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Impact of seated and standing positions on triceps surae muscle activation in unilateral Achilles tendon rupture

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Abstract

Heel-rises are commonly used in the rehabilitation of individuals following Achilles tendon rupture, however, the impact of tendon elongation on triceps surae activation in seated versus standing positions has not been investigated. The purpose of this study was to investigate changes in triceps surae activation during seated compared to standing heel-rises in individuals with Achilles tendon rupture and its relationship to tendon elongation. Ten individuals with a history of Achilles tendon rupture were included in this study. Muscle activity using electromyography was examined during a heel-rise task in seated (unilateral) and standing (bilateral) positions. Soleus activity was not significantly different between sitting and standing on both the ruptured and uninjured side. On the ruptured, side there were no differences in medial or lateral gastrocnemius activity between sitting and standing; however, on the uninjured side medial and lateral gastrocnemius activity was lower in sitting compared to standing. The results of this study suggest that neuromuscular changes in triceps surae activation occur following Achilles tendon rupture. The seated heel-rise position can be used to strengthen all muscles of the triceps surae and is useful when the patient is unable to perform a standing heel-rise.

Keywords

ankle; rehabilitation; exercise; strength

Introduction

The triceps surae is a major power generator in the lower extremity, generating 65-85% of plantar flexion torque^{1,2}. Following Achilles tendon rupture, focal triceps surae deficits have been observed at 10 years or more post injury³⁻⁵. Changes in Achilles tendon length, which

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occur irrespective of whether or not an individual is managed operatively, have been associated with calf atrophy⁶, plantar flexor weakness⁶, and altered biomechanics during running and jumping^{7,8}. The impact of Achilles tendon rupture is not limited to the tendon. Long-term deficits have also been identified in the muscles comprising the triceps surae⁹. Deficits have been observed both in the length and material properties of the tendon¹⁰⁻¹² as well as in the structure and activation of the muscle^{9,13,14}, indicating that both components of the musculotendinous unit are greatly affected by injury.

Recent studies have investigated muscle-tendon interplay following Achilles tendon rupture. For instance, higher triceps surae activation has been seen in individuals with tendon elongation during gait¹⁴ and tendon material properties during jumping¹³ tasks. Both experimental and modeling studies support the notion that both muscle fiber length and tendon elongation factor into heel-rise height^{11,15,16}. It seems that there is an interplay between the tendinous and muscular contributions of the triceps surae that can compensate for some amount of dysfunction of the individual components.

Clinically, strengthening of the plantar flexors is of high priority following injury in order to progressively load the Achilles tendon and improve triceps surae function⁴. Heel-rises are a typical assessment tool and treatment modality used in the rehabilitative care of this population¹⁷⁻¹⁹. Heel-rises may be performed in both seated and standing positions. In studies in healthy individuals, the medial and lateral gastrocnemii and soleus were all found to be active in both positions²⁰, though the seated position is generally considered to target the soleus²¹.

Despite the common use of seated and standing heel-rises in individuals following Achilles tendon rupture, the impact of patient positioning on triceps surae activation in seated versus standing positions has not been investigated in this population. Given impairments in muscle and tendon structure and function observed in other tasks, it is anticipated that the impact of patient positioning during the heel-rise task may not follow the trends observed in healthy individuals. Therefore, the purpose of this study was to investigate alterations in triceps surae activation during seated compared to standing heel-rises in the context of Achilles tendon rupture and their relationship to tendon elongation.

Materials and Methods

To be included in this study, individuals had to have sustained a closed, unilateral Achilles tendon rupture. Participants were recruited from a single physical therapy clinic and had been treated by the same physical therapist for at least 6 months. Participants were excluded if they were unable to perform the resisted standing heel-rise protocol with at least 0.5 cm heel-rise height. This study was approved by the appropriate Institutional Review Board and all participants gave informed consent prior to data collection. This study was performed according to the Declaration of Helsinki.

Participants were first assessed with a clinical examination. The participants then performed two heel-rise tasks – one seated and one standing – with electromyography (EMG) recording muscle activity in the medial and lateral gastrocnemii and soleus.

Clinical Examination

The physical activity scale (PAS) was used to assess participant activity levels²². The PAS is a 6-point scale with scores of 6 indicating the highest amount of physical activity. The Achilles tendon Total Rupture Score (ATRS)²³ and Foot and Ankle Outcome Score (FAOS)²⁴ was used to measure Achilles and foot/ankle related function and quality of life.

Extended field of view ultrasound imaging (GE LOGIQ e, GE Healthcare, Chicago, IL) was used to measure the length of the Achilles tendon from the calcaneal notch to the medial gastrocnemius myotendinous junction^{25,26}. Images were taken at 10MHz using a wide-band linear array probe (GE LOGIQ e, GE Healthcare, Chicago, IL). The average of three measures was used in data analysis.

Heel-rise Tasks

Participants performed a 5-minute warm-up on a stationary bicycle prior to heel-rise testing. The standing heel-rise task was completed bilaterally using a standing heel-rise weight training machine with an external load of 150% of the participant's body weight. The seated test was performed unilaterally with an external load of 75% of the participant's body weight to hold load constant between seated and standing conditions. For both heel-rise conditions, participants were positioned on the edge of step such that their heels could drop off the edge of the step (Figure 1). A linear encoder (MuscleLab®, Ergotest Technology, Oslo, Norway) was used to measure linear displacement of the posterior heel during the heel-rise^{19,27}. Participants performed two sets of 3 heel-rises in both seated and standing positions, with a one-minute rest between sets. In order to quasi-randomize dominant or ruptured limbs, testing was always performed on the right followed by left limb.

Measurement of Muscle Activation

Muscle activation of the soleus and medial and lateral gastrocnemii was assessed using EMG (Model 4020e, MuscleLab®, Ergotest, Oslo, Norway). Gel coated, disposable electrodes (Norotrode 20™, Inter-electrode distance: 22mm) were placed according to the guidelines in the *Anatomical Guide for the Electromyographer*²⁸ (Figure 1). Prior to placement, the skin was prepared by being shaven, cleaned and lightly abraded with an alcohol swab. At the pickup point, the EMG raw signal is amplified and filtered with an 8-600 Hz bandpass filter using a preamplifier. Using a hardwired circuit, the root-mean-square (rms) of the signal was calculated with an averaging constant of 12 ms. The rms signals were then re-sampled at 100Hz using a 16 bit A/D converter.

The EMG data was synced to the linear encoder data using the MuscleLab® system (Ergotest Technology, Oslo, Norway). Muscle activation during the concentric phase of the second repetition was used for EMG analysis. The start of the concentric phase was defined as the point at which the participant achieved 1cm greater than their minimum heel-rise height. The end of the concentric phase was defined as the point at which the participant achieved 1cm less than their maximum heel-rise height. The mean EMG rms was calculated for the concentric phase of the heel-rise. To investigate the change in muscle activity the EMG signal in seated was compared to standing using within limb comparisons as the signal was not normalized.

Statistical Analysis

Within limb comparisons in muscle activation in seated and standing were performed using a paired t-test. Comparisons were performed for the ruptured and uninjured sides. The relationship between muscle activation (defined as a ratio of activity in seated/standing) and tendon elongation (defined as ruptured-uninjured tendon length) was performed using Spearman correlation due to the small number of participants and comparison of ratio data. For all statistical tests, alpha levels were set *a priori* at 0.05.

Results

Twelve individuals (10 male, 2 female) were screened to participate in this study. Two participants (both male) were excluded as they were unable to perform the standing, resisted heel-rise with the required heel-rise height on their ruptured side. Participant demographics are included in Table 1. The injured side was the right in 6 participants and the left in 4 participants. Participants had a significantly higher heel-rise height in seated on their uninjured side (Mean(SD) rupture: 9.6(2.5)cm, uninjured: 12.3(1.5), $p=0.009$). There were no differences in standing heel-rise height as this was a bilateral task (Mean(SD) rupture: 9.2(6.1)cm, uninjured: 10.9(5.2)cm, $p=0.33$).

Medial and lateral gastrocnemius activity was significantly higher in standing than in sitting on the uninjured side, however, there were no significant differences in gastrocnemius activity between positions on the ruptured side (Table 2). There were no significant differences in soleus activity between seated and standing positions on either the ruptured or uninjured side (Table 2).

Participants demonstrated a mean (SD) 2.2(0.6) cm of tendon elongation on the ruptured side. There were no statistically significant relationships between tendon elongation and the ratio of activity in sitting/standing ($\rho = -0.07 - 0.182$).

Discussion

Despite the common use of heel-rises in the rehabilitation of individuals after Achilles tendon rupture, this is the first study to compare triceps surae activity in seated to standing positions within this patient group. The results of this study suggest that there are neuromuscular changes in triceps surae activation following Achilles tendon rupture. We observed that medial and lateral gastrocnemii did not diminish in activity in a seated compared to a standing heel-rise on the ruptured side as it did on the uninjured side. We had proposed that tendon elongation could be a potential mechanism for higher gastrocnemius activity in seated positions, however, we did not observe a relationship between the ratio of gastrocnemius activity between positions and tendon elongation.

In clinical practice, it is commonly thought that ankle plantar flexion strengthening with the knee bent puts the medial and lateral gastrocnemius in a shortened position, resulting in the soleus being targeted during seated heel-rises. However, studies investigating the influence of knee angle on muscle activity in healthy individuals during isometric²⁹ (at 0, 45, and 90 degrees of knee flexion) and heel-rise²⁰ (at 0 and 45 degrees of knee flexion) conditions has

not supported the notion of consistently isolating muscle activity based on knee angle. The results of this study observed at the group level that the activity of the uninjured medial and lateral gastrocnemii significantly decreased by 38% and 30%, respectively, when heel-rises were performed in sitting compared to standing. On the ruptured side, a similar magnitude (30%) but non-significant decrease was observed in the medial gastrocnemius, and a much smaller magnitude (1%), non-significant change was observed in the lateral gastrocnemius on the ruptured side.

We had hypothesized that tendon elongation could be an underlying mechanism for higher levels of gastrocnemius activity and was based on literature finding tendon elongation to relate to strength deficits, soleus and medial gastrocnemius atrophy, and heel-rise performance deficits^{6,11,15}. Prior studies have found a relationship between heel rise height and tendon elongation in individuals 6 and 12 months after Achilles rupture¹¹ as well as calf muscle activation and tendon elongation during a walking task¹⁴. Based on these findings, we hypothesized that activation increases as the muscle needs to contract over a larger excursion in order to adequately tension the tendon. We believed that this increase in activation would be particularly apparent in positions where the musculotendinous unit is in a slackened position as is the case with sitting. We did not observe muscle activity to relate to tendon elongation in this group of participants, however. It is possible that the individuals included in this study were far enough removed from time of injury that remodeling of the myotendinous unit had accommodated for tendon elongation. It could be that other factors associated with muscle remodeling and adaptation, such as muscle fiber length¹⁵, may be more associated with long-term alterations in muscle function.

The findings of this study suggest that all muscles of the triceps surae are active in both seated and standing positions after Achilles tendon rupture. Starting a patient with seated heel-rises early in recovery recruits all triceps surae muscles and might be ideal with there are concerns with standing due to balance and weakness. Once a patient is able to perform heel-rises safely in standing, it may be beneficial to strengthen in both positions as both exercises will utilize all of the triceps surae, but likely target different functional ranges of the muscles. Heel-rise performance has also been used as an outcome, with standardized heel-rise testing previously described in both seated¹⁷ and standing¹⁹ positions. The seated heel-rise test (with 50% of body weight resistance) has been used to capture calf function beginning at 3 months post-injury, and a cut-off of 20 heel-rises has been proposed to predict individuals able to complete a standing, unilateral heel-rise¹⁷. Considering both the relationship between seated and standing heel-rise performance and muscle activity, the seated heel-rise appears to be a good precursor to standing heel-rises both as a rehabilitative strategy and as an outcome measure.

There are several limitations of this study. EMG signal was not normalized due to concerns regarding the ability to maximally volitionally contract the muscles on the injured limb. Because signals were not normalized, between limb comparisons could not be assessed. Muscles of the deep compartment of the lower leg also contribute to plantar flexor force, and flexor hallucis longus has been found to hypertrophy after Achilles tendon rupture⁶ to compensate for loss of triceps surae function³⁰. Due to the limitations of surface EMG, we did not investigate activity of the deep compartment of the lower leg, which likely also

factors into heel-rise performance. Time from injury was not controlled in this study, however, prior studies have found tendon elongation to primarily occur within the first few weeks to months following Achilles tendon rupture³¹⁻³⁴ and altered metabolic activity up to 12 months following Achilles tendon rupture³⁵. Due to concerns regarding study power, we were unable to statistically control for time from injury, however, we did not find any statistically significant relationships between time from injury and the ratio of EMG activity in seated and standing positions on the injured side ($r_{sp} = -0.02-0.28$). This study did include a small sample, and it is possible that seated to standing comparisons in the medial gastrocnemius on the ruptured side were underpowered. Sample size was not able to be determined a priori as data was not available, however, the results of this study could be used to inform sample size calculations in the future.

The strength of this study is that it quantifies muscle activity in all three triceps surae muscles in order to start uncovering the relationships between muscles in the context of injury. The heel-rise tasks used in this study are also commonly used in the clinic, making the findings of this study easily translatable to clinical practice. Finally, the inclusion of tendon length as a measure of tendon structure is a way of investigating the tendon-specific contribution to the musculotendinous unit.

The findings of this study support that both seated and standing heel-rises address all muscles of the triceps surae in individuals after Achilles tendon rupture. There may be a benefit of performing them in both positions, but seated heel-rises can be a good precursor to standing heel-rises when there are concerns for balance or patient safety.

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Perspectives

This is the first study to compare muscle activity between commonly used seated and standing heel-rise tasks in a group of individuals with Achilles tendon rupture. The findings of this study indicate that all triceps surae muscles are active in both positions, supporting the use of the seated heel-rise as a treatment tool and outcome measure particularly when standing heel-rises are not able to be performed.

Figure 1.
Electrode placement and set-up for the standing heel rise

Table 1.**Participant Demographics**

Participant Demographics (n=10)	Mean(SD)
Age (years)	44.2(9.4)
Time from injury (months)	22(18)
Body mass index (kg/m ²)	28.8(3.7)
Physical Activity Scale score (out of 6)	4.3(0.9)
Achilles tendon Total Rupture Score (out of 100)	86.4(10.2)
Foot and Ankle Outcome Score (out of 100)	
Pain subscale	94.4(6.1)
Symptom subscale	90.7(6.1)
Activity subscale	98.3(2.5)
Sport and recreation subscale	88.5(12.7)
Quality of life subscale	75.6(19.0)

Table 2.

Muscle Activity in Seated and Standing.

	Ruptured			Uninjured		
Muscle	Seated (mV)	Standing (mV)	P-value	Seated (mV)	Standing (mV)	P-value
Soleus	0.287(0.106)	0.244(0.153)	0.145	0.359(0.106)	0.316(0.106)	0.084
Medial gastrocnemius	0.331(0.103)	0.470(0.330)	0.076	0.314(0.082)	0.510(0.226)	0.002 *
Lateral gastrocnemius	0.351(0.172)	0.355(0.253)	0.939	0.369(0.141)	0.524(0.257)	0.001 *

* Indicates $p < 0.05$.