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Correlation between contractile properties of quadriceps muscle and functional performance in runners with patellofemoral pain syndrome

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ABSTRACT

Background: Long distance runners commonly complain from patellofemoral pain syndrome (PFPS) that limits their performance and return to sport. Abnormal neuromuscular control of the quadriceps has been demonstrated to cause patellar mal-tracking and hence PFPS. Changes in muscle morphology and neural activity have a role in neuromuscular changes, a key contributor to either primary or secondary injuries. Poor landing mechanics, impaired postural control, as well as changed peripheral muscle activation are all clinical manifestations of neuromuscular control deficiencies caused by central nervous system defects that have a deleterious effect on the contractile characteristics of skeletal muscle. **Objectives:** The purpose of this study was to investigate the correlation between contractile properties of quadriceps muscle and functional performance in long distance runners with PFPS. **Study design:** Cross-sectional study. **Methods:** Thirty runners were recruited form multiple Egyptian clubs. Tensiomyography (TMG) Parameters were assessed regarding Contraction time (Tc), Maximal displacement (Dm), Sustain time (Ts), Relaxion time (Tr) and Delay time (Td) in Rectus femoris (RF), Vastus medialis (VM) and Vastus lateralis (VL) separately and correlated with functional performance; number of repetitions in 30 seconds for anteromedial lunge test, balance and reach test and step-down test. **Outcome measures:** Functional performance was measured using functional performance tests; anteromedial lunge test, balance and reach test and step-down test. **Results:** It was found that VM Tc, VL Dm, were moderately positively correlated with anteromedial lunge ($r = 0.583, 0.404, p<0.05$) respectively. In contrast, RF Tr was negatively correlated with anteromedial lunge ($-0.364, p<0.05$);

VM Ts,Tr,Dm; VL Td were moderately negatively correlated with balance and reach (r = --0.577, -0.388, 0.655 and -0.385, respectively, p<0.05). In contrast, VL Tc was moderately positively correlated with step-down (r = 0.424, p = 0.019). **Conclusion:** All contractile properties of quadriceps muscle are significantly correlated with functional performance in long distance runners with PFPS. Future studies should address these properties, using proper rehabilitation strategies, to improve performance of runners with PFPS.

KEYWORDS

Running related musculoskeletal injuries; Patellofemoral pain syndrome; Tensiomayography; Functional performance.

1. INTRODUCTION

Long-distance running is one of the most popular sports (Van Gent et al., 2007; Van Middelkoop et al., 2008a; Van Poppel et al., 2014). Running related musculoskeletal injuries commonly affect lower limb and especially the knee (Van Middelkoop et al., 2008a, b; Chang et al., 2012; Lopes et al., 2012; Van Hespen et al., 2012; Van Poppel et al., 2014) and had significant negative financial and physical impact on patients limiting their participation. Therefore, rehabilitation intervention strategies are needed (Van der Worp, et al., 2015).

In active individuals, patellofemoral pain syndrome (PFPS) is the most frequent overuse injury of the lower extremities. For example, every year there are over 2.5 million runners who are diagnosed with PFPS. It was found that women have a higher risk of PFPS than men. Recurrent or chronic pain affects 70%-90% of individuals with PFPS (Davis and Powers, 2010) Furthermore, previous study shows that having PFPS as a young adult may increase the risk of developing patellofemoral osteoarthritis in old age (Utting et al.,2005; Thomas et al., 2010; Myer et al., 2010)

The etiology of PFPS has not yet been clearly identified, however, imbalance of the quadriceps musculature, high Q angle, repeated microtrauma to the soft tissue (Ng et al., 2008; Kamatsuki et al., 2018) abnormal neuromuscular control of the vastus medialis obliquus (VMO) as well as VL and maltracking of the patella (Ng and Wong, 2009; Heiderscheit, 2010; Powers. 2010; Souza et al., 2010; Davis and Powers, 2010) are the potential factors that may lead to patellofemoral pain.

The targeted muscle's contraction speed is reflected in a contractile property known as Tc, or the time it takes the muscle to contract between 10% to 90% of its resting length of contraction (Dahmane et al., 2005; Simunic et al., 2017). Ts, defined as the amount of time between the 50% of Dm on either side of the twitch curve, provides a theoretical evaluation of muscle fiber fatigability state (Tous-Fajardo et al., 2010; García-Manso et al., 2011). In addition, the duration of the twitch is represented by Tr, which is the period from 90% to 50% of Dm within the descending curve (Macgregor et al., 2018). Td, or the delay time, is the amount of time that passes between when a muscle's electrical activity starts and when the muscle contracts (Ristanis et al., 2009) is related to athletic performance (Georgoulis et al.,2005; Stemper et al., 2006; Samozino et al.,2007). Muscle transmission of force is accelerated and performance is enhanced with a shorter Td. Td is affected by muscle fatigue (Yavuz et al.,2010), muscle length (Muraoka et al.,2004), muscle training (Kubo et al.,2001; Linford et al.,2006; Grosset et al.,2009), passive muscle stretching (Costa et al.,2012), and the type of muscle activation (Kaneko et al.,2002). Lastly, Dm is the millimeter-based radial movement of the muscular belly, which is dependent on of muscle tone or stiffness and it represents the maximal amplitude of the muscle contraction (Martín-Rodríguez et al., 2017).

Therefore, the aim of the current study is to correlate quadriceps muscle contractile properties with functional performance in runners with PFPS.

2. METHODS

This study was conducted in Haven Cleopatra Hospital in Giza, Egypt, from September 2021 to January 2023, to investigate the correlation between quadriceps muscle, rectus femoris (RF), vastus lateralis (VL) and vastus medialis (VM) contractile properties and functional performance (Anteromedial lunge test, Balance and reach test and Step-down test) in runners with PFPS.

Ethical approval was obtained from the Faculty of Physical Therapy, Ethics and Research Committee at Cairo University (Ethics ID Number: P.T.REC/012/003382).

In order to detect a correlation (r) of 0.5 between muscle contractile properties and performance, based on work of Marinšek and Pavletič (2020), with 80% power (Effect size = 0.8, large effect), Power analysis suggests we would need a total of 30 participants using bivariate normal correlation model.

2.1. Participants

Thirty long-distance runners from Egyptian clubs with PFPS (19 males and 11 females) participated in this study. All participants were (1) between the ages of 18 and 30; (2) regular runners who covered at least 15 kilometers in the week preceding to enrollment; (3) free of a history of rheumatoid, inflammatory, as well as neurologic pathology; (4) uninjured in the lower extremities at the time of enrollment.

A runner who have PFPS were included if they had experienced anterior knee pain for at least three months before to the study. They also had to experience pain of a minimum of 3/10 on a visual analogue scale (VAS) when running or participating in at least three of the following activities: climbing or descending stairs, kneeling, squatting, resisted knee extension, as well as sitting for a prolonged period of time (Labella et al., 2004).

The current study excluded athletes who have foot deformities, either structural or functional leg length discrepancy, biomechanical problems influencing ability to walk as well as performance, a past medical history involving lower- extremity or back surgery.

2.2. Procedures

2.2.1. Assessment of contractile properties

Tensiomyography (TMG), as shown in Fig. 1, was utilized to identify muscle belly enlargement in a transverse plane throughout an isometric muscle contraction (Valenčič,.1990) by utilizing digital high-precision inductive displacement sensor (GK40, Panoptik, Ljubljana, Slovenia) pushed by a spring (0.17 N/mm) on the muscle belly throughout the measurement to ensure a high signal-to noise ratio as well as high reliability (Đorđević et al., 2022). The sensor was placed over the muscle belly on the skin at right angles to the tangential plane. At first, the sensor registered a pressure of around 1.5 x 102 N/mm2 on its tip area of 11.34 mm2 (Valle et al., 2017). Because the distance among electrodes can change the results (Wilson et al., 2018), we used a pair self-adhesive electrodes (5 x 5 cm), with the negative electrode (anode) positioned 5 cm proximally while the positive electrode (cathode) positioned 5 cm distally (Dahmane et al., 2001; Morales-Artacho et al., 2015; Piqueras et al., 2020). Following the procedure, none of the subjects complained of feeling discomfort.

The TMG measurements and procedures in the current study were done according to the work of Loturco et al. (2018). Five parameters: Maximal displasment (Dm), contraction time (Tc), sustain time (Ts), relaxation time (Tr) and delay time (Td) were collected and documented for the VM, RF and VL of the involved and uninvolved limb. All of the measures were carried out while the subjects were in comfortable, pre-defined postures.

Figure 1. TMG-S1

Athletes were measured for RF (Fig. 2) muscle while lying supine on a triangular wedged foam cushion that kept their legs at an angle of 120 degrees of knee flexion. The anterior superior iliac spine (ASIS) as well as the upper border of the patella served as reference points for the placement of the sensor on the anterior thigh. The supine position was used for the VM and VL measurements, with the knee flexed to 30 degrees (0 being the fully extended position). In terms of lateral (VL) and medial (VM), electrodes were positioned 4 fingerbreadths proximally to the upper-medial angle of the patella as well as one handbreadth above the patella, respectively.

Figure 2. Rectus femoris TMG measurement

Following electrode placement, 10 mA electrical stimulation was applied at 5 second intervals (Križaj et al., 2008). The current increase was 20 mA until reaching the supramaximal muscle response (90–110 mA) according to (Tous-Fajardo et al., 2010).

2.2.2. Assessment of functional performance:

Three functional performance tests were performed in this study and were reliable and valid as the main functional tests specified for PFPS functional assessment tests (Loudon et al., 2002). Before measuring, all individuals performed about 10 minutes of warming up. The athletes performed 3 tests in randomized order for both limbs: (a) Anteromedial lunge, (b) Step-down and (c) Balance and reach test. For each test, athletes were allowed a non-counted trial test before starting the actual test.

The anteromedial lunge, with the individual lined up behind the starting line. The individual was asked to lunge forward with the unaffected limb, bending the front leg to a 90-degree angle and crossing across the midline. The athlete allowed 3 reaches and the maximal distance of 3 trials was recorded and marked at the heels level. A piece of tape was placed at 80% of the maximum distance to serve as a benchmark for the series of the timed lunges. Athletes were instructed to perform as many lunges as they could with the sound limb, then by the affected limb, in 30 seconds, each of the lunges below 80% not being recorded (Fig.3) (Loudon et al., 2002).

Figure 3. Anteromedial lunge test

The step-down is a one sided test carried out on a platform that is 8 inches (20.32 cm) in height. Athletes made one step forward and downward on the ground. In order to complete one repetition, the down leg must briefly touch the floor using the heel before returning to full knee extension. Every set was done without using the step limb to help the individual get back up on the step. Subjects were assessed on their ability to do a certain number of repetitions within 30 seconds, and both limbs were evaluated (Loudon et al., 2002).

The participants lined up behind a starting line for the balance and reach test. Athletes put most of their weight on their (tested) leg while extending one leg straight in front of them till the heel touched the ground. The unaffected limb was examined initially. The starting line to the foot's heel distance was measured. Three separate trials' maximum distances were measured and recorded. A tape measure was used to mark 80% of the maximum distance. Athletes were timed for 30 seconds as they attempted as many balance-and-reach lunges as they could with both legs (Loudon et al., 2002).

2.3. Statistical analysis

Descriptive statistics were conducted to present the measured variables. Repeated measures MANOVA was conducted for comparison of functional performance and contractile properties of quadriceps muscle between the affected and non-affected sides. Pearson Correlation Coefficient was conducted to determine the correlation between functional performance and contractile properties of quadriceps muscle. All statistical tests were performed at the p-value less than 0.05 level of significance. The Windows version of the SPSS statistical software (version 25) was used for all analyses. (IBM SPSS; Chicago; IL; USA).

3. RESULTS

Demographic and clinical characteristics of all patients included in this study were presented in table 1.

Table 1. Descriptive statistics, demographic and clinical data of all patients.

	$\bar{X}$ **±SD**
Age (years)	22.83 ± 3.27
Weight (kg)	64 ± 6.55
Height (cm)	174.1 ± 4.60
BMI (kg/m²)	21.11 ± 2.02
VAS	6.6 ± 1.45
	Frequency (percentage)
Females	11 (36.7%)
Males	19 (63.3%)
Dominant side affected	19 (63%)
Presence of previous injury before past 3 month	18 (60%)

$\bar{X}$ *: Mean* *SD: Standard Deviation*

Relationship between functional performance and contractile properties of affected side

The VM Tc, VL Dm, and RF Tr were moderately significantly correlated with anteromedial lunge (r = 0.583, 0.404, and -0.364, respectively). In contrast to VM Tc and VL Dm that were positively correlated, RF Tc was negatively correlated. The VL Tc was moderately positively significantly correlated with step-down (r = 0.424, p = 0.019). The VM Ts and Tr, and VL Td were moderately negatively significantly correlated with balance and reach (Table 2).

Table 2. Correlation between functional performance and contractile properties of affected side

Contractile properties of the affected side	Functional performance of affected side (Rep/30s)					
	Anteromedial lunge		Step-down		Balance and reach	
	r value	p value	r value	p value	r value	p value
Tc (ms)						
Rectus femoris	-0.175	0.355	0.166	0.379	-0.005	0.980
Vastus lateralis	0.138	0.466	**0.424**	**0.019***	-0.141	0.457
Vastus medialis	**0.583**	**0.001***	0.034	0.856	0.193	0.308
Ts (ms)						
Rectus femoris	-0.155	0.414	0.148	0.434	-0.079	0.677
Vastus lateralis	0.118	0.533	0.275	0.141	0.056	0.770
Vastus medialis	0.301	0.106	0.124	0.512	**-0.577**	**0.001***
Tr (ms)						
Rectus femoris	**-0.364**	**0.048***	-0.110	0.564	-0.116	0.542
Vastus lateralis	0.236	0.210	0.284	0.128	0.263	0.160
Vastus medialis	0.042	0.828	-0.299	0.108	**-0.388**	**0.034***
Td						
Rectus femoris	-0.061	0.749	0.012	0.951	0.072	0.704
Vastus lateralis	0.012	0.950	0.017	0.931	**-0.385**	**0.035***
Vastus medialis	-0.173	0.360	0.253	0.177	-0.081	0.669
Dm (mm)						
Rectus femoris	0.249	0.185	0.207	0.272	-0.192	0.310
Vastus lateralis	**0.404**	**0.027***	0.263	0.160	-0.079	0.679
Vastus medialis	0.268	0.152	-0.225	0.231	**-0.655**	**0.001**

*r value: Pearson correlation coefficient; p value: Probability value; *: Significant*

Comparison of functional performance between affected and non-affected sides

The mean value ± SD of functional performance test scores (anteromedial lunge, step-down, and balance and reach) of affected and non-affected sides were showed in table 2. There was a substantial difference in functional performance test scores (anteromedial lunge, step-down, and balance and reach) between affected side and non-affected, in favor of the non-affected side (p = 0.001) (Table 3).

Table 3. Comparison of functional performance between affected and non-affected sides.

Functional performance test (Rep/30s)	Affected sides $\overline{X} \pm$ SD	Non-affected side $\overline{X} \pm$ SD	MD	F- value	p-value	Sig
Anteromedial lunge	14.30 ± 2.15	15.66 ± 2.26	-1.36	22.89	0.001	S
Step-down	15.90 ± 5.24	20.86 ± 4.86	-4.96	15.98	0.001	S
Balance and reach	16.90 ± 4	19.33 ± 5.07	-2.43	5.22	0.03	S

$\overline{X}$: Mean; SD: Standard deviation; MD: Mean difference; p value: Probability value; S: Significant

Comparison of contractile properties between affected and non-affected sides

The mean value ± SD of quadriceps (RF, VM, and VL) contractile properties (Tc, Ts, Tr, Td, and Dm) of affected and non-affected sides were showed in table (4). There was a substantial difference in favor of all contractile properties (except Td) of rectus femoris, VM Tr and Dm of affected side compared with that of non-affected side (p <0.05), and significant difference in favor of VL Dm and Ts (p <0.05) (Table 4).

Table 4. Comparison of contractile properties of quadriceps between affected and non-affected sides.

Contractile properties	Affected sides $\overline{X} \pm$ SD	Non-affected side $\overline{X} \pm$ SD	MD	F- value	p-value	Sig
Rectus femoris						
Tc (ms)	28.21 ± 6.48	25.25 ± 6.01	2.96	8.59	0.007	S
Ts (ms)	119.27 ± 38.27	84.11 ± 32.89	35.16	41.02	0.001	S
Tr (ms)	58.50 ± 19.70	38.72 ± 21.61	19.78	14.90	0.001	S
Td (ms)	30.82 ± 8.06	31.12 ± 13.04	-0.3	0.03	0.86	NS
Dm (mm)	5.17 ± 2.26	4.22 ± 2.33	0.95	10.03	0.004	S
Vastus lateralis						
Tc (ms)	20.02 ± 3.98	20.84 ± 3.66	-0.82	0.99	0.32	NS
Ts (ms)	56.91 ± 27.49	80.53 ± 29.91	-23.62	29.40	0.001	S

Tr (ms)	27.06 ± 17.52	31.44 ± 23.55	-4.38	1.12	0.29	**NS**
Td (ms)	26.54 ± 6.68	27.26 ± 6.33	-0.72	0.23	0.63	**NS**
Dm (mm)	2.68 ± 0.84	3.42 ± 1.18	-0.74	14.72	0.001	**S**
Vastus medialis						
Tc (ms)	22.87 ± 6.03	22.42 ± 5.61	0.45	0.11	0.73	**NS**
Ts (ms)	139.49 ± 40.36	135.66 ± 39.41	3.83	0.22	0.63	**NS**
Tr (ms)	50.85 ± 21.38	42.15 ± 17.93	8.7	7.09	0.01	**S**
Td (ms)	24.40 ± 5.78	25.79 ± 6.88	-1.39	1.18	0.28	**NS**
Dm (mm)	4.44 ± 1.94	3.38 ± 1.58	1.06	14.06	0.001	**S**

$\overline{X}$*: Mean; SD: Standard deviation; MD: Mean difference; p value: Probability value; S: Significant; NS: Non-significant*

4. DISCUSSION

Researchers hypothesized that contractile properties of quadriceps muscle would be correlated with functional performance. Results of the present study failed to reject this hypothesis as there were significant correlations among most of contractile properties and performance, further there was a significant decline in performance in the affected knees.

Reduced strength performance was positively correlated with changes in TMG muscle characteristics, as reported by Hunter et al. (2012) (r = 0.64–0.67, p<0.05)

Davis and Powers (2010) reported that decreased flexibility, quadriceps muscle strength as well as muscle imbalance among vastus medialis obliques (VMO) and VL are risk factors for PFPS.

On the other side the results of the present study found that increased stiffness (lower Dm) of VL and fatigue (increased Tr and Ts) in RF and VM.

Functional performance in affected vs. non-affected side

The results of the current study showed significant difference in all functional performance tests (Anteromedial lunge, Step-down and Balance and reach tests) between both sides in favor of the non-involved side (p=0.001, 0.001, and 0.03, respectively).

The interpretation of the above results supports that runners with PFPS show significantly decrease in their functional performance which will affect their performance in training and competitions.

Long-distance runners have high endurance. However, they also have high power due to neuromuscular development that improves running economy and time-trial performance (Bompa and Buzzichelli, 2018). In addition, endurance runners tend to have reduced RF Tr and Ts and increased Dm especially after acute endurance training. Presence of PFPS reverses these characteristics of long-distance runners leaving them with high fatigue (especially in vasti) and low speed during functional performance (Loturco et al, 2015).

In comparison between contractile properties of the affected and non-affected side of VM it was found that the only affected contractile property parameter in the affected side was the Tr and Dm which increased showing that both VM and RF that may affect excitation contraction coupling inducing fatigue and maybe the cause of prolongation of Tc and Tr either in RF or VM.

While regarding RF, it was found that there was an increase in Ts and Dm in the affected side which means that the muscle able to displace and sustain without early fatigability maybe because the muscle is structured as a slow twitch endurance muscle. The Dm and Ts of VL were decreased showing that the VL in the affected side is stiff and unable to displace efficiently and also fatigues easily. muscular belly radial stiffness has been measured using Dm, and a smaller value for this parameter suggests a more flexible muscular belly. (Hunter et al., 2012; García-Manso et al., 2012; Rey et al., 2012).

The present study failed to support the previous findings that PFPS have an imbalance in the VMO in relation to the VL (normal ratio is 1:1) (Soderberg and Knutson, 2000), as well as delayed onset of activation of VMO in comparison with VL in their functional activity (Cowan et al., 2001; Makhsous et al., 2004; Boling et al., 2006; Wong. 2009; Kim and Song, 2012). This contrasting result may be explained by differences between studies in the type of activity (functional performance test vs. isometric contraction).

Correlation between Rectus Femoris Contractile Properties and Functional Performance Tests

The results of the current study regarding RF contractile properties showed that there is a moderate negative significant correlation between Tr and anteromedial lunge test in the affected side.

In contrary to the current study, Studies have shown that there is a moderate negative correlation (0.3-0.5) among the performance decline and the fluctuation of the Tc as well as among performance decline and the fluctuation of the Dm in the RF. These correlations suggest that smaller shifts in the RF's Tc and Dm are associated with larger decrements (defined as significant declines in performance).

It is possible that the baseline contractile muscle characteristics have a significant effect on players' performance in both high and low intensity activities (Sánchez-Sánchez et al., 2018).

In a 2015 study, Gil et al. examined the correlation between two TMG characteristics (Dm and Tc) and the jumping and sprinting capabilities of 20 professional soccer players. Consistent with our findings, they also observed a significant negative correlation between RF Dm and contact time. (Marinšek and Pavletič, 2020).

The decline in muscle stiffness demonstrated by the enhancement of the Dm in VL is created as a result of fatigue and indicates a loss of strength as well as explosive potential, decreasing the capacity to produce strength rapidly (Macdonald et al., 2013). An unfamiliar increase of the Dm can demonstrate chronic fatigue and this could explain the significant increase in RF and VM of the affected side in the current study (Loturco, et al., 2015).

Although Ts time in the current study seems to be high but it is crucial to state that Muscle fatigue, especially in the lower extremities, has been linked to an increased risk of injury (Greig. 2008; Small et al., 2010). Muscle contraction velocity, muscle belly displacement, and muscular stiffness are all additional considerations (Rey et al., 2012).

Muscle fatigue is linked to larger values of the time variables (Td, Tc, Ts, as well as Tr). All three time variables of the RF in the affected limb (Tc, Ts, and Tr) were shown to be increasing in the current study. This suggests that PFPS has a cumulative influence on the contractile properties of the RF muscles and causes muscular fatigue (Križaj et al., 2008; Rusu et al., 2013).

A significant correlation was reported among TMG parameters and jumping performance, supporting our findings (Loturco et al., 2015).

Correlation between Vastus-Medialis Contractile Properties and Functional Performance Tests

The results of the current study regarding VM contractile properties showed that there is a moderate positive significant correlation between Tc of VM of affected side and anteromedial lunge test($r=0.58$). There was moderate negative correlation between Ts, Dm, and Tr of VM and balance and reach test in the affected side.

It can be difficult to understand this behavior because to the variability of these parameters as well as the probable consequences of the co-activation of other surrounding muscles during the TMG assessment (Rodrguez et al., 2013). In order to characterize the performance, additional studies using different methods are required (Dogramaci et al., 2011).

The explanation of more significant correlations between VM contractile properties and functional performance may be due to important functions of this muscle for knee mobility and stability. It controls the knee's range of motion (ROM) by adjusting the length of the quadriceps muscle group along with extending the knee, which is particularly important near the end of the ROM and represents a dynamic restraint to lateral tracking of the patella (Grob et al., 2018).

Whereas muscular force is usually considered as the most indicative measurement of a muscle's functional capacity (Jackman et al., 2010) and fatigue studies are commonly based on measurements of muscle force (Skurvydas et al., 2010).

The current study found that as VM Dm increases (i.e., improvement in stiffness), functional performance increases. This is supported with the report that power performance in jumping is related to muscle stiffness represented in Dm (Arampatzis and Schade, 2001; Chelly and Denis, 2003; Watsford et al., 2010).

Correlation between Vastus-Lateralis Contractile Properties and Functional Performance Tests

In light of the current study, it was found that there is moderate positive correlation in VL Tc with step down test and Dm with anteromedial lunge test, while Td was correlated moderately negative with balance and reach test in affected side.

In agreement with our study regarding VL positive association between Dm and performance, Hunter et al. (2012) found that muscle fatigue is associated with Dm decrease. However, in contradiction with Hunter et al. (2012) the current finding revealed that increase in time of muscle contraction is associated with improved performance and reported that increased Tc is associated with fatigue. These differences may be due to differences in muscle studied (quadriceps vs. biceps brachii) and activity applied (functional performance test vs. eccentric isokinetic contractions).

Consequently, and supporting results of the current study, lower Dm which corresponds to a greater muscle stiffness and lower Tc which corresponds to higher contraction velocities could indicate superior jumping performance (Marinšek and Pavletič, 2020).

The decreased effectiveness of the excitation-contraction coupling, deterioration in membrane conducting characteristics, and degradation of cellular structure may all contribute to a reduction in Dm, Tc, and a rise in Td. Muscle function is impaired because of a corresponding increase in passive cellular structural stress and resulting inability to completely activate the contractile machinery (reduced amount of crossbridge bindings) (Murayama et al., 2000; Warren et al.,2001; Byrne et al., 2004; Hunter et al., 2012). Altered intracellular Ca2+ regulation or sarcoplasmic reticulum Ca2+

release rate may be the cause behind reduced Dm (Allen. 2009; García-Manso et al., 2012). The Dm as well as contraction velocities may be useful indicators of fatigue because they appear to be valid measurements for neuromuscular assessment (De Paula Simola et al., 2015).

In line with the current study finding, De Paula Simola et al. (2015) found that Tc is associated positively with Dm, However, they contrasted our finding and reported no correlation between Tc and maximum voluntary isometric contraction (MVIC). This contrast may be due to difference in the activity applied (functional performance test vs. MVIC).

In agreement with the current study result, TMG characteristics have been shown to have a positive correlation with the explosive function of leg muscles when performing jumping skills (Marinek & Pavleti, 2020). Lower muscle stiffness is related to better jumping performance, and they discovered a positive correlation among Tc and Dm of VL as well as squat jump velocity. Increase in onset delay of VM even a short delay of 5 ms may result in mal-tracking of the patella as a result of exagerated lateral pulling (Voight and Wieder. 1991; Neptune et al., 2000; Cowan et al., 2002), thereby damaging the PFJ and decreasing functional performance (Grabiner et al., 1994; Ng et al., 2008).

The VMO and VL need to be stimulated at the right time to regulate mediolateral patellar motion and ensure proper knee joint function. Loudon (2016) states that the VMO muscle fibers lie at a 55˚ oblique angle to the patella. This arrangement provides better mechanical support for medial patellar stability compared to VL fibers, which terminate at an angle of only 15 degrees. Postural feedforward causes the VMO and VL to start contraction (Cowan et al., 2001). Normal patellar posture is maintained when the VMO is activated prior to the VL. According to the sequence of anticipatory activation, this type of VMO anticipation provides a mechanical benefit in maintaining of mediolateral balance (Neptune et al., 2000).

In summary, the contractile profile of Egyptian long distance runners presented in the study provides insights on the muscular properties of long distance runners with PFPS at the season's half. Physical therapists and coaches can utilize these findings as a benchmark against which to develop individualized training and rehabilitation plans for their athletes. In conclusion, this study supports the findings of Sánchez-Sánchez et al. (2018) in confirming that TMG as a sufficiently sensitive tool for identifying mechanical changes and help understand the way these changes impact the capacity of runners suffering from PFPS to exert intermittent effort at high levels of intensity.

The reason beyond selection of the sample from long distance runners only is for the particular reason that power as well as endurance athletes are believed differ greatly in muscle fiber type composition in addition to mechanical reactions to maximal voluntary and evoked twitches. Sprinters, in contrast to middle- and long-distance runners, typically favor a forceful muscle contraction in response to internal or external overloads, as a result of their dominance of fast fiber type (Loturco et al., 2015), and due to the same training type, load, duration, and intensity.

Selection of specific runners with PFPS, this is because of large disparity in predisposing factors causing this type of injury especially among runners with the selected age range because power and endurance athletes are thought to markedly differ in muscle fiber type composition and mechanical responses to maximal voluntary and evoked twitches (Loturco et al., 2015; Davies et al., 2015).

This study is not without limitations. The number of runners was too small to identify correlation between all quadriceps muscle contractile properties as well as functional performance for those runners with PFPS, and the reason behind this was the small number of long-distance runners compatible with the criteria of selection of subjects and PFPS dysfunction.

In conclusion, most of contractile properties of quadriceps muscle are significantly correlated with functional performance in long distance runners with PFPS. Future studies should address these properties, using proper rehabilitation strategies, to improve performance of runners with PFPS.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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