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Achilles tendon resting angle relates to tendon length and function

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Abstract

Background—Following Achilles tendon rupture, tendon elongation leads to long term deficits in calf function. A surrogate measure of Achilles tendon length, Achilles tendon resting angle (ATRA), has been described but has not been validated against length measured using ultrasound. Therefore, the purpose of this study was to validate the ATRA against ultrasound. Secondly, this study aimed to identify the relationship of other factors (tendon mechanical properties, heel-rise test performance) to the ATRA.

Methods—Individuals following unilateral Achilles tendon rupture were included. ATRA was measured in knee flexed and extended positions. Tendon elongation was measured using extended field of view ultrasound imaging. Continuous shear wave elastography quantified tendon mechanical properties. The relationship between variables was tested using Spearman's rho. Sub-group analysis was used to compare subjects with less than or greater than one year following rupture.

Results—42 participants (mean(SD) of 18.2(35.9) months following rupture) were included. Tendon elongation related with relative ATRA with knee flexed ($\rho=0.491$, $p=0.001$) and knee extended (0.501 , $p=0.001$) positions. In individuals greater than 1 year following rupture, relative ATRA with the knee flexed related to shear modulus ($\rho=0.800$, $p=0.01$) and total work on the heel-rise test ($\rho=-0.782$, $p=0.008$) relative to the uninjured side.

Conclusion—Relative ATRA in both knee flexed and knee extended positions has a moderate relationship to tendon elongation within the first year following rupture. After one year, the relative ATRA with knee flexed may be a better indicator of tendon elongation and also related to tendon mechanical properties and heel-rise test performance.

Level of Evidence—III, case-control study

Keywords

Achilles Rupture; Elongation; Ultrasound; Outcomes

INTRODUCTION

Achilles tendon rupture leads to long term deficits in plantar flexor strength, power^{10,12}, and endurance, that alter the biomechanics of the entire kinetic chain during activities such as running and jumping.²³ It has also been reported that the majority of functional improvement happens within the first year^{12,15}, which raises concerns that lack of early recovery of function may be associated with long-term deficits. In particular, decreased performance of a single leg heel-rise within the first year has been related to larger asymmetries during dynamic functional tasks at 5 years post injury.² However, the heel-rise test is only able to be performed by 50% of individuals at 3 months post-injury¹, so measures that could indicate recovery of long term function within the first 3 months following rupture are of great interest to identify patients who are likely to have a better/worse prognosis.

Measurement of tendon elongation has been suggested to fill this void in clinical assessment tools.^{16,19–21} In the long term, tendon elongation is of great concern particularly in active patients, as it results in functional impairments including end range plantar flexion weakness¹⁴, changes in triceps surae activity²¹, and altered running and jumping biomechanics.² With the advancement of extended field of view ultrasound imaging, tendon length is a reliable^{17,19}, clinically viable measure which has been found to relate to heel-rise performance.²⁰ This measure does require specialized equipment, which can be limiting in some clinical environments. Achilles tendon resting angle (ATRA), or ankle resting angle, has been suggested and used as a surrogate measure of tendon length.^{3,8} In this test, patients are positioned in prone with the knee either extended or flexed to 90 degrees, and the passive angle that the foot falls is measured using a goniometer.^{3,4,8} The ATRA is a quick measure that only requires a very inexpensive piece of equipment increasing its clinical utility.

Studies have validated the ATRA with knee extended to cadaveric specimens.⁷ These studies indicated that an increase of ankle dorsiflexion angle of 12 degrees related to an increase in tendon length of 1 cm.⁷ While clinically informative, this study is limited by using a transection model with tendon ends held together with steel plates to simulate tendon elongation, which does not account for the material properties of soft tissue. Prior studies have indirectly validated the ATRA with knee flexed to heel-rise height during a unilateral heel-rise³, as heel-rise height has been suggested to relate to tendon length.²⁰ Furthermore, studies have found the ATRA to be responsive to change over time.⁵

The purpose of this study was to determine the strength of the relationship of the ATRA in both knee extended and knee flexed positions with tendon length measured using ultrasound as a validation study. Secondly, this study seeks to identify the relationship between the ATRA with tendon material properties and patient functional performance to better understand its clinical utility.

MATERIALS AND METHODS

Study Design and Participants

Individuals with history of a complete Achilles tendon rupture were recruited. Participants were excluded if they had an augmented repair or reconstruction, bilateral Achilles tendon rupture, or any other condition affecting the ankle plantar flexors (i.e. lumbar radiculopathy with plantar flexor weakness).

Achilles Tendon Resting Angle

Achilles tendon resting angle was measured in both knee extended⁸ and knee flexed^{3–5} positions. The participant was positioned prone with knees extended and feet hanging off the plinth. A digital inclinometer placed on the lateral, plantar aspect of the foot was used to measure foot angle (Figure 1). This was then repeated with the knee passively flexed to 90 degrees on visual inspection. Relative foot angle was calculated for both knee positions by subtracting the injured from the uninjured limb. Therefore, if the foot is positioned in relatively more dorsiflexion on the injured side, the relative angle will be a positive number; a negative number indicates relatively more plantar flexion on the injured side.

Measurement of Tendon Length

Tendon length in centimeters from the calcaneal insertion to the gastrocnemius myotendinous junction was measured using ultrasound imaging with extended field of view settings.^{17,19} The participant was positioned prone with knees extended and feet hanging off the plinth. The average of three trials was used in analysis. Amount of tendon elongation was defined as the difference between injured and uninjured sides (positive values indicating greater tendon length on the injured side).

Measurement of Tendon Mechanical Properties

Tendon mechanical properties were quantified using continuous shear wave elastography. In this technique, participants/subjects/patients/individuals were placed prone with knee extended and feet secured against a foot plate. An external actuator is set to vibrate at a specific set of frequencies and linear tissue displacement is tracked using ultrasound imaging.^{6,22} The average of three trials was used for analysis. Shear wave speed is calculated, and a biomechanical model was used to determine shear modulus and viscosity.⁶ Tendon mechanical properties are included in analysis as a relative difference between injured and uninjured sides (difference = healthy-injured value).

Measurement of Function – Heel-rise Test

Participants' calf endurance was measured using the heel-rise test.¹⁸ In this test, the participant stands barefoot on a 10 degree slant board and performs unilateral heel rises at a rate of 30 heel-rises per minute to fatigue. A linear encoder (MuscleLab®, Ergotest Technology) taped to the participant's heel measured the linear displacement i.e. vertical rise of the heel for each repetition. Total work (total displacement · body weight) was recorded for both ruptured and uninjured sides. Relative performance on the heel-rise test of injured

to uninjured sides was described using the total work limb symmetry index (LSI) ($LSI = \text{injured/uninjured value} * 100$).

Statistical Analysis

Parametric assumptions were not met for this data set, however, for the purposes of side-to-side comparisons there was a balanced study design (each ruptured limb had an uninjured control limb). Therefore, a paired t-test was used to compare differences in resting angle and tendon length between sides. Spearman's rho was used to determine the strength of relationships between relative ATRA and tendon elongation, heel-rise test total work LSI, and difference in shear modulus and viscosity. As data specific to this research question was unavailable an a priori power analysis was not performed, however, post hoc power analysis revealed a statistical power of 0.95. For the purposes of data analysis, the entire group was considered as a whole and secondary, subgroup analysis was performed based on time from rupture (individuals less than versus individuals greater than 1 year following rupture). This subgrouping was based on concerns that tendon elongation may only relate to ATRA early in recovery whereas later in recovery factors outside of elongation, such as accommodation of the muscle, may be more at play.

RESULTS

Forty-two participants (34 male, 8 female; mean(SD) age 45.9(16.2) years; 31 managed surgically with open repair, 11 managed non-surgically) were included in this study. Participants were a mean(SD) of 18.2(35.9), range 1-167 months following rupture. For subgroup analysis, 32 individuals were within the first year following rupture and 10 were greater than 1 year following rupture.

Total Cohort

Ruptured tendons were found to be longer (mean(SD) 1.6(2.0) cm) with the ATRA indicating greater dorsiflexion on the ruptured side (Table 1). Ruptured tendons also had significantly lower shear modulus and viscosity. Functionally, participants performed significantly less total work on the ruptured side during the heel-rise test.

Tendon elongation related positively with relative ATRA with knee flexed ($\rho=0.491$, $p=0.001$) and knee extended ($\rho=0.501$, $p=0.001$) (Figure 2,3). With regard to heel-rise test performance, increasing symmetry on the heel-rise test was related with lower (indicating more similar angle to uninjured side) relative ATRA with knee flexed ($\rho=-0.502$, $p=0.002$). There was no relationship between relative ATRA and tendon mechanical properties.

Subgroup Analysis

The ATRA indicated greater dorsiflexion on the injured side in both subgroups (Table 1). Greater tendon elongation was found to relate to increased dorsiflexion on the relative ATRA with knee flexed and extended in individuals less than one year following rupture ($ATRA_{flex} \rho=0.445$, $p=0.01$, $ATRA_{ext} \rho=0.608$, $p<0.001$); however, related only to the

relative ATRA with knee flexed in individuals greater than one year following rupture ($\rho=0.758$, $p=0.01$).

In individuals greater than one year following rupture, increasing dorsiflexion with the relative ATRA with the knee flexed related to decreasing shear modulus on the injured relative to the uninjured side ($\rho=0.800$, $p=0.01$). In this subgroup, increasing dorsiflexion with the relative ATRA with the knee flexed was also related to decreased total work on the heel-rise test relative to the uninjured side ($\rho=-0.782$, $p=0.008$). No relationship between relative ATRA in either position was observed with tendon mechanical properties or heel-rise test limb symmetry in individuals less than one year following rupture.

DISCUSSION

The results of this study indicate that the relative ATRA in both knee flexed and knee extended positions has a moderate relationship to tendon elongation within the first year following rupture. After one year, the relative ATRA with the knee flexed may be a better indicator of tendon elongation than with the knee extended. Furthermore, after one year following injury, the relative ATRA with the knee flexed is also related to tendon mechanical properties and heel-rise test performance.

The relative ATRA with knee flexed has previously been shown to be sensitive to change longitudinally over the first year following Achilles tendon rupture with repair.⁵ Further the relative ATRA with knee flexed has indicated a significant increase in relative dorsiflexion on the injured side from the time of repair to 3 months following surgery.⁵ Similarly, studies of tendon elongation following Achilles repair using radiographic techniques have found elongation to occur within the first 8 weeks post repair.^{11,13} Taken together with the results of the current study, it seems that the ATRA is a useful surrogate measure for tendon elongation that responds to changes over time within the first year following injury, however, the greatest clinical utility may be early (within the first 12 weeks) in recovery.

Interestingly, in individuals greater than one year following rupture, the relative ATRA with knee flexed also related to factors outside of tendon elongation. It may be that as tendon length stabilizes within the first year following injury, additional factors such as recovery of tendon mechanical properties and muscle function come into play. Prior work has suggested that tendon length may be more related to tendon stress than mechanical properties⁹, so it may be that relationships between the relative ATRA and mechanical properties only begin to appear once tendon length has remained stable. From the standpoint of heel-rise performance, heel-rise height at one year post injury has been shown to be related to long term outcomes following Achilles rupture.² Because the relative ATRA relates to heel-rise performance later in recovery, it may be interesting to explore the relationship of the ATRA early in recovery to heel-rise outcomes at 1 year to see if the ATRA could be used from a prognostic standpoint.

This study is primarily limited by cross-sectional study design, which limits any longitudinal analysis such as the predictive ability of the ATRA for long-term outcomes. Additionally, the group of individuals included in this study was heterogeneous with regard to treatment and

co-morbidities. This may decrease the strength of relationships observed in the study, but makes the findings of this study very generalizable to a typical, clinical population of individuals with Achilles tendon rupture. Furthermore, the intention of this study was to validate the clinical measure of the ATRA, so the population included is representative of a general population of individuals with Achilles tendon rupture and is not intended to provide support for any particular treatment technique.

Achilles tendon elongation has been repeatedly shown to relate to patient outcomes both in the short-term and long-term after Achilles tendon rupture. The relative ATRA is a quick measure that does not require any costly equipment and moderately relates to Achilles tendon length within the first year post injury. Taken together with prior work investigating the ATRA's sensitivity to change over time^{3,5}, it seems that the ATRA is a clinically useful tool in monitoring patients for Achilles tendon elongation. Additional longitudinal studies would be beneficial in investigating the prognostic value of this measure to help inform its clinical utility in individuals following Achilles tendon rupture.

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Figure 1. Measurement of Achilles tendon resting angle with knee flexed. Note the comparison between the resting angle of the foot on the injured side relative to the angle on the uninjured side. A relative ATRA indicating a more dorsiflexed position is indicated by a positive number.

Figure 2.
Relationship between tendon elongation and relative Achilles tendon resting angle with knee extended for total cohort.

Figure 3.
Relationship between tendon elongation and relative Achilles tendon resting angle with knee flexed for total cohort.

Table 1

Between limb comparison of Achilles tendon resting angle (ATRA), tendon structure, and heel-rise test performance.

Variable	Total Cohort			Individuals Less Than 1 Year Post-Rupture			Individuals Greater Than 1 Year Post-Rupture		
	Ruptured	Healthy	p-value	Ruptured	Healthy	p-value	Ruptured	Healthy	p-value
ATRA _{flex} (degrees)	10.3 (8.6)	16.3 (6.4)	<0.001*	10.0 (8.7)	15.6 (6.0)	<0.001*	11.0 (8.6)	18.6 (7.4)	0.002*
ATRA _{ext} (degrees)	7.9 (8.6)	15.9 (6.0)	<0.001*	8.6 (1.6)	16.0 (6.1)	<0.001*	5.5 (5.5)	15.5 (6.1)	0.002*
Achilles Length to Gastrocnemius (cm)	22.3 (2.6)	20.7 (2.3)	<0.001*	22.0 (2.7)	20.8 (2.4)	0.001*	23.2 (2.3)	20.3 (1.7)	0.001*
Heel-rise Test Work (J)	847.4 (758.0)	2167.2 (903.8)	<0.001*	787.0 (807.4)	2223.0 (933.3)	<0.001*	992.2 (638.8)	2033.3 (860.8)	<0.001*
Shear Modulus (kPa)	88.4 (16.5)	97.0 (18.2)	0.04*	89.6 (16.4)	96.0 (19.5)	0.21	84.7 (17.5)	99.9 (14.3)	0.03*
Viscosity (Pa-s)	34.6 (11.9)	55.5 (11.6)	<0.001*	34.6 (11.4)	54.8 (12.2)	<0.001*	34.8 (14.0)	57.5 (10.0)	0.001*

Abbreviations: ATRA_{ext} - Achilles tendon resting angle with knee extended; ATRA_{flex} - Achilles tendon resting angle with knee flexed.

* p < 0.05