Acta Orthopaedica et Traumatologica Turcica 53 (2019) 272–277

Contents lists available at ScienceDirect

Acta Orthopaedica et Traumatologica Turcica

journal homepage: https://www.elsevier.com/locate/aott

Ultrasonographic assessment of quadriceps and patellar tendon thicknesses in patients with patellofemoral pain syndrome

Ahmet Özcan Kızılkaya [a, *], Hilal Ecesoy [b]

[a] Department of Physical Therapy and Rehabilitation, Konya Academy Hospitals, Konya, Turkey
[b] Department of Physical Therapy and Rehabilitation, Necmettin Erbakan University, Meram Faculty of Medicine, Konya, Turkey

ARTICLE INFO

Article history:
Received 8 August 2018
Received in revised form
28 January 2019
Accepted 23 April 2019
Available online 15 May 2019

Keywords:
Patellofemoral pain syndrome
Ultrasonography
Quadriceps tendon thickness
Patellar tendon thickness
Patellar tendon area

ABSTRACT

Objective: The aim of this study was to compare ultrasonographically measured quadriceps and patellar tendon thicknesses between Patellofemoral Pain Syndrome (PFPS) patients and age- and gender-matched healthy controls.

Methods: Among patients who presented to physical therapy and rehabilitation outpatient clinic in January–December 2016, 61 volunteers (28 men and 33 women; mean age: 30.79 ± 6.55 years) who were eligible considering the inclusion and exclusion criteria were enrolled. 30 were diagnosed with PFPS, and the remaining were age- and gender-matched healthy volunteers. Mean age was 30.03 ± 5.67 years in healthy subjects and 45.2% were of male gender. The patient group had mean age of 31.57 ± 7.37 years and 46.7% of the patients were male. Q angles were measured at standing, supine and sitting positions. Patellar and femoral tendon thicknesses and areas were measured ultrasonographically. Kujala questionnaire were used to evaluate the functional status of the participants.

Results: No significant difference was detected between groups regarding profession, educational background, and body mass indices (BMI) ($p > 0.05$). Q angle values were significantly higher in the patient group when compared to controls at standing (17.03 ± 3.84 vs. 13.87 ± 1.75°, $p < 0.001$), supine (16.20 ± 3.74 vs. 13.45 ± 1.79°, $p = 0.001$) and sitting (16.50 ± 3.28 vs. 13.71 ± 1.72°, $p < 0.001$) positions. Kujala score was significantly lower in the PFPS group when compared to controls (70.57 ± 8.37 vs. 98.58 ± 2.05, $p < 0.001$). Patellar (0.39 ± 0.08 vs. 0.32 ± 0.05 cm, $p < 0.001$) and quadriceps (0.64 ± 0.10 vs. 0.52 ± 0.09 cm, $p < 0.001$) tendon thicknesses were significantly higher in the PFPS group when compared to controls. There was no significant difference between groups regarding patellar tendon areas ($p > 0.05$). Patellar tendon thickness values of ≥0.35 cm were found to have 66.7% sensitivity and 67.7% specificity for PFPS diagnosis in the ROC curve analysis (area under curve: 0.771, 95% confidence interval: 0.655–0.887, $p < 0.001$). Quadriceps tendon thickness values of ≥0.54 cm were found to have 80% sensitivity and 71% specificity for PFPS diagnosis in the ROC curve analysis (area under curve: 0.824, 95% confidence interval: 0.710–0.939, $p < 0.001$). In PFPS patients, quadriceps tendon thickness had significant positive correlation with age ($r = 0.405$, $p = 0.027$) and BMI ($r = 0.450$, $p = 0.013$); and significant negative correlation with Kujala score ($r = -0.441$, $p = 0.015$). In the multivariate regression analysis, quadriceps tendon thickness was independently associated with the presence of PFPS (Exp (B): 3.089, 95% confidence interval: 1.344–7.100, $p = 0.008$).

Conclusion: Our study demonstrates that ultrasonographically measured patellar and quadriceps tendon thicknesses are significantly higher in subjects with PFPS and particularly, quadriceps tendon thickness may be used for the diagnosis.

Level of Evidence: Level III, Therapeutic Study.

Introduction

Patellofemoral pain syndrome (PFPS) is a common clinical condition that is characterized by anterior knee pain.[1] Severe pain

* Corresponding author. Tel.: +905544619744.
E-mail addresses: draokizilkaya@hotmail.com (A.Ö. Kızılkaya), hllkocabas@yahoo.com (H. Ecesoy).

Peer review under responsibility of Turkish Association of Orthopaedics and Traumatology.

https://doi.org/10.1016/j.aott.2019.04.009

occurs in proximity of patella during flexion of the knee due to weight-bearing nature of the knee joint. Pain is positively correlated with the amount of stress on the joint.[1] PFPS is commonly encountered in runners and subjects younger than 40 years old.[1]

In PFPS, anatomic or functional abnormalities may be seen in patella, musculotendinous junctions, or both.[1]

Although not fully elucidated, PFPS is thought to be a multifactorial disease.[1] Abnormal lower extremity alignment (increased Q angle, genu valgum, tibia varum, structural abnormalities of the patella, etc.), weakness of the muscles located around the knee and hip joints and excessive physical activity are among the leading causes.[2] These are believed to result in impaired knee extension, increased patellofemoral contact pressure and patellofemoral joint stress, eventually leading to PFPS development.

Diagnosis of PFPS is made by clinical evaluation. History and physical examination have important role in diagnosis.[3] Kujala score and visual analog scale (VAS) may be used for the assessment of functional status and pain severity, respectively. In contrary, imaging modalities are of limited use in PFPS diagnosis. A specific imaging finding does not exist for PFPS and imaging modalities are frequently used for exclusion of alternative diagnoses.[4]

The possible changes in quadriceps and patellar tendon thicknesses in PFPS patients have not been evaluated yet. In this study, we aimed to compare quadriceps and patellar tendon thicknesses between control subjects and PFPS patients and determine whether tendon thicknesses had a diagnostic value in PFPS. In addition, we sought to investigate the relationship between quadriceps and patellar tendon thicknesses with functional scoring and pain severity in the patient group.

Materials and methods

Study population

Among patients who presented to physical therapy and rehabilitation outpatient clinic in January–December 2016, 61 volunteers who were found eligible were included in the study. Thirty participants were diagnosed with PFPS, the remaining 31 were age and gender-matched control subjects. Local ethics committee approved the study (2016/706) and informed consent was obtained from all participants.

Patients aged between 18 and 45 years and have recurrent knee pain episodes when crouching or anterior knee pain episodes after sitting with the knee flexed that lasted more than a month and positive patellar grind test were included in the study. All of the patients included in the study had knee MRI for the exclusion of other pathologies those may be related to the anterior knee pain. Patients with clinical symptoms related to other knee pathologies, patellar subluxation/dislocation, prior knee surgery, hip-spine related pain episodes, knee effusion, meniscal or intra-articular pathologies or lesions of ligaments, inflammatory diseases such as rheumatoid arthritis or ankylosing spondylitis were excluded.

Clinical evaluation

Detailed history and physical examination findings were recorded. In order to exclude other pathologies that cause knee pain; patellar plica tests (to exclude plica syndrome), Apley compression and distraction tests, McMurray tests, varus-valgus stress tests, anterior and posterior drawer tests, pivot shift and Lachman tests (to exclude meniscus and cruciate ligament injuries) were performed. Quadriceps and patellar tendons, bursae and iliotibial band were palpated to assess tenderness. VAS pain scores were recorded both at rest and during activity. Kujala anterior knee pain scale was used to assess functional status of patients. Q angle was evaluated at supine, standing and sitting positions with the knees flexed 90° using a goniometer.

Ultrasonography

An experienced and blinded physician, using a linear 7–12 MHz probe (GE Logiq P5), performed ultrasonographic evaluations. Patellar tendon thickness was measured as previously described by Skou et al by placing the probe longitudinally and measuring the region 1 cm distal to the patellar apex.[5] Patellar tendon area was measured axially from the region 1 cm distal to the patellar apex. Quadriceps tendon thickness was measured from the region 1 cm proximal to the patellar apex.

Statistical analysis

Shapiro–Wilk test was used to test whether parameters were normally distributed. Normally distributed parameters were presented as mean ± standard deviation and skewed continuous parameters were expressed as median (interquartile range defined as 25th percentile- 75th percentile). Categorical data was expressed as number and percentages and were compared using Chi-square test. Independent samples t-test was used to compare two groups of normally-distributed parameters. Correlation between two parameters was assessed using either Pearson's (in case of linear relationship) or Spearman's test (in case of non-linear relationship). Binomial regression analysis was performed to determine the independent associates of PFPS presence. ROC curve analysis was used to determine the sensitivity and specificity of tendon thicknesses for the diagnosis of PFPS. A two-tailed $p < 0.05$ was considered statistically significant.

Results

Baseline sociodemographic and clinical characteristics of the study population

Baseline sociodemographic and clinical characteristics of the study population are shown in Table 1. Mean age of the study population was 30.79 ± 6.55 years and 45.9% of them were of male gender. Age ($p = 0.367$), gender ($p = 0.906$), educational and occupational status ($p = 0.384$, $p = 0.190$ respectively) were similar in healthy control and patient groups. BMI was also similar in healthy control and patient groups ($p = 0.683$).

Q angle was significantly greater in the patient group compared to healthy controls (standing: $p < 0.001$, supine: $p = 0.001$, sitting: $p < 0.001$). Kujala score was significantly lower in the patient group compared to healthy controls ($p < 0.001$).

Patellar and quadriceps tendon thicknesses assessed using ultrasonography were significantly higher in the patient group compared to healthy controls (both $p < 0.001$). Patellar tendon area was similar in both groups ($p = 0.624$).

History and clinical assessment in the patient group

Details regarding history and clinical assessment in the patient group are shown in Table 2. Most of the PFPS patients (90%) had right-side dominance and the affected side was the right lower extremity in 73.3% of the patients. Median time from the onset of symptoms was 15 months and median duration of symptoms was 30 min. Median time to occurrence of knee pain with flexion was 5 min. Median VAS at rest and sitting were 0 and 6.5, respectively.

Table 1
Baseline clinical and sociodemographic characteristics of the study population (n = 61).

Parameters	Study group (n = 61)	Control group (n = 31)	Patient group (n = 30)	p value
Sociodemographic parameters				
Age, years	30.79 ± 6.55	30.03 ± 5.67	31.57 ± 7.37	0.367
Gender: male, n (%)	28 (45.9)	14 (45.2)	14 (46.7)	0.906
Educational status				
Primary school	4 (6.6)	2 (6.5)	2 (6.7)	0.384
Middle school	6 (9.8)	2 (6.5)	4 (13.3)	
High school	12 (19.7)	5 (16.1)	7 (23.3)	
University	28 (45.9)	15 (48.4)	13 (43.3)	
Master's degree	4 (6.6)	4 (12.9)	0 (0)	
Associate degree	7 (11.5)	3 (9.7)	4 (13.3)	
Occupational status				
Unemployed	6 (9.8)	2 (6.5)	4 (13.3)	0.190
Self-employed	18 (29.5)	8 (25.8)	10 (33.3)	
Public servant	23 (37.7)	13 (41.9)	10 (33.3)	
Laborer	7 (11.5)	6 (19.4)	1 (3.3)	
Student	7 (11.5)	2 (6.5)	5 (16.7)	
Clinical parameters				
Body mass index, kg/m^2	24.46 ± 3.73	24.62 ± 3.40	24.66 ± 4.09	0.683
Q angle°				
standing	15.43 ± 3.34	13.87 ± 1.75	17.03 ± 3.84	**<0.001***
supine	14.80 ± 3.20	13.45 ± 1.79	16.20 ± 3.74	**0.001***
sitting	15.08 ± 2.94	13.71 ± 1.72	16.50 ± 3.28	**<0.001***
ΔQ1	−0.28 ± 1.37	−0.26 ± 0.82	−0.30 ± 1.78	0.907
ΔQ2	−0.62 ± 1.44	−0.42 ± 092	−0.83 ± 1.82	0.271
ΔQ3	0.34 ± 1.48	0.16 ± 0.64	−0.53 ± 2.01	0.340
Kujala score	84.80 ± 15.34	98.58 ± 2.05	70.57 ± 8.37	**<0.001***
Ultrasonographic parameters				
Patellar tendon thickness, cm	0.35 ± 0.08	0.32 ± 0.05	0.39 ± 0.08	**<0.001***
Patellar tendon area, cm^2	0.85 ± 0.19	0.86 ± 0.15	0.84 ± 0.23	0.624
Quadriceps tendon thickness, cm	0.58 ± 0.11	0.52 ± 0.09	0.64 ± 0.10	**<0.001***

*p value < 0.05 denotes statistical significance.

Correlation and ROC curve analysis in the patient group

The correlations between patellar tendon thickness and clinical parameters are shown in Table 3. Patellar tendon thickness was not significantly correlated with BMI, age, Q angle (standing/supine/sitting) or Kujala score in subjects diagnosed with PFPS. In addition, no significant correlation was found between patellar tendon thickness and time from the onset of symptoms, duration of symptoms, and time to occurrence of knee pain with flexion or VAS at sitting. There was a statistically significant positive correlation between patellar tendon thickness and VAS at rest ($r = 0.396$, $p = 0.030$). No statistically significant correlation existed between patellar tendon thickness and patellar tendon area or quadriceps tendon thickness. ROC curve analysis revealed that a patellar tendon thickness ≥0.35 cm determined the presence of PFPS with a sensitivity and specificity of 66.7% and 67.7%, respectively (AUC: 0.771, 95% confidence interval: 0.655–0.887, $p < 0.001$).

Table 2
History and clinical assessment in the patient group (n = 30).

Parameters	Patient group (n = 30)
History	
Dominant side	
right, n (%)	27 (90.0)
left, n (%)	3 (10.0)
Affected side	
right, n (%)	22 (73.3)
left, n (%)	8 (26.7)
Time from the onset of symptoms, months	15 (19.5–42.0)
Duration of symptoms, minutes	30 (10–60)
Clinical assessment	
Time to occurrence of knee pain with flexion, minutes	5 (2–15)
VAS at rest	0 (0–2)
VAS at sitting	6.5 (6–8)

VAS, visual analog scale for pain.

The correlations between quadriceps tendon thickness and clinical parameters are shown in Table 4. Quadriceps tendon thickness was significantly correlated with BMI ($r = 0.405$, $p = 0.027$), age ($r = 0.450$, $p = 0.013$) and Kujala score ($r = -0.441$, $p = 0.015$). Quadriceps tendon thickness was also significantly correlated with patellar tendon area ($r = 0.715$, $p < 0.001$). On the other hand, no statistically significant relationship was detected between quadriceps tendon thickness and Q angle, patellar tendon thickness, VAS, time from the onset of symptoms, duration of symptoms or time to occurrence of knee pain with flexion. ROC curve analysis revealed that a quadriceps tendon thickness ≥0.54 cm determined the presence of PFPS with a sensitivity and specificity of 80% and 71%, respectively (AUC: 0.824, 95% confidence interval: 0.710–0.939, $p < 0.001$).

Independent associates of PFPS presence in the study population

Independent associates of PFPS presence were determined using binomial regression analysis and the results are given in Table 5. Following the univariate regression model, which included parameters that significantly differed between patient and control groups-namely patellar tendon thickness, quadriceps tendon thickness and Q angle (standing, sitting and supine)-, a multivariate regression model was applied. Q angle measured in standing (OR: 1.577, 95% confidence interval: 1.173–2.120, $p = 0.003$) and quadriceps tendon thickness (OR: 3.089, 95% confidence interval: 1.344–7.100, $p = 0.008$) were found to be independent associates of PFPS presence.

Discussion

Patellofemoral pain syndrome is known to account for 25% of the knee injuries.[6] Despite its high prevalence, no gold standard examination or imaging modality for PFPS diagnosis has been described. In our study, quadriceps and patellar tendon thicknesses

Table 3
The relationship between patellar tendon thickness and clinical parameters in the patient group (n = 30).

		Patellar tendon thickness, cm
Body mass index, kg/m^2	Pearson correlation coefficient	0.216
	P value	0.251
Age, years	Pearson correlation coefficient	0.139
	P value	0.464
Q angle (standing)°	Pearson correlation coefficient	0.030
	P value	0.876
Q angle (supine) °	Pearson correlation coefficient	0.124
	P value	0.513
Q angle (sitting) °	Pearson correlation coefficient	0.088
	P value	0.642
Patellar tendon area, cm^2	Pearson correlation coefficient	0.189
	P value	0.317
Quadriceps tendon thickness, cm	Pearson correlation coefficient	0.196
	P value	0.300
Kujala score	Pearson correlation coefficient	0.026
	P value	0.892
VAS at rest	Spearman correlation coefficient	0.396
	P value	**0.030***
VAS at sitting	Spearman correlation coefficient	0.051
	P value	0.787
Time from the onset of symptoms, months	Spearman correlation coefficient	−0.145
	P value	0.445
Duration of symptoms, minutes	Spearman correlation coefficient	0.170
	P value	0.369
Time to occurrence of knee pain with flexion, minutes	Spearman correlation coefficient	−0.187
	P value	0.321

VAS, visual analog scale for pain.
*p value < 0.05 denotes statistical significance.

Table 4
The relationship between quadriceps tendon thickness and clinical parameters in the patient group (n = 30).

		Quadriceps tendon thickness, cm
Body mass index, kg/m^2	Pearson correlation coefficient	0.405
	P value	**0.027***
Age, years	Pearson correlation coefficient	0.450
	P value	**0.013***
Q angle (standing)°	Pearson correlation coefficient	−0.213
	P value	0.259
Q angle (supine) °	Pearson correlation coefficient	−0.344
	P value	0.062
Q angle (sitting) °	Pearson correlation coefficient	−0.335
	P value	0.070
Patellar tendon area, cm^2	Pearson correlation coefficient	0.715
	P value	**<0.001***
Patellar tendon thickness, cm	Pearson correlation coefficient	0.196
	P value	0.300
Kujala score	Pearson correlation coefficient	−0.441
	P value	**0.015***
VAS at rest	Spearman correlation coefficient	0.230
	P value	0.221
VAS at sitting	Spearman correlation coefficient	0.050
	P value	0.793
Time from the onset of symptoms, months	Spearman correlation coefficient	−0.181
	P value	0.339
Duration of symptoms, minutes	Spearman correlation coefficient	−0.195
	P value	0.301
Time to occurrence of knee pain with flexion, minutes	Spearman correlation coefficient	−0.240
	P value	0.201

VAS, visual analog scale for pain.
*p value < 0.05 denotes statistical significance.

measured using ultrasonography in PFPS patients have been compared with that of the age and gender-matched control subjects for the first time in the literature. Our findings suggest that patellar and quadriceps tendon thicknesses are significantly increased in PFPS patients and quadriceps tendon thickness may be used to determine PFPS presence.

Factors that have a role in PFPS pathogenesis may be classified under three main groups: factors related to the joint (local factors), factors related to the lower extremity biomechanics and factors related to exercise.[7] Patellar hypermobility, weakness of quadriceps muscle and lack of flexibility of the soft tissue are among the local factors. Pelvic muscle dysfunction and gait abnormalities are among factors related to the lower extremity biomechanics.[7]

Quadriceps muscle is among the most important supporting structures of the patellofemoral joint. Observational studies have reported decreased quadriceps torque in subjects diagnosed with

Table 5
Independent associates of Patellofemoral Pain Syndrome presence.

	B	S.E.	Wald	df	p value	Exp(B)	95% CI for EXP(B)	
							Lower limit	Upper limit
Univariate analysis								
Patellar tendon thickness, mm	1923	0.594	10,487	1	**0.001***	6841	2136	21,905
Quadriceps tendon thickness, mm	1305	0.348	14,099	1	**<0.001***	3689	1866	7293
Q angle (standing),°	0.375	0.115	10,560	1	**0.001***	1455	1160	1823
Q angle (supine), °	0.324	0.105	9512	1	**0.002***	1383	1125	1700
Q angle (sitting), °	0.418	0.127	10,877	1	**0.001***	1519	1185	1946
Multivariate analysis								
Patellar tendon thickness, mm	1464	0.808	3288	1	0.070	4324	0.888	21,051
Quadriceps tendon thickness, mm	1128	0.425	7056	1	**0.008***	3089	1344	7100
Q angle (standing),°	0.456	0.151	9097	1	**0.003***	1577	1173	2120
Q angle (supine), °	−0.052	0.371	0.020	1	0.889	0.949	0.459	1964
Q angle (sitting), °	0.210	0.330	0.407	1	0.524	1234	0.646	2357

*p value < 0.05 denotes statistical significance.

PFPS.[4,8–10] A recent meta-analysis has demonstrated a significant relationship between quadriceps atrophy and presence of PFPS, when compared with the asymptomatic extremity and a healthy control group.[11] An association between PFPS and atrophy in vastus medialis oblique (VMO) muscle, whose fibers attaches to distal patella horizontally and contribute significantly to medial patellar stability, has also been reported.[12–15] In contrary, whether a causal link exists between quadriceps and VMO atrophy and PFPS pathogenesis is still unclear. Currently, there are two prospective studies that aim to clarify this relationship.[16,17] Although Milgrom et al[17] had reported no association between knee extension strength and PFPS development, Boling et al[16] described decreased quadriceps strength as a predisposing factor for PFPS. Pooled analysis of both studies has suggested a significant relationship between decreased knee extension strength and PFPS development.[18] Loss of flexibility in soft tissues around the knee joint is accepted to be another risk factor for PFPS. Excessive strain related with the lateral of the knee, particularly originating from the lateral retinaculum, causes inappropriate positioning of the patella. Some cross-sectional studies have revealed an association between iliotibial band thickness and presence of PFPS.[19,20] Iliotibial band has been reported to be stretched in most of runners diagnosed with PFPS (67%).[21] Further biomechanical studies should evaluate whether patellar and quadriceps tendon thickness increase detected in PFPS patients contribute to patellar stress and loss of flexibility. In addition to loss of flexibility, widespread ligamentous laxity is also believed to contribute to PFPS pathogenesis.[22]

On the other hand, several studies have proposed that tension of quadriceps femoris muscle may be a risk factor for PFPS.[23,24] From the mechanical point of view, tension of the quadriceps muscle increases the backward force exerted by patella against the trochlea and the stress on the patellofemoral joint, particularly during physical activity.[24] Therefore, increased quadriceps and patellar tendon thicknesses in the patient group compared to controls detected using ultrasonography in our study may be a reflection of increased muscle tension contributing to disease pathogenesis.

Although several scoring systems have been developed for the evaluation of knee pathologies, only a few have focused on PFPS. Kujala patellofemoral score, developed in 1993 by Kujala et al, is a functional assessment scale to evaluate knee pathologies associated with patellofemoral system.[25] This scale has been designed particularly for the evaluation of PFPS, patellar dislocation or subluxation. It is short and easy-to-understand. Crossley et al have demonstrated that this scoring system is valid, reliable and sensitive in subjects diagnosed with PFPS.[26] Turkish version of Kujala patellofemoral score has also been shown to be valid and reliable in Turkish population.[27] In our study, quadriceps tendon thickness, which has been found to be an independent predictor of PFPS, has also been found to be negatively correlated with Kujala patellofemoral score in a statistically significant way. This finding suggests that quadriceps tendon thickness may have a role in the diagnosis and pathogenesis of PFPS.

Patellofemoral pain syndrome is a clinical diagnosis and imaging modalities have a limited role in the diagnostic process. Imaging is particularly useful for excluding alternative diagnoses in the management of PFPS. Plain knee radiography, followed by computed tomography and magnetic resonance imaging are used for the evaluation of knee pain.[28,29] Our study is the first to demonstrate the benefits of ultrasonography, which is a non-invasive, easy-to-apply, widely-used imaging modality without exposing the patient to radiation or contrast media, for the diagnosis of PFPS. Quadriceps tendon thickness determined using ultrasonography is found to be an independent predictor of PFPS in our study. This finding may facilitate the clinical diagnosis of PFPS.

Limitations of the study

Our study has failed to demonstrate any causality due to its cross-sectional design. In addition, lack of the evaluation for biomechanical stress parameters has limited the elucidation of the exact role of ultrasonographic assessment in PFPS pathogenesis.

Conflicts of interest

No conflict of interest.

References

1. Thomee R, Augustsson J, Karlsson J. Patellofemoral pain syndrome: a review of current issues. *Sports Med*. 1999;28(4):245–262.
2. Islam K, Duke K, Mustafy T, Adeeb SM, Ronsky JL, El-Rich M. A geometric approach to study the contact mechanisms in the patellofemoral joint of normal versus patellofemoral pain syndrome subjects. *Comput Methods Biomech Biomed Eng*. 2015;18(4):391–400.
3. Earl JE, Vetter CS. Patellofemoral pain. *Phys Med Rehabil Clin N Am*. 2007;18(3):439–458 [viii].
4. Kaya D, Citaker S, Kerimoglu U, et al. Women with patellofemoral pain syndrome have quadriceps femoris volume and strength deficiency. *Knee Surg Sports Traumatol Arthrosc*. 2011;19(2):242–247.
5. Skou ST, Aalkjaer JM. Ultrasonographic measurement of patellar tendon thickness–a study of intra- and interobserver reliability. *Clin Imaging*. 2013;37(5):934–937.
6. Taunton JE, Ryan MB, Clement DB, McKenzie DC, Lloyd-Smith DR, Zumbo BD. A retrospective case-control analysis of 2002 running injuries. *Br J Sports Med*. 2002;36(2):95–101.
7. Dye SF. The pathophysiology of patellofemoral pain: a tissue homeostasis perspective. *Clin Orthop Relat Res*. 2005;436(1):100–110.

8. Dvir Z, Shklar A, Halperin N, Robinson D, Weissman I, Ben-Shoshan I. Concentric and eccentric torque variations of the quadriceps femoris in patellofemoral pain syndrome. *Clin Biomech (Bristol, Avon)*. 1990;5(2):68–72.
9. Werner S. An evaluation of knee extensor and knee flexor torques and EMGs in patients with patellofemoral pain syndrome in comparison with matched controls. *Knee Surg Sports Traumatol Arthrosc*. 1995;3(2):89–94.
10. Callaghan MJ, Oldham JA. Quadriceps atrophy: to what extent does it exist in patellofemoral pain syndrome? *Br J Sports Med*. 2004;38(3):295–299.
11. Giles LS, Webster KE, McClelland JA, Cook J. Does quadriceps atrophy exist in individuals with patellofemoral pain? A systematic literature review with meta-analysis. *J Orthop Sports Phys Ther*. 2013;43(11):766–776.
12. Farahmand F, Senavongse W, Amis AA. Quantitative study of the quadriceps muscles and trochlear groove geometry related to instability of the patellofemoral joint. *J Orthop Res*. 1998;16(1):136–143.
13. Lin F, Wang G, Koh JL, Hendrix RW, Zhang LQ. In vivo and noninvasive three-dimensional patellar tracking induced by individual heads of quadriceps. *Med Sci Sports Exerc*. 2004;36(1):93–101.
14. Jan MH, Lin DH, Lin JJ, Lin CH, Cheng CK, Lin YF. Differences in sonographic characteristics of the vastus medialis obliquus between patients with patellofemoral pain syndrome and healthy adults. *Am J Sports Med*. 2009;37(9):1743–1749.
15. Pattyn E, Verdonk P, Steyaert A, et al. Vastus medialis obliquus atrophy: does it exist in patellofemoral pain syndrome? *Am J Sports Med*. 2011;39(7):1450–1455.
16. Boling MC, Padua DA, Marshall SW, Guskiewicz K, Pyne S, Beutler A. A prospective investigation of biomechanical risk factors for patellofemoral pain syndrome: the Joint Undertaking to Monitor and Prevent ACL Injury (JUMP-ACL) cohort. *Am J Sports Med*. 2009;37(11):2108–2116.
17. Milgrom C, Finestone A, Eldad A, Shlamkovitch N. Patellofemoral pain caused by overactivity. A prospective study of risk factors in infantry recruits. *J Bone Joint Surg Am*. 1991;73(7):1041–1043.
18. Pappas E, Wong-Tom WM. Prospective predictors of patellofemoral pain syndrome: a systematic review with meta-analysis. *Sports Health*. 2012;4(2):115–120.
19. Hudson Z, Darthuy E. Iliotibial band tightness and patellofemoral pain syndrome: a case-control study. *Man Ther*. 2009;14(2):147–151.
20. Puniello MS. Iliotibial band tightness and medial patellar glide in patients with patellofemoral dysfunction. *J Orthop Sports Phys Ther*. 1993;17(3):144–148.
21. Waryasz GR, McDermott AY. Patellofemoral pain syndrome (PFPS): a systematic review of anatomy and potential risk factors. *Dyn Med*. 2008;7(1), 9.
22. al-Rawi Z, Nessan AH. Joint hypermobility in patients with chondromalacia patellae. *Br J Rheumatol*. 1997;36(12):1324–1327.
23. Piva SR, Goodnite EA, Childs JD. Strength around the hip and flexibility of soft tissues in individuals with and without patellofemoral pain syndrome. *J Orthop Sports Phys Ther*. 2005;35(12):793–801.
24. Witvrouw E, Lysens R, Bellemans J, Cambier D, Vanderstraeten G. Intrinsic risk factors for the development of anterior knee pain in an athletic population. A two-year prospective study. *Am J Sports Med*. 2000;28(4):480–489.
25. Kujala UM, Jaakkola LH, Koskinen SK, Taimela S, Hurme M, Nelimarkka O. Scoring of patellofemoral disorders. *Arthroscopy*. 1993;9(2):159–163.
26. Crossley KM, Bennell KL, Cowan SM, Green S. Analysis of outcome measures for persons with patellofemoral pain: which are reliable and valid? *Arch Phys Med Rehabil*. 2004;85(5):815–822.
27. Kuru T, Dereli EE, Yaliman A. Validity of the Turkish version of the Kujala patellofemoral score in patellofemoral pain syndrome. *Acta Orthop Traumatol Turc*. 2010;44(2):152–156.
28. Tomsich DA, Nitz AJ, Threlkeld AJ, Shapiro R. Patellofemoral alignment: reliability. *J Orthop Sports Phys Ther*. 1996;23(3):200–208.
29. Elias DA, White LM. Imaging of patellofemoral disorders. *Clin Radiol*. 2004;59(7):543–557.