

Research article

The effect of mild symptomatic patellar tendinopathy on the quadriceps contractions and the Fente motion in elite fencers

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Abstract

To investigate how mild symptomatic patellar tendinopathy (PT) affects quadriceps contractions and the Fente motion, this case-control study examined elite fencers who continue to train and play fully with mild tendon pains. Twenty-four elite fencers (10 women) with mild symptomatic PT and 24 controls (10 women) participated in the study. Concentric/eccentric isokinetic strength of the quadriceps was tested, and peak torque and total work were recorded. Kinematic data from the knee during the Fente motion were collected. The first analysis period (P1) was after heel contact to the maximal flexion of the knee, and the second (P2) was right after P1 to heel-off. Normalized peak torque and work of concentric/eccentric contractions were not significantly different. Affected fencers demonstrated significantly reduced angular velocities at P2 ($p = 0.042$). The male fencers did not demonstrate any differences. The affected female fencers demonstrated significantly weaker concentric peak torque at $60^\circ \cdot s^{-1}$ ($p = 0.009$) and $180^\circ \cdot s^{-1}$ ($p = 0.047$) and less concentric work at $60^\circ \cdot s^{-1}$ ($p = 0.020$). They also demonstrated significantly reduced average angular velocities at P2 ($p = 0.001$). Therefore, mild symptomatic PT seems to have an effect on the isokinetic concentric contraction of the quadriceps and the angular velocity of the knee during the backward Fente motion in elite female fencers who are participating fully in training and competition.

Key words: Patellar tendinopathy, elite fencers, isokinetic, kinematics.

Introduction

Patellar tendinopathy (PT) is a common condition in sports, particularly at the elite level (Gaida et al., 2004). The average prevalence of PT in sports is 14%, although some sports, such as volleyball, have a prevalence of up to 45% (Ramos et al., 2009). Clinical studies have indicated that athletes who subject their patellar tendons to higher loads and increased knee flexion angles are at a greater risk for tendinopathy (Lian et al., 1996; 2003). Although we could not find previous studies on the prevalence of PT among elite fencers, we believe that many elite fencers suffer from this pathology, specifically during the Fente motion which is an offensive movement consisting of retraction of the rear leg combined with projection of the front leg, just like lunging.

Elite athletes who are participating fully in their training and competition with mild to moderate tendon pain comprise a large portion of those who suffer from PT (Young et al., 2005). Likewise, elite fencers also train intensely, especially to perform the quick and correct

Fente motion which is very important in competition, although they have symptomatic PT. Because pain on patellar tendon could be the limiting factor for activity, we hypothesized that even mild symptomatic PT in elite fencers could affect their athletic performance. However, previous clinical studies on PT have mostly focused on clinical outcomes with regard to various therapeutic regimens, and only a few studies have evaluated the effect of symptomatic PT on the performance of athletes who jump, such as volleyball players (Lian et al., 1996; 2003). We are aware of no previous study that has evaluated the effects of symptomatic PT on leg extensor biomechanics or athletic performance in elite fencers. Therefore, to investigate how mild symptomatic PT affects quadriceps contractions and the Fente motion, this case-control study assessed the isokinetic strength of the quadriceps and the knee kinematics during the Fente motion in elite fencers who continue to train and play fully with their mild tendon pains.

Methods

Participants

The present study was designed as a case-control group comparison of elite fencers who were training and playing fully at the national training center of the Korean Olympic Committee (KOC). This study was approved by the committee for ethics in research at our institute, and all subjects provided written informed consent. Thirty-one elite fencers who reported visual analog scale (VAS) score for anterior knee pain of not more than 3 during the Fente motion were evaluated. To be included, fencers had to have tenderness in the inferior pole of the patella (insertional) and an abnormal hypoechoic lesion (loss of normal hyperechoic fibrillar pattern) on ultrasound examination. Ultrasound was performed using a 12 MHz real-time linear-array transducer (Logiq e; GE Medical System, Sungnam, South Korea). All ultrasound examinations were carried out by the same experienced sport physician with additional training in musculoskeletal ultrasound. Participants were excluded from the study when they could not participate in the official training or competition due to the considerable knee pain. They were also excluded if they had Osgood-Schlatter disease or Sinding-Larsen-Johansson disease, recent direct trauma, joint effusion, limited range of motion, or any knee surgery in the preceding 12 months. Seven subjects in the affected group were not included in the data analysis because they exhibited the preceding exclusion criteria.

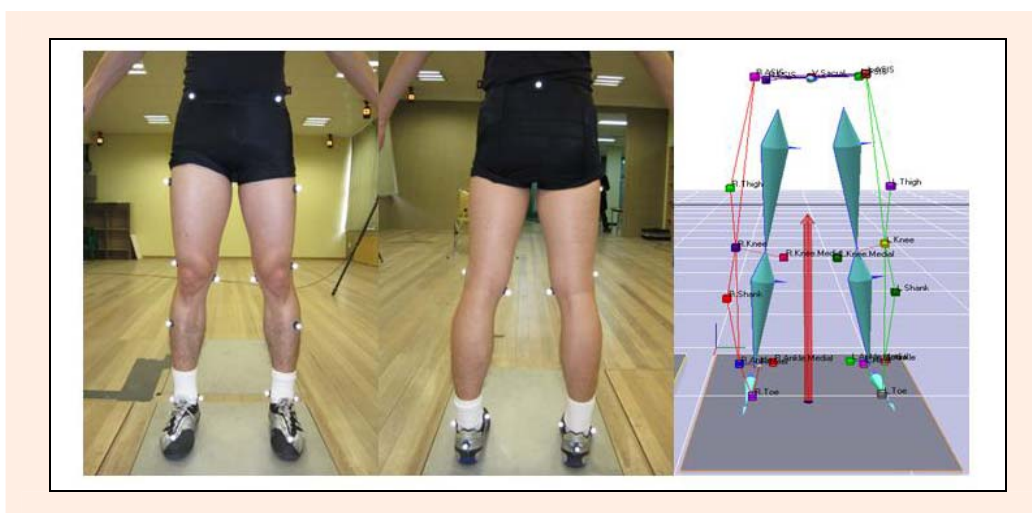


Figure 1. Helen Hays Marker Set (19 reflective markers).

A group of elite fencers without PT and matched by age, gender, height, and weight served as controls, because previous studies have shown that these variables can influence biomechanical results (Grau et al., 2008). Thus, 24 elite fencers (10 women) with mild symptomatic PT confirmed by clinical diagnosis and imaging and 24 elite fencers (10 women) without PT as controls participated in the study.

Isokinetic measures of the quadriceps

Concentric/eccentric isokinetic strength of the quadriceps was tested using a Biodex system 3 dynamometer (Biodex Medical System, Shirley, NY, USA), which provided mechanically reliable measures of torque, position and velocity on repeated trails (Drouin et al., 2004; Feiring et al., 1990). The setup was individualized for each participant, including aligning the lateral femoral condyle with the lever arm axis of rotation. Our testing velocities were set from slow to high angular velocities at $60^{\circ}\cdot\text{s}^{-1}$, $180^{\circ}\cdot\text{s}^{-1}$, and $300^{\circ}\cdot\text{s}^{-1}$. Multiple testing velocities were chosen to reinforce the validity of acquired data as well as due to the dominance of their use in past literature (Drouin et al., 2004; Feiring et al., 1990). The participants were stabilized and required to perform 3 sub-maximal familiarization trials carrying out concentric/eccentric actions at the 10° – 100° range of knee motion, followed by 3 recorded maximal trials at the same range, at each angular velocity. A 3-minutes recovery period was taken between the trial and test sets, during which the machine was calibrated to a reference point for the reliable data collection. All participants were instructed to carry out the trial with minimal tendon pain only, but they were also instructed to ask for stopping the test when they feel considerable pain. Peak torque (Nm) and total work (J) were recorded and normalized for mass (kg^{-1}). Each test was conducted by a physical therapist experienced in isokinetic testing.

Kinematic measures of the knee

Kinematic data were collected using a 12-camera, 3-dimensional motion analysis system (Eagle; Motion Analysis Corp., Santa Rosa, CA, USA) at a sampling frequency of 120 Hz. Based on the Helen-Hays marker set (Kadaba et al., 1990), 19 reflective markers were attached

to the participant at anatomical landmarks in the static standing position to calculate the center of the knee and ankle joints (Figure 1). Fifteen landmarks of 19 reflective markers were used for obtaining movement data; a pair of anterior superior iliac spines, mid-thighs, lateral femoral condyles, mid-shanks, lateral malleoli, heels, the areas between the second and third metatarsophalangeal joints, and the midline of the sacrum. The remaining 4 landmarks were as follows; a pair of medial femoral condyles and medial malleoli. The motion analyses were carried out with at least 3-hour rest after isokinetic tests, and then each participant performed 3 trials of the Fente motion after 15-min personal warm-up exercises. The motion was performed in exactly the same manner as that in competition and as fast as possible. The first analysis period (P1) was after heel contact to the maximal flexion of the knee joint angle, and the second (P2) was right after P1 to heel-off (Figure 2).

Coordinate data were digitized in Cortex software (Motion Analysis Corp., Santa Rosa, CA, USA). Kinematic data were filtered using a fourth-order zero-lag Butterworth 12-Hz low-pass filter. SIMM (Software for Interactive Musculoskeletal Modelling; Musculographics Inc., Chicago, IL, USA) was used to quantify 3-dimensional knee kinematics. The average and maximal knee angular velocities were chosen as our assessment measures.

Statistical analysis

All data are presented as mean (SD). Statistical tests were performed using SPSS Version 12 for Windows. Differences between the groups for the concentric/eccentric peak torque per body weight (BW), isokinetic total work per BW, and knee angular velocity were analyzed using 1-way analysis of variance. Group by sex interaction effect on the variables was measured when it is needed to compare the level of contribution of each sex. $P < 0.05$ was considered significant.

Results

There were no significant differences in age, height, weight, body mass index, or career between groups (Table

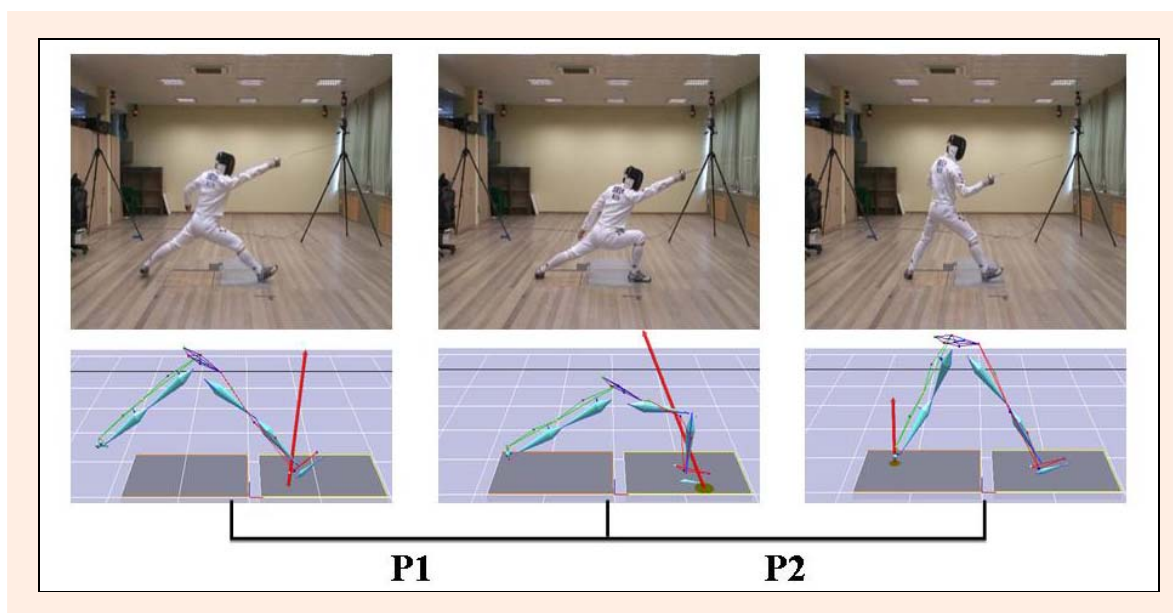


Figure 2. Kinematic analysis period divisions.

1). All participants completed the assessments without any dropout, and there were no adverse events reported during the study. Normalized peak torque and work of concentric/eccentric contractions of the quadriceps at each velocity were not significantly different between the 2 groups (Table 2). Angular velocities at P1 showed no significant difference between the 2 groups (Table 3). However, affected subjects demonstrated significantly reduced angular velocities at P2 ($p = 0.042$, $F = 4.357$) compared with those of control subjects (Table 3). The male subjects in the 2 groups did not demonstrate any differences in normalized concentric/eccentric peak torque, work, or knee angular velocities at P1 or P2 (Tables 2 and 3). The affected female subjects demonstrated significantly weaker concentric peak torque at $60^\circ \cdot s^{-1}$ ($p = 0.009$, $F = 8.686$) and $180^\circ \cdot s^{-1}$ ($p = 0.047$, $F = 4.561$) and less concentric work at $60^\circ \cdot s^{-1}$ ($p = 0.020$, $F = 6.478$) than the control subjects (Table 2). They also demonstrated significantly reduced average angular velocities at P2 ($p = 0.001$, $F = 29.407$) compared with those of control subjects (Table 3). Group by sex interaction effect for P2 angular velocity was significant ($p = 0.001$, $F = 13.410$).

Discussion

PT usually affects athletes whose sport involves repetitive explosive extension or eccentric flexion of the knee like that involved in the Fente motion (Lavagnino et al., 2008). A clinical study suggested that the likelihood of PT was significantly related to high loading forces in the knee extensor mechanism combined with deep knee flex-

ion angles (Richards et al., 1996). A laboratory study also supported the findings, as an increase in knee flexion and applied patellar tendon force is predicted to significantly increase localized tensile strain in the PT lesion (Lavagnino et al., 2008). However, conflicting studies have suggested that pathologic changes in PT represent an adaptational change to an increase in compressive forces secondary to an impingement of the inferior pole of the patellar tendon during flexion (Hamilton and Purdam, 2004; Johnson et al., 1996). Regardless of the etiopathogenesis, elite fencers are certainly at high risk for developing PT, and the large contingent of them continues to compete with tendon pain during the season (Young et al., 2005). The objective of the present study was to investigate how mild symptomatic PT affects quadriceps contractions and the Fente motion among elite fencers. Therefore, unlike previous tendinopathy studies which have recruited participants who have disabling tendon pain, often to the extent that they have ceased or considerably reduced sports participation (Gaida et al., 2004; Jonsson and Alfredson, 2005), we recruited elite fencers who continued to train fully with bothersome tendon pain. Thus our results could particularly be applicable to clinical sports medicine practice.

We initially looked for significant differences between the groups in isokinetic measures and knee kinematics because pain has inhibitory influences on muscle (Crossley et al., 2007) and therefore tendon pain during strength testing would compromise the isokinetic test or the Fente motion. However, our results demonstrated that only average angular velocity at P2 was significantly

Table 1. Characteristics of participants. Values are mean (\pm standard deviation).

Group	N	Age, year	Height, m	Weight, kg	BMI, $kg \cdot m^{-2}$	Career, year
Tendinopathy	24	22.6 (3.1)	1.74 (.08)	68.0 (10.3)	22.4 (2.0)	8.6 (2.8)
male	14	21.4 (2.3)	1.79 (.04)	74.1 (8.7)	23.0 (2.2)	7.5 (1.9)
female	10	24.3 (3.3)	1.66 (.04)	59.4 (4.9)	21.6 (1.4)	10.2 (3.2)
Control	24	23.2 (3.1)	1.72 (1.0)	65.4 (10.3)	21.9 (1.7)	9.4 (3.0)
male	14	23.0 (3.0)	1.78 (.06)	71.9 (6.7)	22.6 (1.5)	8.9 (2.6)
female	10	23.4 (3.3)	1.64 (.07)	56.4 (7.0)	21.0 (1.6)	10.1 (3.5)

Table 2. Isokinetic measures of quadriceps. Values are means (\pm standard deviation).

	Mode	Tendinopathy group			Control group			
		Total (n=24)	Male (n=14)	Female (n=10)	Total (n=24)	Male (n=14)	Female (n=10)	
60°·s ⁻¹	PT/BW (N·kg ⁻¹)	Conc	269.0 (52.4)	300.8 (38.3)	224.5 (33.8)*	279.1 (38.7)	288.6 (43.1)	265.7 (28.5)
		Ecc	316.7 (79.2)	347.7 (70.3)	273.3 (72.7)	309.7 (72.7)	316.9 (77.5)	299.7 (68.2)
	Work/BW (J·kg ⁻¹)	Conc	300.8 (58.3)	333.1 (46.1)	255.6 (41.5)*	315.3 (41.2)	328.5 (43.8)	297.0 (30.3)
		Ecc	302.1 (91.3)	333.6 (82.1)	258.0 (88.7)	295.1 (66.9)	294.3 (69.4)	296.2 (66.8)
180°·s ⁻¹	PT/BW (N·kg ⁻¹)	Conc	189.0 (47.4)	213.9 (40.7)	154.2 (32.3)*	200.0 (27.0)	213.2 (20.5)	181.6 (24.6)
		Ecc	297.5 (101.6)	339.9 (103.1)	238.0 (65.7)	297.7 (66.0)	312.9 (75.9)	276.4 (44.0)
	Work/BW (J·kg ⁻¹)	Conc	230.3 (53.9)	256.1 (43.0)	194.2 (47.6)	241.7 (35.2)	258.5 (24.2)	218.1 (35.4)
		Ecc	302.4 (118.4)	353.5 (114.4)	230.7 (84.5)	295.9 (69.9)	301.7 (80.8)	287.9 (54.2)
300°·s ⁻¹	PT/BW (N·kg ⁻¹)	Conc	155.2 (49.2)	170.9 (56.3)	133.2 (26.0)	170.1 (45.4)	186.0 (51.3)	147.9 (23.1)
		Ecc	304.3 (91.4)	339.8 (97.4)	254.5 (54.1)	300.3 (62.4)	312.3 (73.9)	283.6 (39.2)
	Work/BW (J·kg ⁻¹)	Conc	180.3 (51.4)	195.9 (56.5)	158.3 (35.0)	200.2 (24.9)	213.1 (19.9)	182.2 (19.9)
		Ecc	313.9 (115.4)	358.5 (119.3)	251.5 (77.8)	305.1 (98.7)	310.2 (110.4)	297.9 (84.8)

PT/BW, Peak torque/Body weight; Work/BW, Work/Body weight; conc, concentric contraction; ecc, eccentric contraction

* Indicates significant difference between patellar tendinopathy and control groups ($p < 0.05$)

reduced in the affected group. Neither concentric/eccentric isokinetic peak torque/BW nor work/BW differed between groups. Therefore, symptomatic PT did not seem to affect isokinetic performance if fencers were able to train and play fully despite their symptoms. However, the present study indicated that concentric peak torque/BW and work/BW were significantly decreased in affected female fencers. Furthermore, P2 angular velocity was also significantly reduced only in the female fencers with a significant interaction effect of group by sex indicating that the reduction of P2 angular velocity in the affected group could be attributable mainly to female fencers, not male fencers.

It is well established that women are more likely to sustain certain kinds of sports injury in collagen-rich connective tissue such as ligament and tendon (Hansen et al., 2008; 2009; Magnusson et al., 2007). There have been previous studies supporting the notion that gender may influence tendon adaptability to physical activity, yet the underlying reasons for the gender-specific difference remains unclear (Hansen et al., 2008; 2009; Magnusson et al., 2007). Compared to men, women have a lower tendon collagen synthesis rate following acute exercise, which is further attenuated with elevated estradiol levels (Hansen et al., 2009; Hansen et al., 2008). A previous study also reported that habitual training resulted in a larger patellar tendon in men but not in women (Magnusson et al., 2007). This suggests that the human patellar tendon in men adapts to regular physical activity by hypertrophy while similar exercise had no detectable impact on the tendon size in women.

In addition to these gender-specific differences in tendon metabolism, women have a lower mechanical strength of their tendons (Magnusson et al., 2007). A recent experimental study demonstrated a gender-based difference in the mechanical properties of the human patellar tendon (Onambélé et al., 2007). The study reported a significant decrease in stiffness and an increase in strain in female patellar tendons compared with those of males, indicating that a stiffer tendon is able to transfer the muscle forces to the bone more rapidly than a less stiff tendon. The strength and biomechanical properties of tendons play an important role in the force transmission of contractile energy from muscle to skeletal bones (Hansen et al., 2008). Therefore, we assume that these studies could partly support our results in that male subjects demonstrated comparable measures when they were suffering from tolerable PT, whereas female subjects who had less mechanical advantage in patellar tendons were seemingly affected more substantially, and thus demonstrated less isokinetic performance.

A previous study indicated that motion analysis is useful for detecting knee pain associated with the patellar tendon (Fu et al., 2009). We assessed knee kinematics and found reduced P2 angular velocities in the affected group, especially among female fencers. We assume that the rotational inertia of the knee during the forward movement of the Fente motion (i.e., until the knee angular velocity reaches 0°·s⁻¹) probably lessened the difference in angular velocities despite symptomatic PT; thus, P1 angular velocity was not different between groups. However, initiation of P2 should overcome stationary inertia of BW.

Table 3. Kinematic measures of knee. Values are means (\pm standard deviation).

	Mode	Tendinopathy group			Control group		
		Total (n=24)	Male (n=14)	Female (n=10)	Total (n=24)	Male (n=14)	Female (n=10)
P1 (Angular Velocity)	Average	262.8 (53.7)	241.0 (51.4)	293.2 (42.2)	285.3 (70.5)	259.4 (58.5)	321.4 (72.5)
	Maximum	593.2 (148.7)	583.6 (183.9)	606.6 (85.4)	563.3 (146.4)	492.1 (101.7)	663.1 (144.6)
P2 (Angular Velocity)	Average	189.2 (36.8)*	202.8 (39.9)	170.1 (21.8)*	210.1 (32.4)	196.0 (28.8)	229.8 (27.2)
	Maximum	411.5 (105.1)	405.2 (79.0)	420.4 (138.0)	400.9 (95.5)	352.9 (55.7)	468.0 (101.3)

* Indicates significant difference between patellar tendinopathy and control groups ($p < 0.05$)

Furthermore, there is a short period of eccentric contraction in the initial phase of concentric exercise (Jonsson and Alfredson, 2005). Therefore, this is the position where the eccentric quadriceps contraction reaches a peak level, and the concentric contraction also starts at the peak level almost at the same time (Rees et al., 2009). Thus, the maximal forces are loaded on the pathologic patellar tendon during the initial phase of P2 and this could be associated with the decreased angular velocity at P2.

Sports that have a greater prevalence of PT include those that involve high-intensity movements in which the ground reaction force is transmitted directly to the quadriceps through eccentric movements that are 1.5 to 2 times more intense than the maximum concentric strength (Ramos et al., 2009). However, it is still questionable whether the PT is affected by contraction mode (Kongsgaard et al., 2009). A cross-sectional study that investigated the clinical features of PT indicated that isometric knee extensor strength appeared important in PT, but the authors could not conclude whether the reduced thigh strength that compromised function in PT was cause or effect (Crossley et al., 2007). Another study showed a trend toward decreased eccentric strength at 180°/s in the leg affected by unilateral PT (Gaida et al., 2004). Although the differences were not significant, the authors inferred that eccentric strength decreased to protect the tendon from abusive levels of stress. Likewise, eccentric loading is thought to cause more pain than concentric loading in PT (Rabin, 2006).

Contrary to this, the present study demonstrates that concentric, but not eccentric, quadriceps strength was significantly weaker in affected female fencers. A recent *in vivo* investigation demonstrated that peak tension forces in eccentric exercise are of the same magnitude as those seen in concentric exercise (Rees et al., 2009). The study suggested that, although there has been *in vitro* evidence to suggest that eccentrically generated peak forces should be higher than concentrically generated peak forces, this does not extend to *in vivo* situations. Rather, a few studies have suggested that athletes who had PT and who were actively playing (like ours) performed better on jump tests than healthy control subjects, especially on tests involving eccentric work (Lian et al., 1996; 2003). In 1 randomized controlled study that compared concentric and eccentric quadriceps training for PT, there was a high frequency of dropping out (4 out of 9 tendons) in the concentric group because of severe pain after training, but rather eccentric quadriceps training on a decline board reduced pain (Jonsson and Alfredson, 2005). Although different measures in different research settings may be the reason for the conflicting findings with regard to the effect of contraction modes on PT, we believe that these studies could help explain our results, that is, more pain during concentric contractions might be one of the factors that contributed in part to our results. Furthermore, it could support recent trials on the conservative treatment of PT with eccentric quadriceps training, in which a rehabilitation program could be more successful than concentric training (Jonsson and Alfredson, 2005; Rabin, 2006; Rees et al., 2009; Young et al., 2005).

We compared the isokinetic performance of the groups at testing velocities of 60°·s⁻¹, 180°·s⁻¹, and 300°·s⁻¹ in order to cover the various speed specific torques produced during the Fente motion. Muscles produce greater concentric forces at slower velocities, whereas eccentric strength stays the same or increases slightly as velocity increases (Boling et al., 2009), as shown in our results. Accordingly, isokinetic concentric strength test at a lower angular velocity would impose more force on the patellar tendon than that at a higher velocity. Therefore, the greater concentric contraction of the quadriceps at a lower angular velocity would compromise the isokinetic tests more significantly in participants with symptomatic PT. This is in keeping with our results in which concentric peak torque/BW and work/BW were significantly decreased at the lower range of angular velocities in affected female fencers although there were no participants who complained a considerable pain enough to ask for stopping the test.

Considering that P2 consists of concentric knee extension, reduced angular velocity during the backward Fente motion (P2) appeared to be related to decreased concentric contraction of the quadriceps. However, the isokinetic measures were performed as open kinetic chain exercises by its nature whereas the Fente motion was performed as closed kinetic chain exercise. Therefore, we are not sure whether the kinematic and isokinetic results correlate with each other, as the relationship between isokinetic assessment and functional performance is still unclear (Augustsson and Thomeé, 2000).

In the present study, we examined elite fencers who were participating fully in training and competition at the national training center of the KOC. Therefore, our results should be interpreted cautiously, as they describe a select group of elite fencers of similar age, level of symptoms, duration and intensity of training, and sporting ability. We used a subjective categorical classification for the tendon pain, where 'mild' was defined as VAS score of being 0-3 inclusive because we are unaware of specific validity and reliability data available for the VAS score in the assessment of the patellar tendon pain. Because we recruited elite fencers with the mild tendon pain, the data may not be applicable to all fencers or to other athletes of different sports who are suffering from a different severity of PT. In addition, although the Biodex System 3 Dynamometer has been shown to produce highly significant reliability in assessing clinically relevant measures of human muscle function (Drouin et al., 2004; Feiring et al., 1990), it should be noted that there still is a possibility of the potential technical error of the equipment in the present study because we didn't provide our own reliability data for the isokinetic testing. Therefore, we look forward to further advanced studies investigating the relationship of PT to the biomechanics of athletes' performance and to actual sporting ability in many kinds of sports events. Our study was a case-control study with a relatively small number of participants. Although several significant results were reported, these data need further verification through a prospective cohort study with a large sample size.

Conclusion

In the present case-control study, mild symptomatic PT seems to influence elite female fencers performing the isokinetic concentric contraction of the quadriceps and the angular velocity during the backward Fente motion. It may be reasonable to speculate that elite female fencers who are participating fully in training and competition are more likely to be affected substantially by symptomatic PT in their sporting ability than male fencers.

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Key points

- It is likely that even mild symptomatic patellar tendinopathy could affect the athletic performances in elite fencers.
- Elite female fencers are more likely to be affected substantially by symptomatic patellar tendinopathy in their sporting ability than male fencers.
- Because weak concentric knee extensors may affect the performance in fencing, not only eccentric training for symptomatic patellar tendinopathy but also proper concentric training of the quadriceps may be helpful in a rehabilitation program of elite female fencers who are participating fully in their training and competition.

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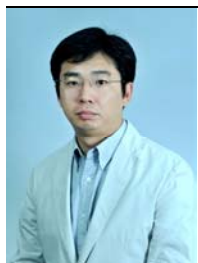
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