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ORIGINAL

The effect of front and back squat techniques on peak loads experienced by the Achilles tendon

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

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abstract

Background A primary technique in the discipline of strength and conditioning the squat has two principal 'back and front' variants. Despite the physiological and strength benefits of the squat, the propensity for musculoskeletal injury is high. The current investigation examined the influence of the front and back squat variations on the load experienced by the Achilles tendon.

Material/Methods Achilles tendon loads were obtained from eighteen experienced male participants as they completed both back and front squats. Differences between squat conditions were examined using Bonferroni adjusted ($p = 0.0125$) paired t-tests.

Results The results showed that the peak Achilles tendon load was significantly greater in the back squat (2.67 ±0.74 B.W) condition compared to the front squat (2.37 ±0.69 B.W).

Conclusions Given the proposed relationship between the magnitude of the load experienced by the Achilles tendon and tendon pathology, the back squat appears to place lifters at greater risk from Achilles tendon injury. Therefore, it may be prudent for lifters who are predisposed to Achilles tendon pathology to utilize the front squat in their training.

Key words biomechanics, squat, tendinopathy

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INTRODUCTION

The barbell squat is one of the primary techniques in the discipline of strength and conditioning [1, 2]. The squat is a closed chain kinetic exercise and has been shown to be biomechanically similar to a number of athletic motions [3], hence it is typically utilized as a core exercise in training routines designed to augment athletic performance [4]. The two principal variants of the squat are the back and the front squat lifts. Although both squats are mechanically similar, slight variations exist in terms of technique and muscular involvement [5].

Unfortunately, the nature of the barbell squat with high levels of flexion/extension at the lower extremity joint means that the propensity for injury is high [6, 7]. Whilst the majority of clinical work has focussed on the aetiology of knee disorders associated with squat lifting, there is currently a paucity of published work concerning other musculoskeletal structures, such as the Achilles tendon.

During the squat the Achilles tendon functions to transmit forces from the medial and lateral gastrocnemius and soleus muscles to the calcaneus to facilitate plantar and dorsiflexion of the ankle during the descent and ascent phases of the lift [8]. Achilles tendon pathology is associated with repetitive and excessive loading of the tendon itself, leading to the generation of microscopic tears in the tendons collagen fibres which are likely to experience high forces during the squat [9, 10]. Although physical activity has been shown to mediate positive tendon synthesis, excessive loads that are applied too frequently lead to collagen degradation and vastly increased susceptibility to injury [11]. Although previous analyses have considered the biomechanical variations between the front and back squat lifts, there remains little clinical research concerning the two squat modalities and the majority of what has been conducted has concerned the patellofemoral and tibiofemoral joints as opposed to the Achilles tendon.

The aim of the current investigation was, therefore, to examine the influence of the front and back squat techniques on the loads experienced by the Achilles tendon. A study of this nature may provide important clinical information to those who habitually engage in squatting activities regarding their susceptibility to Achilles tendon pathology when performing different variants of the lift. This study tests the hypothesis that Achilles tendon loads will be greater when performing the back squat.

MATERIAL AND METHODS

Participants

Eighteen male participants (mean age 23.61, SD 4.17 years, mean height 1.78, SD 0.10 m and mean body mass 75.63, SD 6.54 kg) who were experienced in both front and back squat lifting volunteered to take part in the current investigation. Participants were recreational runners who trained at least 3 times per week. Ethical approval was obtained from the University Ethics Committee and the procedures outlined in the declaration of Helsinki were followed.

Procedure

Participants completed five repetitions in each squat condition using their normal squat technique. The load was consistent for both conditions; participants lifted 70% of their back squat 1 repetition maximum, which was selected on the basis of the recommendations provided by Brzycki [12]. To remove any order effects, participants completed their squats in a randomised order. To acquire ankle joint kinetic information, the right foot was positioned onto a piezoelectric force platform (Kistler, Kistler Instruments Ltd., Alton, Hampshire) which sampled at 1000 Hz.

Kinematic information was captured at 250 Hz using an eight camera optoelectric motion analysis system (QualisysTM Medical AB, Goteburg, Sweden). The calibrated anatomical systems technique (CAST) was utilised to quantify ankle joint kinematics [13]. To define the anatomical frames of the right foot and shank, retroreflective markers were positioned onto the calcaneus, 1st and 5th metatarsal heads, medial and lateral malleoli, medial and lateral femoral epicondyles. A carbon-fibre tracking cluster consistingof four non-linear retroreflective markers was positioned onto the shank segment and securely positioned using tape. The foot was tracked using the calcaneus, 1st and 5th metatarsal markers. Retroreflective markers were attached using strong double-sided tape. Static calibration trials were obtained with the participant in the anatomical position in order for the positions of the anatomical markers to be referenced in relation to the tracking clusters/markers.

Data processing

Ground reaction force and kinematic information were smoothed using Visual 3D (C-Motion, Germantown, MD, USA) after being filtered at 50 Hz and 6 Hz respectively using a Butterworth low pass 4th order zero-lag filter [14]. Ankle joint kinematics were calculated using an XYZ cardan sequence of rotations [15]. Kinematic curves were normalized to 100% of the squat movement then processed trials were averaged. Ankle joint kinetics were computed using Newton-Euler inverse-dynamics. Net external ankle joint moments were then calculated.

An algorithmic model was used to determine the Achilles tendon load. The Achilles tendon load (ATL) was determined by dividing the plantar flexion moment (MPF) by the estimated Achilles tendon moment arm (MA). The moment arm was quantified as a function of the ankle sagittal plane angle (SAK) using the procedure described by Self and Paine [16]:

$$\text{ATL} = \text{MPF} / \text{MA}$$

$$\text{MA} = -0.5910 + 0.08297\ \text{SAK} - 0.0002606\ \text{SAK}^2$$

ATL was normalized to bodyweight (B.W.), and ATL loading rate (B.W.^{s-1}) was also calculated as a function of the change in the tendon force from an initial contact to the peak force divided by the time to the peak force.

Statistical Analyses

Differences in the Achilles tendon load as a function each of squat condition were examined using paired samples t-tests. The alpha criterion for statistical significance was adjusted to $p = 0.0125$ using a Bonferroni correction to control type I error. Effect sizes were calculated using Cohen's D. All statistical analyses were conducted using SPSS 21.0 (SPSS Inc., Chicago, USA).

RESULTS

Table 1 and Figure 1 present the Achilles tendon kinetics obtained as a function of orthotic intervention. The results indicate that the squat technique significantly influenced Achilles tendon kinetics.

Table 1. Achilles tendon load parameters measured during the front and back squat lifts

	Front		Back		
	Mean	SD	Mean	SD	
Peak plantarflexion moment (N.m.kg)	1.13	0.33	1.27	0.33	*
Peak Achilles tendon force (B.W)	2.37	0.69	2.67	0.74	*
Time to Achilles tendon force (s)	1.33	0.37	1.33	0.35	
Achilles tendon loading rate (B.W.s)	2.06	1.45	2.22	1.11	

Notes: * = significant differences

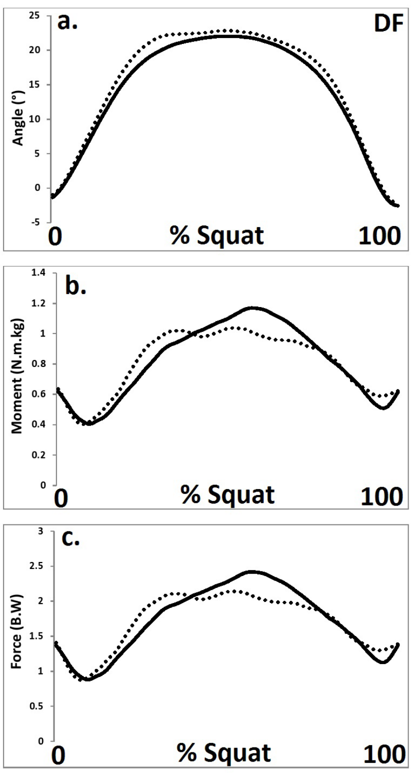

Fig 3. Ankle kinetics and kinematics as a function of front and back squat conditions, black = back squat, dot = front squat (a= ankle angle, b = ankle moment c = Achilles tendon load) (DF = dorsiflexion)

The results showed that the peak plantarflexion moment was significantly ($t(17) = 2.93$, $p < 0.0125$, $D = 1.42$) lower in the front squat in comparison to the back one (Table 1, Figure 1a). In peak the Achilles tendon load was also significantly ($t(17) = 3.32$, $p < 0.0125$, $D = 1.61$) lower in the front squat in comparison to the back one (Table 1, Figure 1b).

DISCUSSION

The current investigation aimed to examine the influence of the front and the back squat techniques on loads experienced by the Achilles tendon. This represents the first comparative study to examine the effects of different squat modalities on the forces experienced by the Achilles tendon.

The key observation from this study supports the hypothesis that the Achilles tendon load is significantly greater when performing the back squat in comparison to the front squat. Despite the ensuing reduction in the Achilles tendon load being relatively small (0.3 B.W), examination of individual results indicates that16 of the 18 participants demonstrated reductions in the peak Achilles tendon load during the front squat condition. This observation has clinical significance with regards to the aetiology and progression of Achilles pathology for those who undertake squat lifting, andit may provide insight into the mechanisms by which the symptoms of Achilles tendonopathy may be attenuated through alterations in the squat technique [17]. The symptoms of Achilles tendinopathy are believed to be associated with frequent and excessive loads experienced by the tendon [11, 18]; mechanical loads that exceed tolerable levels initiate collagen and extracellular matrix synthesis and subsequently facilitate degradation of the tendon itself [10]. Thus it can be speculated that those who habitually utilize the back squat in favour of the front squat are more susceptible to Achilles tendon pathology.

The reduction in Achilles tendon load associated with the front squat condition may relate to a number of biomechanical mechanisms. Firstly, the front squat was associated with and increased the peak dorsiflexion angle. Increases in dorsiflexion are associated with lengthening of the moment arm of the Achilles tendon, which given that the load experienced by the tendon is a function of the plantarflexor moment divided by the moment arm, ultimately leads to a reduction in the force experienced by the tendon itself [16]. In addition, previous analyses examining mechanical differences between the two squat conditions have shown a significantly greater anterior tilt of the trunk segment in the back squat condition [19]. This has the effect of moving the ground reaction force vector away from the ankle joint centre, which led to the increased ankle moment that was observed in the current investigation. As such, this study advocates that utilization of the front squat may be appropriate forthose who are predisposed to Achilles tendon pathology.

CONCLUSIONS

In conclusion, the findings from the current study show that the front squat condition was associated with significant reductions in Achilles tendon kinetic parameters compared to the back squat. Given the proposed relationship between the magnitude of the load experienced by the Achilles tendon during dynamic activities and Achilles tendon pathology, it is suggested that those at risk of developing injuries related to the Achilles tendon may attenuate this risk through more frequent utilization of the front squat in their training.

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