indicator of physical function.[6,15] Participants were instructed to keep their balance for at least 3 seconds after landing, and the distance (in centimeters) from the point of takeoff to where the heel touched the floor was measured. Prior to testing, subjects received standardized instructions, the physical therapist demonstrated the procedure, and each performed 1 to 3 practice trials. Three successful trials were completed with each leg, and the longest distance of these 3 subjected to analysis. This jump test was always the last test performed, with the uninjured side being tested first.[6,15]

Questionnaires

The symptoms and level of physical activity of our subjects were assessed using the Achilles tendon Total Rupture Score (ATRS) and Physical Activity Scale (PAS),[12,21,24] respectively. The ATRS exhibits high validity, reliability, and sensitivity for assessment of symptoms and physical activity following treatment for ATR.[12,21] The patient responds to its 10 questions, 5 addressing symptoms and 5 physical activity, on an 11-grade Likert-type scale (0 = major limitations/symptoms to 10 = no limitations/symptoms). The maximal total score is 100, with a lower score indicating more severe symptoms and limitation of physical activity. The PAS provides a valid and reliable measurement of physical activity,[24] with a score of 6 reflecting heavy physical exercise several times per week and a score of 1 no physical activity.

Statistical Analyses

Means and standard deviations were calculated. Since not all parameters were normally distributed, the nonparametric Wilcoxon signed-rank test was applied to compare the injured and uninjured legs. Comparisons between the patient and control groups were performed with the Mann-Whitney test, and possible correlations examined by the nonparametric Spearman test. A P value <.05 was considered to be significant, and all statistical analyses were performed using SPSS software (version 20; IBM, Armonk, New York, USA).

RESULTS

Physical Examination

Physical examination of the hip revealed reduced adduction on the injured side (mean $\pm$ standard deviation [SD], $11.7^\circ \pm 3.6^\circ$ vs $12.9^\circ \pm 4.1^\circ$; $P = .005$) but no differences with respect to the knees (Table 2). Ankle dorsiflexion with the knee extended was greater on the injured side, whereas there were no differences with the knee flexed 90° (Table 2).

TABLE 2
Physical Examination Results (N = 52 Patients)[a]

	Injured Side	Noninjured Side	P Value
Dorsiflexion, deg			
Straight knee (0°)	11.1 ± 4.8	9.2 ± 5.9	.020
Bent knee (90°)	15.7 ± 5.2	14.9 ± 6.3	.437
Plantar flexion, deg	36.8 ± 10.1	40.5 ± 8.7	.001

[a]Values are expressed as mean ± standard deviation.

Plantar flexion was lower, but dorsiflexion was greater on the injured side. Consequently, total range of motion was the same as the uninjured side. No differences were noted in the subtalar joints.

Three-Dimensional Gait Analysis

In the control group, there were no differences in the parameters assessed by 3D GA between the right and left sides or between the dominant side (ie, the leg chosen to kick a ball) and the nondominant side.

Intraobserver reproducibility of the ankle gait analysis parameters was excellent and varied between 0.963 and 0.913, except for 0.786 in 1 parameter.

Temporal Spatial Data

Among patients, there were no differences between the injured and uninjured sides with respect to step length and step time, stance and swing phase time, or cadence. In comparison with the control group, the patients exhibited a shorter step length on the injured side (mean ± SD, 0.65 ± 0.06 vs 0.68 ± 0.05 m; $P = .017$), as well as on the uninjured side (0.65 ± 0.07 vs 0.68 ± 0.05 m; $P = .014$). In addition, stance time on both the injured and uninjured sides was longer in the patient group ($P = .009$). However, step time, swing time, and cadence did not differ.

Kinematics

The hip kinematics on the injured and uninjured sides of the patients were similar. Comparison of hip kinematics to the control group revealed decreased hip peak flexion on the injured side (mean ± SD, 25.7° ± 5.4° vs 28.0° ± 5.6°; $P = .037$), as well as on the uninjured side (mean ± SD, 25.3° ± 5.4° vs 28.0° ± 5.6°; $P = .013$).

With respect to the knee, peak flexion was higher and maximal flexion in loading response lower on the injured side, with no difference in peak extension (Table 3). Comparison of the knee joint kinematics revealed reduced motion in patients on both the injured and uninjured sides compared with the control group (Table 3).

With respect to the ankle joint, peak dorsiflexion was greater on the injured side compared with the uninjured. Moreover, peak plantar flexion and plantar flexion at toe-off were both lower on the injured side (Table 3, Figure 2). In addition, at the time of peak power production, the ankle angle (degree of dorsiflexion) was greater on the injured side, with no difference in angular velocity (velocity of plantar flexion in the ankle joint) (Table 3, Figure 2).

Furthermore, in the ankle joint, the position of the foot was more dorsiflexed, with a delay of movement events in the sagittal plane in the second half of stance phase, both on the uninjured and, in particular, the injured side (Table 3).

Kinetics, Moments

The hip and knee moments on the injured and uninjured sides did not differ. Concerning the ankle, neither the peak plantar flexion nor peak dorsiflexion moments differed between sides ($P = .236$ and .936, respectively). Late in the stance phase, at the time of peak power production in the ankle, the plantar flexion moment was reduced on the injured side (mean ± SD, 0.84 ± 0.19 vs 0.90 ± 0.14 N·m; $P = .003$).

In comparison with the control group, the peak plantar flexion moment on the injured side was lower (mean ± SD, 1.41 ± 0.28 vs 1.52 ± 0.13 N·m; $P = .021$), without any significant differences on the uninjured side.

Kinetics, Work

The only difference in knee and hip muscle work between the injured and uninjured sides of the patients was more negative hip work on the injured side (Table 4). In the case of the ankle, positive work was lower and negative work higher on the injured side (Table 4, Figure 3). In comparison with the control group, work with both the knee and ankle on both the injured and uninjured sides was decreased (Table 4).

One-Legged Jump for Distance

The maximal 1-legged jump distance was shorter on the injured side (mean ± SD, 89.5 ± 33.9 vs 96.2 ± 34.5 cm; $P = .001$).

Questionnaires

The ATRS score of the patients (mean ± SD) was 78.6 ± 16.8 versus 99.8 ± 1.1 in healthy controls[21] and was correlated with the kinematic parameters of the ankle on the injured side (plantar flexion in loading response correlation coefficient [CR], 0.366, $P = .008$; peak dorsiflexion CR, 0.341, $P = .013$; dorsiflexion during terminal swing CR, 0.277, $P = .049$). For the uninjured ankle, the ATRS correlated with the timing of peak dorsiflexion (CR, 0.33; $P = .031$), plantar flexion in loading response (CR, 0.357; $P = .010$), and dorsiflexion in terminal swing (CR, 0.284; $P = .043$). In the knee on the uninjured side, flexion at initial contact was also correlated with the ATRS (CR, 0.294; $P = .036$). Furthermore, the ATRS correlated with the 1-legged jump distance on both the injured (CR, −0.694; $P = .001$) and uninjured sides (CR, −0.599; $P = .001$).

Concerning the level of physical activity, the PAS score was greater before (mean ± SD, 4.1 ± 0.9; range, 2-6) than after (mean ± SD, 3.7 ± 0.9; range, 2-6) ATR ($P = .001$). This score also correlated with the 1-legged jump distance both before (CR, 0.341; $P = .033$) and after (CR, 0.317; $P = .049$) injury.

TABLE 3
Knee and Ankle Kinematics in the Sagittal Plane of ATR Patients (Injured and Uninjured Sides) and Controls[a]

	Side	Patients (n = 52)	Controls (n = 20)	*P* Value[b]
Knee				
Peak extension, deg	Injured	−1.1 ± 3.7	—	.067
	Uninjured	−0.5 ± 3.0	0.2 ± 2.2	.252
	P value	.582		
Peak flexion, deg	Injured	56.2 ± 5.9	—	.027
	Uninjured	55.1 ± 4.7	58.8 ± 3.3	.001
	P value[c]	.042		
Range of motion, deg	Injured	57.3 ± 5.4	—	.333
	Uninjured	55.6 ± 5.0	58.7 ± 3.6	.004
	P value[c]	.004		
Ankle				
Dorsiflexion at initial contact, deg, **a**	Injured	0.2 ± 1.9	—	.069
	Uninjured	−0.6 ± 2.2	−0.7 ± 2.5	.890
	P value[c]	.013		
Plantar flexion in loading response, deg, **b**	Injured	5.0 ± 2.1	—	.237
	Uninjured	4.2 ± 2.1	4.4 ± 2.1	.671
	P value[c]	.052		
Peak dorsiflexion, deg, **c**	Injured	14.3 ± 2.9	—	.010
	Uninjured	13.3 ± 2.6	12.7 ± 2.6	.361
	P value[c]	.016		
Timing peak dorsiflexion, % of gait cycle, **c**	Injured	48.2 ± 5.2	—	.001
	Uninjured	46.4 ± 3.2	44.2 ± 3.2	.002
	P value[c]	.001		
Plantar flexion at toe-off, deg, **d**	Injured	6.6 ± 4.4	—	.001
	Uninjured	9.0 ± 4.1	10.4 ± 4.3	.095
	P value[c]	.001		
Peak plantar flexion, deg, **e**	Injured	11.2 ± 4.5	—	.001
	Uninjured	13.1 ± 5.4	15.3 ± 5.3	.026
	P value[c]	.004		
Dorsiflexion in terminal swing, deg, **f**	Injured	3.5 ± 2.1	—	.001
	Uninjured	2.7 ± 2.2	1.9 ± 2.2	.096
	P value[c]	.026		
Plantar flexion angle at time of peak power production, deg	Injured	8.6 ± 3.3	—	.001
	Uninjured	6.9 ± 2.9	5.2 ± 3.0	.008
	P value[c]	.001		
Angular velocity at peak power production, deg/s	Injured	113.4 ± 35.1	—	.317
	Uninjured	110.0 ± 33.1	122.6 ± 38.3	.141
	P value[c]	.594		

[a]Values are expressed as mean ± standard deviation. Lowercase boldfaced letters correspond to the various events illustrated in Figure 3. ATR, Achilles tendon rupture.
[b]Comparison of patients and controls.
[c]Comparison of injured and uninjured side.

Comparison With Respect to Time After Injury

Comparison on the basis of time since the injury (shorter or longer than 3.1 years) revealed that the half (26 patients) with shorter rehabilitation jumped farther (mean, 99.9 vs 79.0 cm; $P = .044$). In contrast, on the uninjured side, there was no difference. Moreover, the level of physical activity (PAS) was higher in the patients with less elapsed time since injury (mean ± SD, 4.0 ± 0.9 vs 3.4 ± 0.8; $P = .027$).

Comparison With Respect to Age

The younger half of patients (26 younger than 48 years) jumped farther than those who were older, both on the injured (mean, 106.0 vs 62.0 cm; $P = .001$) and uninjured sides (112.0 vs 70.4 cm; $P = .001$). The differences between the sides were not significant ($P = .634$). Gait analysis revealed higher dorsiflexion in the ankles of the older patients (mean, 15.4° vs 13.2°; $P = .008$). The ATRS of the younger group was greater (mean, 83.8 vs 73.7; $P = .044$).

Comparison With the Surgically Treated Group

We could not show any significant differences in any of the above discussed variables when comparing the surgically treated group (14 patients) with nonsurgically treated patients (52 patients).

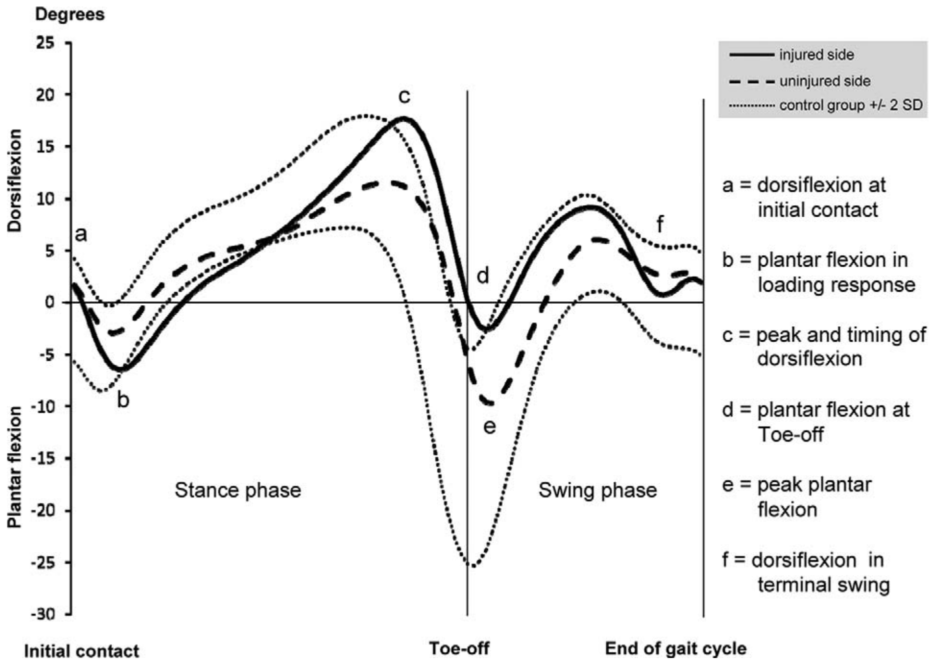

Figure 2. Ankle kinematics in the sagittal plane. Ankle movement (*y*-axis) during the gait cycle (*x*-axis) on the injured and uninjured side of 1 representative patient. (a) Dorsiflexion at initial contact; (b) plantar flexion in loading response; (c) peak and timing of dorsiflexion; (d) plantar flexion; (e) dorsiflexion in terminal swing.

TABLE 4
Hip, Knee, and Ankle Kinetics in the Sagittal Plane of ATR Patients (Injured and Uninjured Sides) and Controls[a]

Work, J/kg[b]	Joint	Side	ATR Patients (n = 52)	Controls (n = 20)	*P* Value[c]
Positive work/generation	Hip	Injured	14.0 ± 5.2	—	.441
		Uninjured	13.5 ± 5.2	15.3 ± 5.1	.140
		P value[d]	.111		
	Knee	Injured	5.1 ± 3.4	—	.001
		Uninjured	5.7 ± 3.9	8.1 ± 3.2	.001
		P value[d]	.382		
	Ankle	Injured	16.6 ± 5.0	—	.001
		Uninjured	19.9 ± 4.9	23.3 ± 3.9	.001
		P value[d]	.001		
Negative work/absorption	Hip	Injured	11.3 ± 5.6	—	.262
		Uninjured	10.1 ± 4.9	12.5 ± 5.0	.032
		P value[d]	.041		
	Knee	Injured	13.3 ± 4.0	—	.001
		Uninjured	13.9 ± 4.4	16.6 ± 3.7	.003
		P value[d]	.153		
	Ankle	Injured	13.2 ± 3.6	—	.373
		Uninjured	11.9 ± 3.7	12.3 ± 3.7	.331
		P value[d]	.010		

[a]Values are expressed as mean ± standard deviation. ATR, Achilles tendon rupture.
[b]Positive work = generation and negative work = absorption.
[c]Comparison of patients and controls.
[d]Comparison of injured and uninjured side.

DISCUSSION

This long-term follow-up of patients with ATR who received nonsurgical treatment revealed increased dorsiflexion in the ankle joint on physical examination. Gait analysis showed a dorsal shift of the ankle movement along with reduced muscle work on the injured side. The 1-legged jump distance on the injured side for patients was less than for control subjects, as were self-reported physical function and the level of physical activity following injury.

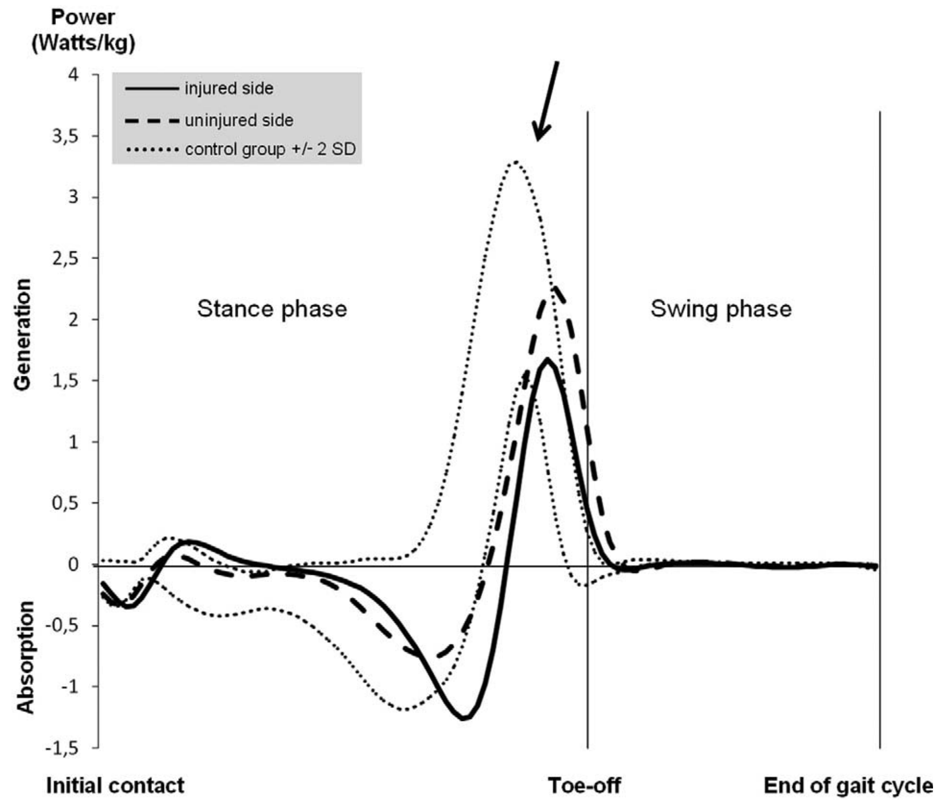

Figure 3. Ankle kinetics in the sagittal plane. Power (*y*-axis) during the gait cycle (*x*-axis) on the injured and uninjured sides of 1 representative patient. The values for the control group ± 2 standard deviations (SD) are indicated and the peak power generation marked with an arrow. Clearly, the positive work (the area under the curve above the *x*-axis) is less on the injured than the uninjured side.

Several previous studies have documented tendon elongation following ATR, with increased dorsiflexion in the ankle joint as determined by physical examination.[18,30] Other studies have quantified elongation of the tendon employing radiographic markers[4,10,18,25] or a combination of motion capture and ultrasound.[26] However, it remains unclear how tendon elongation influences function. Here, we observed alterations indicating tendon elongation, both by physical examination and in the movement data provided by the 3D GA.

Interestingly, on physical examination with the knee extended, we found increased dorsiflexion on the injured side, suggesting elongation of the gastrocnemius but not the soleus muscle. Corresponding changes in movement were noted in the 3D GA, with increased peak dorsiflexion during the stance phase with the knee extended. The 3D GA also revealed reduced plantar flexion on the injured side, implying a dorsal shift in the position of the foot during stance phase. Moreover, peak dorsiflexion was delayed and the angle at toe-off lower on the injured side during walking. These findings suggest not only an anatomic elongation of the tendon but also a functional effect, especially on the gastrocnemius muscle following ATR.

Applying 3D GA to 49 ATR patients with surgical repair for as long as 12 months postoperatively, Don et al[5] found changes in step length, along with attenuated peak dorsiflexion in the ankle and range of motion on the injured side. After 24 months, gait had normalized, except for more pronounced ankle dorsiflexion, range of motion, and angular impulse in plantar flexion during the lengthening phase. However, these patients were relatively young (30 ± 5 years old) and are therefore not representative of the overall ATR population.[5] In our patients treated nonsurgically, we also observed changes in the 3D GA, including dorsiflexion and the forces acting across the ankle joint. Whether the extent of such changes is influenced by the treatment regimen cannot be determined from our study.

The impact of possible elongation of the Achilles tendon on force and work capacity was assessed utilizing additional 3D GA parameters. At the point in the gait cycle when peak power was being generated (at the end of stance phase), our patients demonstrated enhanced ankle dorsiflexion and an attenuated plantar flexion moment but no altered angular velocity, suggesting tendon elongation. These observations constitute evidence for a long-term functional influence of ATR on the gastrocnemius muscle.

However, there is also evidence that at the end of stance phase, the soleus muscle is affected. This muscle controls tibial advancement over the plantigrade foot in midstance by eccentric and, to a certain extent, by isometric muscle contraction. During this period of stance, the activity of the soleus muscle appears to be adequate after ATR. However, at the end of stance phase, when plantar flexion of the ankle occurs and peak power is being generated, more demand is made on this muscle and it cannot control the ankle plantar flexion moment, as to achieve optimal effect on the gastrocnemius muscle.

Kangas et al[10] reported less muscle weakness and greater range of active ankle motion after surgical compared with nonsurgical treatment of ATR and concluded that this was due to less tendon elongation. However, these investigators noted no difference in isometric ankle strength as determined using a dynamometer. In the present study, where we emphasize the functional aspect of muscle activity, our 3D GA revealed reduced positive muscle work (power generation) in the ankle joint. In addition, the negative muscle work (absorption) on the injured side was greater than on the uninjured side. These observations suggest long-term functional impairment of both the gastrocnemius and soleus muscles following ATR. We interpret the reduction in knee muscle work, both positive and negative, as yet another consequence of calf muscle insufficiency, which influences the so-called plantar flexion knee extension couple, so that the complex interaction of the muscle over 2 joints (knee and ankle) cannot be performed in an optimal manner.

Employing isometric measurements of strength with a Biodex machine after ATR, Mullaney et al[19] observed plantar flexion weakness at 20° and, less pronounced, at 10° and suggested anatomical elongation as a possible cause. However, the relationship between this weakness and gait is unclear. At the time of toe-off during the gait cycle, which is very close to when maximal positive work is being performed, we found that decreased plantar flexion was reduced by 6.4° on the injured side and 8.9° on the uninjured side. We conclude that assessment of plantar flexion work at 10° and, especially, at 20° in a static setting provides little information about gait performance and muscle work during walking.

In the more physically demanding 1-legged jump, we found a significant decrease in jump distance on the ruptured side, even though Vanrenterghem states that the glutei, hamstrings, and quadriceps muscles are responsible for the greater part of maximal jump performance, with the calf muscles and Achilles tendon contributing relatively little.[28] Although we agree that this performance involves many variables, including pain, swelling, crepitus, neuromuscular coordination and balance, and joint stability,[1] we believe that calf muscle strength is also of importance in the 1-legged jump. Since such a jump not only requires concentric muscle contraction at take off but also eccentric muscle contraction/absorption when landing, it seems reasonable that performance depends to a substantial extent on calf muscle activity and strength.

The ATRS, which assesses symptoms and physical activity, was lower in this study (82.3 points) than that reported by Olsson et al[23] for ATR patients receiving surgical and nonsurgical treatment (90 and 89 points, respectively) 2 years after injury. It is of interest to note that in earlier studies, the treatment regimens did not influence this score. In our present 2- to 5-year follow-up, we expected a higher score because of the relatively long period of possible natural recovery and improvement. However we found no correlation between the ATRS and time after injury. Our interpretation is that in patients with ATR receiving nonsurgical treatment, intermediate-term improvement is not to be expected. With respect to the level of physical activity (PAS), our finding that age correlated with physical activity is in line with the report by Olsson et al.[23]

Age exerted a strong influence on the 1-legged jump performance, on both the injured and uninjured side, of our ATR patients. The correlation between shorter jump distance and greater age might indicate the limitations involved in applying this test to older individuals. At the same time, there was no correlation between age and the difference in jumping distance with the injured and uninjured sides. For this and for practical reasons, we restricted the use of the test to patients younger than 63 years.

One limitation of our present investigation is the relatively small number of patients and healthy control individuals. Moreover, our patients followed various regimens regarding casts and orthosis and, in addition, we had no control over the physical therapy performed by each individual. Another limitation is that for 6 of our patients, some time elapsed between injury and diagnosis and treatment. Moreover, though 3D GA provides objective measurements, there are difficulties with this technique, including the placement of reflective markers. Here, all marker placements were performed by the same physical therapist, and the small intraobserver test indicated excellent reproducibility.

CONCLUSION

Objective quantitative assessment by 3-dimensional gait analysis after Achilles tendon rupture followed by nonsurgical treatment revealed significant long-term deficiencies that influenced both gait and more demanding physical tasks. There were pronounced reductions in both muscle strength and function 2 to 5 years after injury. More extensive future studies involving surgical and nonsurgical treatment could provide valuable information on long-term prognosis that would help in deciding how to treat otherwise healthy and active individuals.

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