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SEX VARIATION IN PATELLAR TENDON KINETICS DURING RUNNING

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ABSTRACT
Purpose. The aim of the current investigation was to determine whether female recreational runners exhibit distinct patellar tendon loading patterns in relation to their male counterparts. **Methods.** Twelve male (age 26.55 ± 4.11 years, height 1.78 ± 0.11 m, mass 77.11 ± 5.06 kg) and twelve female (age 26.67 ± 5.34 years, height 1.67 ± 0.12 m, mass 63.28 ± 9.75 kg) runners ran over a force platform at 4.0 m · s^{-1}. Lower limb kinematics were collected using an eight-camera optoelectric motion capture system which operated at 250 Hz. Patellar tendon loads were examined using a predictive algorithm. Sex differences in limb, knee and ankle joint stiffness were examined statistically using independent samples *t* tests. **Results.** The results indicate that patellar tendon force (male = 6.49 ± 2.28, female = 7.03 ± 1.35) and patelllar tendon loading rate (male = 92.41 ± 32.51, female = 111.05 ± 48.58) were significantly higher in female runners. **Conclusions.** Excessive tendon loading in female runners indicates that female runners may be at increased risk of patellar tendon pathologies.

Key words: running, sex, patellar tendon

Introduction

Distance running represents a popular physical activity that has been demonstrated as physiologically beneficial [1]. Despite this fact, it has been shown that 19.4–79.3% of all who participate in recreational running activities will suffer from a chronic pathology over the course of 1 year [2]. Female runners are known to be at increased risk from chronic injuries in relation to males with the knee being the most common site of injury [3].

In humans, the tendon is a viscoelastic connective tissue that deforms proportionally in relation to the applied load [4]. Sporting movements that expose tendons to high loads lead to an increased risk of injury due to the associated tendon deformation [5]. Patellar tendinopathy represents a chronic knee pathology characterised by anterior knee pain and tenderness of the inferior aspect of the patella at the attachment of the patellar tendon [6]. Patellar tendinopathy is caused by high forces and high levels of strain experienced by the tendon itself [7–9]. Repeated utilization of the knee extensor mechanism during dynamic activities may overload and impair the tendon [7]. Overuse tendon injuries may account for up to 22% of chronic pathologies in athletic populations [6]. Patellar tendinopathy is particularly prevalent in running and jumping activities but is also frequently observed in soccer and tennis [7].

The biomechanical differences between sexes during running have been examined previously. Ferber et al. [10] showed that female runners exhibited a significantly greater peak hip adduction, hip internal rotation and knee abduction angle during the stance phase. Sinclair et al. [11] investigated differences in kinetics and 3-D kinematics of running. They indicated that peak knee abduction and internal rotation were significantly greater in females. Sinclair et al. [12] also examined sex differences in tibiocalcaneal kinematics during the stance phase of running. It was demonstrated that peak eversion and tibial internal rotation were significantly larger in female runners. In addition, Sinclair and Selfe [13] investigated sex variations in patellofemoral loading during running, finding that females experienced a much larger patellofemoral load in comparison to males. Finally, Greenhalgh and Sinclair [14] studied sex differences in the loads experienced at the Achilles tendon in recreational runners, confirming that male runners were associated with significantly larger Achilles tendon loads than females. However, there is currently a lack of published information regarding the loads experienced by the patellar tendon during running as a function of sex.

The aim of the current investigation was therefore to determine whether female recreational runners exhibit distinct patellar tendon loading patterns in relation to their male counterparts in hopes that it may provide clinical insight into the aetiology of knee pathologies in runners.

Material and methods

Twelve male (age 26.55 ± 4.11 years, height 1.78 ± 0.11 m, mass 77.11 ± 5.06 kg) and twelve female (age 26.67 ± 5.34 years, height 1.67 ± 0.12 m, mass 63.28 ± 9.75 kg)

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recreational runners took part in this investigation. Ethical approval was obtained and the participants provided their written informed consent. All runners were considered to present a rearfoot strike pattern as they exhibited an impact peak in their vertical ground reaction force (GRF) time-curve [15].

Participants ran at 4.0 m · s^{-1}, striking an embedded force platform (Kistler Instruments, UK) embedded in the floor (Altrosports 6mm, Altro Ltd,) with their right (dominant) foot [16]. Running velocity was quantified using Newtest 300 infrared timing gates (Newtest, Finland), and a maximum deviation of ± 5% from the predetermined velocity was allowed. The stance phase was delineated as the duration over which > 20 N of vertical force was applied to the force platform [17]. Runners completed five successful trials.

Kinematics and ground reaction forces data were synchronously collected. The force platform sampled at 1000 Hz. Kinematic data was captured at 250 Hz via an eight-camera motion analysis system (Qualisys Medical, Sweden). To model the body extremity segments in six degrees of freedom, the calibrated anatomical systems technique was utilized [18]. To define the segment co-ordinate axes of the right shank and right thigh, retroreflective markers were placed unilaterally onto the medial and lateral malleoli, medial and lateral epicondyles of the femur and also the greater trochanter. Carbon fibre tracking clusters were positioned onto the shank and thigh segments. Static calibration trials were obtained allowing for the anatomical markers to be referenced in relation to the tracking clusters.

Ground reaction force and marker trajectories were filtered at 50 and 12 Hz, respectively, using a low-pass fourth-order zero-lag Butterworth filter and analysed using Visual 3-D software (C-Motion, USA). Kinematics of the knee were quantified using an XYZ cardan sequence of rotations (where X – medial-lateral; Y – anterior-posterior and Z – vertical axes). Knee kinetic and kinematic curves were normalized to 100% of the stance phase. Joint moments were computed using Newton-Euler inverse-dynamics. The net joint moments were subsequently normalized to participants' body mass (Nm · kg^{-1}).

To estimate patellar tendon kinetics a predictive algorithm was utilized [19]. Patellar tendon load (PTL) was determined by dividing the knee extensor moment (KM) by the estimated patellar tendon moment arm (PTMA). The moment arm was quantified as a function of the sagittal plane knee angle by fitting a second-order polynomial curve to the data provided by [20] showing patellar tendon moment arms at different knee flexion angles. PTL was normalized to each participant's body weight (BW).

$$PTL = KM / PTMA$$

PTL loading rate (BW · s^{-1}) was calculated as a function of the change in PTL from initial contact to peak force divided by the time to peak force.

Sex differences in knee kinetics were examined using independent samples *t* tests. The alpha level was adjusted to 0.0125 using a Bonferroni correction. Effect sizes were calculated using partial eta^2 ($p\eta^2$). The data were pre-screened for normality using the Shapiro–Wilk test. Statistical procedures were conducted using SPSS v 22.0 (SPSS, USA).

Results

Table 1 and Figure 1 present the sex differences in patellar tendon force during the stance phase of running. Although the knee kinetic curves were qualitatively similar, the results do indicate that patellar tendon kinetic parameters were significantly influenced as a function of sex.

The results show that females exhibited a significantly greater knee moment than males; $t_{(22)} = 3.58$, $p < 0.0125$, $\eta^2 = 0.54$ (Table 1, Figure 1b). In addition, peak PTF was also shown to be significantly larger in females; $t_{(22)} = 3.36$, $p < 0.0125$, $\eta^2 = 0.51$ (Table 1, Figure 1c). Finally, it was demonstrated that PTF loading rate was significantly higher in female runners; $t_{(22)} = 3.65$, $p < 0.0125$, $\eta^2 = 0.56$ (Table 1).

Discussion

This study aimed to document potential sex differences in patellar tendon load in recreational runners. This study represents the first comparative investigation to examine patellar tendon force patterns in male and female runners and may provide insight into the prevalence of patellar tendon disorders in runners.

The first key observation from the current investigation is that peak PTF was found to be significantly larger in female runners. It is hypothesized that this relates to the significant increases in knee extensor moment exhibited by female runners in comparison to males. Increases in knee joint moments have been observed previously in females during landing tasks [21, 22]. This finding may have clinical significance regarding the aetiology of patellar tendon injury in females as the consensus regarding the development of patellar tendino-

Table 1. Patellar tendon kinetics as a function of sex

	Male		Female		
	mean	*SD*	mean	*SD*	
Peak knee moment (Nm · kg^{-1})	2.29	0.85	2.56	0.39	*
Patellar tendon force (BW)	6.49	2.28	7.03	1.35	*
Time to patellar tendon force (s)	0.07	0.01	0.07	0.02	
Patellar tendon load rate (BW · s^{-1})	92.41	32.51	111.05	38.58	*

* significant difference

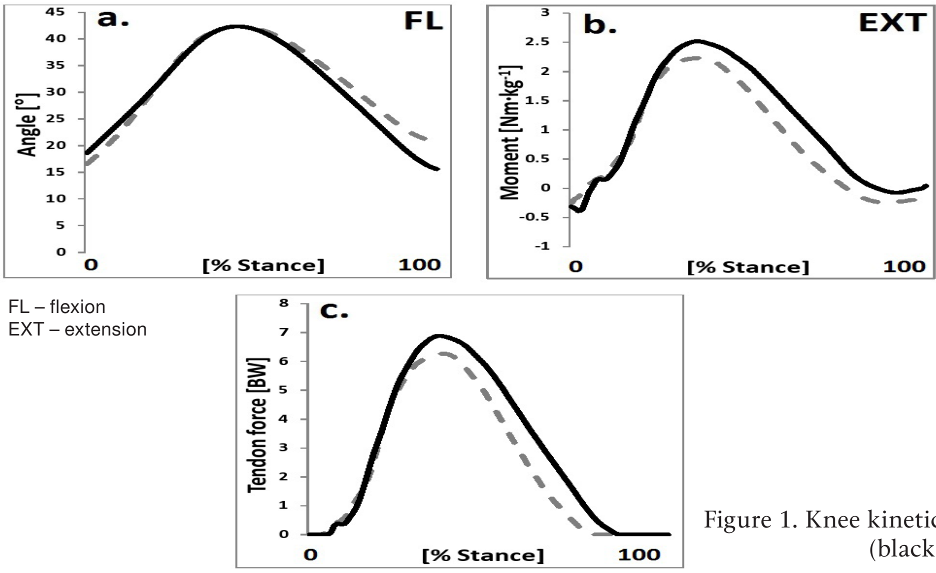

Figure 1. Knee kinetics and kinematics as a function of sex (black – female, grey – male)

pathy is that symptoms are the function of excessive patellar tendon loading [5].

The current investigation also showed that patellar tendon loading rate was significantly larger in female runners. It is likely that this is a function of the increased peak patellar tendon load as the duration over which the force was experienced was similar between sexes. Like all viscoelastic tissues, tendons exhibit an elastic region when they change in length as a function of force application (i.e. strain). When the tendon experiences strain outside this region there is an amplified risk of degradation [5, 7–9]. A higher loading rate indicates that the degree of tendon strain is correspondingly greater, placing the tendon at further risk from injury. This finding in conjunction with the observed increases in peak PTF indicates that female runners may be at increased risk from patellar tendinopathy.

Conclusions

Although previous analyses have considered the biomechanical differences between male and female runners, the current knowledge regarding the effects of sex on patellar tendon loading has yet to be investigated. The observations of the current investigation show that female recreational runners exhibit significantly greater patellar tendon loading compared to males. Given the proposed relationship between patellar tendon loading and patellar tendinopathy, the current investigation does appear to provide some insight into the high incidence of knee pathologies in females. Future analyses may seek to implement strategies aimed at reducing knee loading in female runners.

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