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ORIGINAL ARTICLE

Magnetic resonance imaging for assessment of the quadriceps tendon cross-sectional area as an adjunctive diagnostic parameter in patients with patellofemoral pain syndrome

Jae Ni Jang, MD[1], SoYoon Park, MD[1], Sukhee Park, MD[1], Yumin Song, MD[1], Jae Won Kim, MD, PhD[2], Keum Nae Kang, MD[3], Young Uk Kim, MD, PhD[1]

[1]Department of Anesthesiology and Pain Medicine, Catholic Kwandong University, College of Medicine, International ST. Mary`s Hospital, Incheon, Republic of Korea

[2]Catholic Kwandong University, College of Medicine, Incheon, Republic of Korea

[3]Department of Anesthesiology and Pain Medicine, National Police Hospital, Seoul, Republic of Korea

Patellofemoral pain syndrome (PFPS) is a common cause of anterior knee pain in young individuals.[1-3] It has several causes, including abnormal lower extremity alignment (structural abnormalities of the patella, genu valgum, increased quadriceps angle, and tibia varum), weakness of the hip and knee muscles, and excessive physical activity. These can result in patellofemoral joint stress, increased patellofemoral contact pressure, impaired knee extension, and ultimately, the development of PFPS, which can also lead to osteoarthritis.[4-6]

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Correspondence: Young Uk Kim, MD. Department of Anesthesiology and Pain Medicine, Catholic Kwandong University International St. Mary's Hospital, Catholic Kwandong University College of Medicine, Seo-gu, Incheon 22711, Republic of Korea.

E-mail: uk201@ish.ac.kr

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ABSTRACT

Objectives: In this study, we aimed to provide a more valuable diagnostic parameter and more equivocal assessment of the diagnostic potential of patellofemoral pain syndrome (PFPS) by comparing the quadriceps tendon cross-sectional area (QTCSA) with the quadriceps tendon thickness (QTT), a traditional measure of quadriceps tendon hypertrophy.

Patients and methods: Between March 2014 and August 2020, a total of 30 patients with PFPS (16 males, 14 females; mean age, 30.4±11.2 years; range, 16 to 49 years) and 30 healthy individuals (19 males, 11 females; mean age: 30.8±13.8 years; range, 17 to 62 years) who underwent knee magnetic resonance imaging (MRI) were retrospectively analyzed. T1-weighted turbo spin-echo transverse MRI scans were obtained. The QTCSA was measured on the axial angled phases of the images by drawing outlines, and the QTT was measured at the most hypertrophied quadriceps tendon.

Results: The mean QTT and QTCSA in the patients with PFPS (6.33±0.80 mm and 155.77±36.60 mm^2, respectively) were significantly higher than those in the control group (5.77±0.36 mm and 111.90±24.10 mm^2, respectively; $p<0.001$, for both). The receiver operating characteristic curve was used to confirm the sensitivities and specificities for both the QTT and QTCSA as predictors of PFPS. The optimal diagnostic cut-off value for QTT was 5.98 mm, with a sensitivity of 66.7%, a specificity of 70.0%, and an area under the curve (AUC) of 0.75 (range, 0.62 to 0.88). The optimal diagnostic cut-off value for QTCSA was 121.04 mm^2, with a sensitivity of 73.3%, a specificity of 70.0%, and an AUC of 0.83 (range, 0.74 to 0.93).

Conclusion: Based on our study results, the QTCSA seems to be a more reliable diagnostic indicator for PFPS than QTT.

Keywords: Diagnosis, hypertrophy, magnetic resonance imaging, patellofemoral pain syndrome, quadriceps muscle.

Patellofemoral pain syndrome is typically diagnosed based on the results of clinical evaluations; thus, physical examination and medical history data are important. Visual Analog Scale and Kujala scores can assess pain severity and functional status, respectively;[7,8] however, there are limitations to using imaging to diagnose PFPS. An objective imaging method for diagnosing PFPS has not been established, and imaging modalities are typically used to rule out differential diagnoses. Thus, clinical and diagnostic tests can be sometimes insufficient for identifying PFPS.

Magnetic resonance imaging (MRI) has been used to assess PFPS and is important for detecting and characterizing the status of the knee tendon, particularly changes in the quadriceps tendon (QT) of patients with PFPS.[9-13] The QT thickness (QTT) is significantly higher in patients with PFPS and can be used for diagnostic purposes;[14] however, the QTT in PFPS differs from that in hypertrophy. The QT may undergo asymmetrical thickening or partial atrophy, which can occur at any location.[15] Few studies have investigated the anatomical basis of QT hypertrophy; therefore, to assess the correlation between QT hypertrophy and PFPS, we measured the QT cross-sectional area (QTCSA). We defined the area perpendicular to the thickest QT as the QTCSA, believing that the QTT is meaningful when measured at the thickest level of the QT. The QTT measurements are prone to errors due to the potential for asymmetrical thickening or partial atrophy of the QT. Unlike measurement of the QTT, measurement of the QTCSA may be less affected by such errors, as it is assessed across the entire QTCSA.

To the best of our knowledge, the correlation between the QTCSA and PFPS has not yet been analyzed. Additionally, no studies have reported the best clinical diagnostic cut-off values for the QTT and QTCSA. Therefore, in the present study, we hypothesized that the QTCSA would be higher in patients with PFPS than in normal individuals. In this study, we aimed to compare the accuracy of MRI-measured QTT and QTCSA for diagnosing PFPS and to determine which of these factors was a more accurate predictor of PFPS.

PATIENTS AND METHODS

This single-center, retrospective study was conducted at Catholic Kwandong University International St. Mary's Hospital, Department of Anesthesiology and Pain Medicine, Pain Clinic between March 2014 and August 2020. All patients diagnosed with PFPS by a board-certified experienced radiologist were included. Inclusion criteria for the PFPS group were as follows: *(i)* anterior knee pain while climbing stairs or squatting; *(ii)* MRI performed within three months of the first PFPS diagnosis; *(iii)* popping sounds or crackling in the knee when climbing stairs or standing up; *(iv)* anterior knee pain with knees bent; and *(v)* anterior knee discomfort that increases with the increase in the intensity of activity. Exclusion criteria were as follows: *(i)* a history of knee fracture; *(ii)* L3, L4, or L5 lumbar radiculopathy; *(iii)* previous knee surgery, including procedures such as arthroscopy, ligament reconstruction, or meniscal repair; *(iv)* previous QT surgery, including procedures such as QT repair or reconstruction; *(v)* meralgia paresthetica; *(vi)* structural abnormalities of the knee, including-but not limited to-meniscal tears, ligamentous instability (e.g., anterior cruciate ligament tears), or chondral lesions; and *(vii)* muscular abnormalities around the knee, including significant atrophy, tears, or other pathologies. Finally, a total of 30 patients (16 males, 14 females; mean age, 30.4±11.2 years; range, 16 to 49 years) with PFPS were included. The control group consisted of 30 healthy individuals (19 males, 11 females; mean age: 30.8±13.8 years; range, 17 to 62 years). The QTT and QTCSA of the patients with PFPS were compared with healthy individuals.

Protocol for MRI

The MRI was performed using the 3T Avanto (Siemens Healthcare, Erlangen, Germany) with 3T scanners (Philips Healthcare, Best, Netherlands). We conducted MRI using T1-weighted turbo spin-echo transverse MRI scans acquired with a slice thickness of 3.0 mm, intersection gap of 0.9 mm, repetition time/echo time of 514 msec/10 msec, a 160×160-mm^2 field of view, and a 512×358 matrix.

Image analysis

The QTT was measured at the thickest part of the QT. The QTCSA was analyzed through the transverse-angled sections outlining the locations where the QTT was measured (Figure 1a, b). The QTT and QTCSA were measured on the MRI scans using a custom-developed image analysis software.

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 22.0 software (IBM Corp., Armonk, NY, USA). Descriptive data were expressed in mean ± standard deviation (SD), median (min-max) or number and frequency, where applicable. Demographic data of the control and PFPS groups were analyzed using the independent t-test. Receiver operating characteristic (ROC) curves were used to

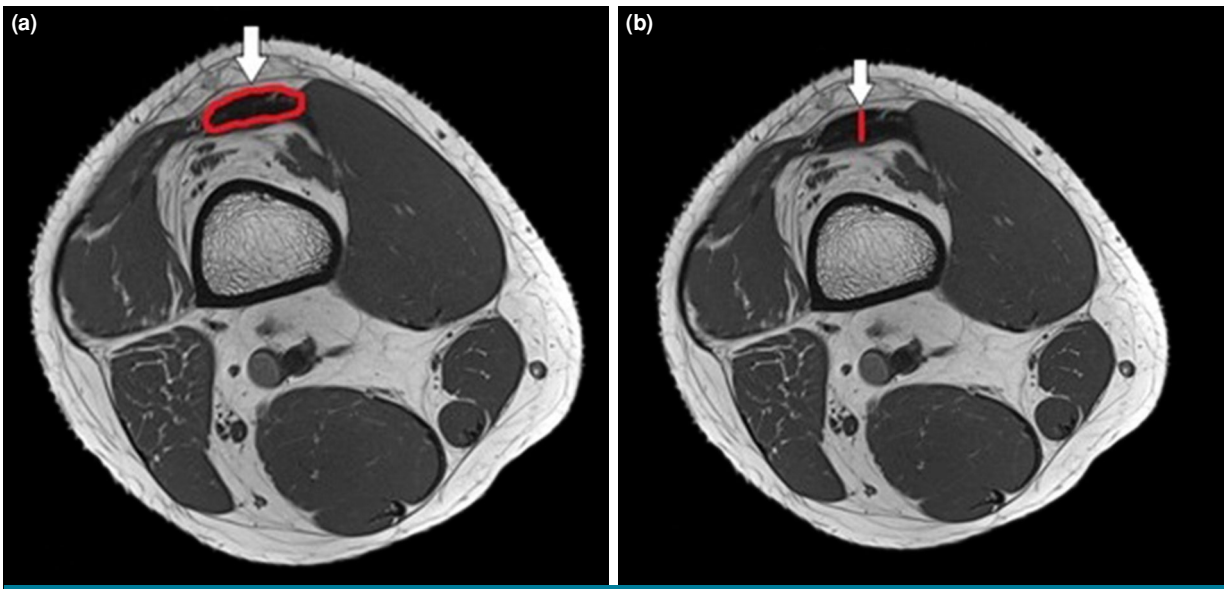

FIGURE 1. Transverse turbo spin-echo T1-weighted knee-magnetic resonance images of the quadriceps tendon. **(a)** Quadriceps tendon cross-sectional area. **(b)** Quadriceps tendon thickness.

investigate the sensitivity, specificity, and area under the ROC curve (AUC) to confirm the validity of the QTT and QTCSA as predictors of PFPS. A *p* value of <0.05 was considered statistically significant.

RESULTS

Demographic and baseline data of the patient and control groups are summarized in Table I.

The mean QTT was 5.77±0.36 mm in the control group and 6.33±0.80 mm in the PFPS group, while the mean QTCSA was 111.90±24.10 mm^2 in the control group and 155.77±36.60 mm^2 in the PFPS group (Table I). The QTT and QTCSA of the PFPS group were significantly higher than the control group (p<0.001, for both).

The optimal diagnostic cut-off value for QTT was 5.98 mm, with a sensitivity of 66.7%, a specificity of 70.0%, and an AUC of 0.75 (range, 0.62 to 0.88) (Table II, Figure 2). The optimal diagnostic cut-off value for QTCSA was 121.04 mm^2, with a sensitivity of 73.3%, a specificity of 70.0%, and an AUC of 0.83 (range, 0.73 to 0.93) (Table III, Figure 2). Upon comparing the QTT and QTCSA as predictors of PFPS, the QTCSA demonstrated a higher sensitivity than the QTT, and an AUC closer to 1. Therefore, the QTCSA demonstrated a stronger correlation with PFPS than the QTT.

TABLE I
Demographic and baseline data of the patient and control groups

	Healthy group (n=30)		PFPS group (n=30)		
Variable	n	Mean±SD	n	Mean±SD	*p*
Age (year)		30.8±13.8		30.4±11.2	NS
Sex					NS
Males	19		16		
Females	11		14		
QTT (mm)		5.77±0.36		6.33±0.80	<0.001
QTCSA (mm^2)		111.90±24.10		155.77±36.60	<0.001

PFPS: Patellofemoral pain syndrome; SD: Standard deviation; QTT: Quadriceps tendon thickness; QTCSA: Quadriceps tendon cross-sectional area; NS: Not statistically significant (p>0.05).

TABLE II
Cut-off values for quadriceps tendon thickness

QTT (mm)	Sensitivity (%)	Specificity (%)
3.39	100	0
5.27	90.0	10.0
5.86	76.7	56.7
5.98*	66.7	70.0
6.19	53.3	96.7
7.60	6.7	100

QTT: Quadriceps tendon thickness; * The optimal cut-off value on the receiver operating characteristic curve.

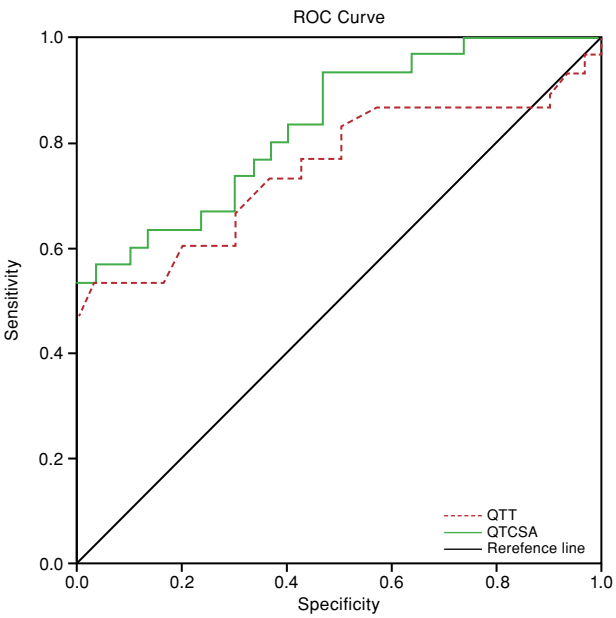

FIGURE 2. ROC curves of QTCSA and QTT for the prediction of PFPS QTCSA AUC (95% CI) = 0.83 (0.73-0.93); QTT AUC (95% CI) = 0.75 (0.62-0.88).
AUC: Area under the curve; CI: Confidence interval; PFPS: Patellofemoral pain syndrome; ROC: Receiver operating characteristic; QTCSA: Quadriceps tendon cross-sectional area; QTT: Quadriceps tendon thickness.

TABLE III
Cut-off values for the quadriceps tendon cross-sectional area

QTCSA (mm)	Sensitivity (%)	Specificity (%)
75.14	100	3.3
96.57	96.7	26.7
110.23	93.3	53.3
121.04*	73.3	70.0
140.79	63.3	86.7
194.39	10.0	100

QTCSA: Quadriceps tendon cross-sectional area; * The optimal cut-off value on the receiver operating characteristic curve.

DISCUSSION

Our study indicated an association between the QTCSA and PFPS. The QTCSA was significantly higher in patients with PFPS than in healthy controls. In the current study, the most optimal cut-off value for QTCSA was 121.04 mm^2, with a sensitivity of 73.3% and an AUC of 0.83. The most optimal cut-off value for QTT was 5.98 mm, with a sensitivity of 66.7% and an AUC of 0.75. These QTCSA and QTT values can be considered standards, as to the best of our knowledge, no other studies have assessed optimal cut-off values for both QTCSA and QTT before. Our study findings suggest that both the QTCSA and QTT are significantly associated with PFPS. Additionally, since the sensitivity of the QTCSA is superior to that of the QTT, the QTCSA may be considered a more accurate diagnostic index for PFPS.

Patellofemoral pain syndrome is defined as discomfort originating from the patellofemoral articular structures, and excludes other peripatellar and intra-articular pathologies. Abnormal patellar tracking and static malalignment are also associated with PFPS.[6,16] Fulkerson[17] proposed that an imbalance in the extensor mechanism can lead to an overload of the subchondral bone and retinaculum, resulting in pain due to the activation of nociceptive fibers in the synovium, retinaculum, or bone. This mechanism may be activated due to imbalances in the force vectors of the quadriceps components or an imbalance in the material properties of the lateral versus medial portions of the QT.[15,18]

Imaging modalities have a limited role in diagnosing PFPS. The procedure of plain knee radiography, followed by ultrasonography and computed tomography, is typically used to identify the causes of anterior knee pain.[14] Our study demonstrated the benefits of using MRI, which is non-invasive and does not require radiation to make a diagnosis of PFPS. Additionally, ultrasound imaging is usually limited to visualizing soft tissues, whereas MRI has a superior diagnostic utility for assessing larger areas encompassing soft tissues, joints, bones, muscles, and cartilage.[19] In the present study, the QTCSA as measured using MRI was a significant diagnostic predictor of PFPS. Therefore, our results may facilitate the accurate clinical diagnosis of PFPS.[20]

The QTT is a major morphological diagnostic index for the assessment of PFPS. A previous study analyzed the "halfway" of the QT as the QTT and reported that QTT measurements were useful in assessing PFPS.[14] Kizilkaya and Ecesoy[14]

reported that a QTT value of 0.54 cm demonstrated high specificity and sensitivity during ROC curve analysis for the diagnosis of PFPS. However, asymmetrical thickening or partial atrophy of the QT can occur anywhere;[21] thus, assessment errors may be frequent. In contrast with the measurement of the QTT, the measurement of the QTCSA is not susceptible to these errors, as it is measured across the entire QTCSA. To circumvent the assessment errors associated with the asymmetrical hypertrophy of the QT, we used the QTCSA as a new diagnostic imaging index. Thus, we consider the QTCSA to be an important morphological factor for assessing QT hypertrophy.

Nonetheless, this study has some limitations. First, it includes a small number of patients. Second, there may have been errors in measuring the QTCSA and QTT using MRI. The outcomes of single-slice MRI analysis are typically good for QTCSA and QTT measurements; however, they may not be homogeneous due to differences in the thicknesses of the sections used for MRI resulting from individual anatomic variations. Even so, the measurement accuracy was good for the T1-weighted turbo spin-echo transverse images in which the QT appeared. Finally, PFPS has several causes, including overuse of the knee joint, tightness of anatomical structures (retinaculum or iliotibial band), weakness of muscles surrounding the knee, and misalignment of the patella, as it moves through the femoral groove.[22] However, we only focused on the QT in the present study. Despite these limitations, our study is the first to show the association between the QTCSA and PFPS.[20]

In conclusion, QTCSA measurement is a simple and reliable method with a high indicative value for predicting PFPS. The cut-off values for the QTT and QTCSA reported in the present study can serve as viable standards, as no studies have previously reported their optimal cut-off values previously. Additionally, QTCSA measurement represents a new, objective, and indicative morphological diagnostic method for predicting PFPS; thus, this new adjuvant method would facilitate the diagnosis of PFPS.

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Ethics Committee Approval: The study protocol was approved by Institutional Review Board of the Catholic Kwandong University College of Medicine, Republic of Korea (date: 22.12.2020, no: IS20RISI0081). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: The requirement for informed consent was waived due to the retrospective nature of the study.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Researched the data, designed the analysis, and wrote the manuscript: J.N.; Analyzed data, reviewed, and edited the manuscript: S.Y.P., S.P.; Helped with data curation and interpretation: Y.S., J.W.K.; Performed statistical analysis: K.N.K.; Supervised and managed the research and critically reviewed and edited the manuscript, takes full responsibility for the work, the study design, access to data, and the decision to submit and publish the manuscript: Y.U.K.

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