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A New Perspective to Assess Patellar Surface-Trochlear Sulcus Compatibility: Narrowed Patellar Angle is Associated with Greater Trochlear Sulcus Angle

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ABSTRACT

Objective: In this study, the relationship between patella angle – trochlear sulcus angle (TSA) discrepancy was investigated. A specific cutoff value of patella angle (PA), TSA, trochlear groove depth (TGD), and medial trochlear/lateral trochlear length (MT/LT) ratio for effusion, fat-pad edema, chondromalacia, meniscal and ligament tear were investigated. By doing so, to the best of our knowledge, we bridged the gap in literature since these relationships between the above-mentioned measurements have almost never been examined.

Methods: A total of 446 patients were evaluated on magnetic resonance imaging. PA and TSA were calculated with. the highest specificity and sensitivity in predicting effusion, fat-pad edema, and patellar chondromalacia. A specific cutoff value of PA, TSA, TGD and MT/LT for effusion, fat-pad edema, chondromalacia, meniscal tear, and ligament tear were investigated.

Results: A low-level and insignificant correlation was found between PA and TSA in the negative direction. TSA value. with the highest sensitivity and specificity in predicting the presence of effusion, fat-pad, and chondromalacia was found ≤131, ≤129.6, and >125.8, respectively. Tibial tubercle-trochlear groove (TT-TG) distance. measurement was significantly less in the group with Medial Meniscus (MM) rupture. Increased TT-TG distance posed a risk for quadriceps tendinosis 1.127 times and increased medial trochlea length (MT) posed a risk for quadriceps tendinosis 1.167 times.

Conclusion: Certain cutoff values of PA and TSA may predispose risk for meniscal tear, effusion, fat-pad edema, and chondromalacia. A negative correlation was present between the patella angle and TSA.
Keywords: Knee, MRI, meniscus, chondromalacia, fat-pad edema

1. INTRODUCTION

Knee mal-alignment may be associated with the onset and progression of several pathologies such as medial and lateral meniscal (MM and LM) injuries, anterior and posterior cruciate ligament (ACL and PCL) tear, effusion, fat-pad edema, and patellar chondromalacia. The size and shape of the femur, patella and tibia may also contribute to variations in knee biomechanics (1). There are many angles and measurements that concern the knee joint. The patellar tendon length, patellar height, tibial tubercle-trochlear groove (TT-TG) distance, patella angle (PA), trochlear sulcus angle (TSA), trochlear groove depth (TGD), medial trochlea length (MT), lateral trochlea length (LT), medial trochlear/lateral trochlear length (MT/LT) ratio, lateral patellar tilt angle (LPTA), patella-patellar tendon angle (P-PTA), quadriceps patellar tendon angle (QPA), Insall-Salvati index (ISI), medial trochlear inclination (MTI), lateral trochlear inclination (LTI) are measurements that help to better understand anatomical variations (2). Researchers examining the relationship between pathologies and anatomical variations in this field have followed a certain trend and examined similar issues (2–5).

In our study, the relationship between patella angle-TSA discrepancy and a specific cutoff value of patella angle, TSA, TGD, and MT/LT for effusion, fat-pad edema, chondromalacia, meniscal tear, and ligament tear were investigated. By doing so, to the best of our knowledge, we bridged the gap in literature since these relationships between the above-mentioned measurements have almost never been examined.

2. METHODS

Five hundred patients who underwent knee Magnetic Resonance Imaging (MRI) examination were included in the study and analyzed retrospectively between 2021-2022. Fifty-four patients were excluded from the study and a total of 446 patients' knee MRIs were evaluated. We excluded

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patients with history of surgery involving the lower extremity, chemoradiotherapy, history of known malignancy, prosthesis or ligament graft, severe osteoarthritis, space-occupying mass and systemic diseases causing chronic joint dysfunction such as rheumatoid arthritis from our study. Only MRIs performed for acute or chronic mechanical knee pain were included. Ethical approval was obtained from a local (Clinical Researches Ethical committee, Protocol Code:2021-137) committee.

Patients were divided into three sub-groups: normal, degeneration, and tear according to their meniscus. The patients were also further divided into subgroups such as normal, partial tear, total tear, and mucoid degeneration according to their cruciate ligaments. Fat-pad edema was classified as superolateral (SL) Hoffa, non-SL Hoffa, prefemoral, and suprapatellar according to its location. The presence of patellar chondromalacia was evaluated. The effusion was divided into groups as suprapatellar, retropatellar, infrapatellar, and intraarticular, according to its location. The patellar tendon length, patellar height, LPTA, P-PTA, Q-PA, MTI and LTI, PA, TSA, TGD, MT, LT, MT/LT ratio, TT-TG distance, and ISI were measured for each patient.

The relationship between PA and TSA discrepancy was investigated. PA and TSA were calculated with the highest specificity and sensitivity in predicting effusion, fat-pad edema, and patellar chondromalacia. Our analysis reported that the patella angle value is ≤120.9 with the highest sensitivity (48.92%) and specificity (75.86%) in predicting the presence of effusion with the highest and most significant area under the curve. TSA was evaluated between the groups with a patella angle value of ≤120.9 and >120.9, and it was evaluated whether there was a difference between the measurements.

Patella angle values with the highest sensitivity and specificity were calculated to predict the presence of MM injury, LM injury, ACL, and PCL tear. Predictive values of MT/LT ratio for MM and LM tear were calculated. The cutoff ISI value for fat-pad edema was evaluated. Furthermore, we investigated whether there were significant PPTA and QPA values that could predict fat-pad edema. Additionally, the change in frequency of pathology and measurements with increasing TT–TG distance values were examined. Finally, this research looked at how the frequency of pathology and measurements change with increasing MTI and LTI distance. The change of frequency of the pathologies was evaluated as TSA, TGD, MT, and LT increased or decreased.

2.1. Measurements

ISI, P-PTA, QPA, patellar tendon length, and patellar height were measured in the midsagittal plane where the quadriceps tendon, patellar tendon, and upper and lower ends of the patella are best seen (6). Patella height is a measurement from the distal pole to the proximal pole of the patella. ISI is the ratio of the patellar tendon length to the maximum length of the patella (7). PPTA is the angle between the line connecting the upper-lower pole of the patella and the tuberositas tibia. QPA is the angle between the quadriceps tendon and a line from the upper pole of the patella (5).

The posterior condylar line is selected as a reference line. LPTA is the angle between the parallel line to the lateral patellar facet and the lines drawn along the posterior femoral condyles (8). MTI angle is defined as the intersection between the medial trochlear facet and a tangential line drawn through the posterior femoral condyle. LTI angle is the intersection between the lateral trochlear facet and a tangential line drawn through the posterior femoral condyle (9). The angle between the lines which are parallel to the medial and lateral patellar facets is PA. TSA is the intersection of two lines parallel to the medial and lateral trochlear facets. TGD is calculated by subtracting the distance between the deepest point of the TG and the line parallel to the surfaces of the posterior femoral condyles from the mean of the greatest anteroposterior (AP) distance of the medial and lateral femoral condyles (5). TT-TG is measured as a mediolateral distance from the apex of the tibial tuberosity to the base of the trochlear groove (Figure 1).

MM and LM are evaluated on PD images according to abnormal high signal intensity. Meniscal degeneration is accepted as focal or linear areas of hyperintensity, without an extension to the articular surface. Meniscal tear is accepted as abnormal hyperintensity that extends to the superior or inferior articular surface (10). A thickened and irregular but intact ligament is evaluated as mucoid degeneration. A complete fiber discontinuity and partial tear are evaluated as hyperintensity within the ligaments.

2.2. MRI image protocol

MRI was undertaken using a 1.5-T MRI scanner (Magnetom Aera; Siemens Healthcare, Germany) with a limb matrix knee coil (a Tim coil). The knee MRI protocol was the fat-suppressed PD sequence in coronal, axial, and sagittal planes, and the T1-weighted and T2-weighted sequence in the coronal plane. The coronal plane exam is performed parallel to the midline of the femur and tibia. Each scan examined the knee joint from lateral condyle up to mediale condyle. Phase directions in the axial scans were head to feet.

2.3. Statistical analysis

Statistical analysis of the data was made by using IBM Statistical Package of Social Science (IBM SPSS V26) and MedCalc (Version 19.3.1) package programmes at 95% confidence level. The Shapiro-Wilk normality test was executed to analyze the distribution of data, and Levene's test was used to analyze group homogeneity. Continuous variables are analysed as mean, standard deviation and median values, and categorical variables are presented as number and percentage. T-test and Mann-Whitney U test were used to analyse the effects of the following variables age, sex, ISI, MTI, QPA, and other measurement variables. The relationship between chondromalacia, presence of effusion, and fat-pad edema groups was investigated by chi-square test. The ANOVA test was used to compare QPA and LPTA between the ACL, PCL, MM injury, and LM injury groups. The relationship between ISI and TT-TG distance and other variables was analyzed by Spearman correlation. Patellar angle and TGD with the highest specificity and sensitivity in predicting effusion, fat-pad edema, and chondromalacia were calculated using ROC analysis, and the Youden index. Logistic Regression Analysis was applied with the variables found to be significant. A value of p less than.05 is considered statistically significant.

Table 1. *Number and percentage of pathological changes detected in patients*

	n	%
Medial Meniscus		
Normal	124	27,8
Degeneration	154	34,5
Rupture	168	37,7
Lateral Meniscus		
Normal	356	79,8
Degeneration	53	11,9
Rupture	37	8,3
ACL Degeneration Grade		
Normal	338	75,8
Partial Rupture	64	14,3
Total Rupture	28	6,3
Mucoid Degeneration	16	3,6
PCL Degeneration Grade		
Normal	440	98,7
Partial Rupture	2	0,4
Mucoid Degeneration	4	0,9

MM: Medial meniscus, LM: lateral meniscus, ACL: anterior cruciate ligament, PCL: posterior cruciate ligament. n: number of the patients

3. RESULTS

A total of 446 patients were included in the study, 258 of them were women. The mean age was 43.50 ± 10.21 years. MM tear was detected in 168 (37.7%) patients and LM tear was present in 37 (8%) patients. There were total tears in the ACL in 28 (6.3%) patients (Table 1). Suprapatellar fat-pad edema was observed in 90 (20.2%) of the patients, and patellar chondromalacia was observed in 340 (76.2%) patients. Forty-two patients had quadriceps tendinosis (Figure 2). The mean values of the measurements are shown in table 2.

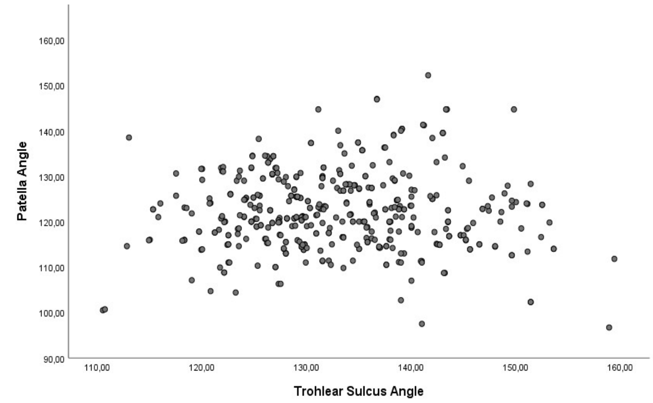
A low-level and insignificant correlation was found between patella angle and TSA in the negative direction (R: – 0.023) (p=.635) (Graphic 1). Patella angle values with the highest sensitivity and specificity in predicting the presence of effusion, fat-pad, and chondromalacia were found to be ≤120.9,>119.8, and <122.9, respectively. The patella angle values ≤117.8 and ≤125.5 show the highest sensitivity and specificity in predicting the presence of MM and LM tears, respectively.

Table 2. *Measurements and mean values of the patients included in the study*

Variables	Mean ± SD	Median
Patellar tendon lenght (mm)	41,72 ± 5,96	41,4
Patellar height (mm)	41,30 ± 4,50	41,0
ISI	1,02 ± 0,17	1,01
TT-TG distance	9,89 ± 4,09	10,3
Patella angle	122,26 ± 8,37	121,3
TSA	132,93 ± 8,77	132,1
TGD	7,06 ± 1,68	7,0
MT	12,92 ± 2,73	13,0
LT	23,80 ± 3,01	23,7
MT/LT	0,55 ± 0,13	0,5
LPTA	12,13 ± 6,00	11,6
PPTA	141,36 ± 6,87	141,8
QPA	132,54 ± 10,66	131,9
MTI	25,90 ± 6,04	26,0
LTI	24,91 ± 4,61	24,7

Mann-Whitney U is used. ISI: Insall-Salvati Index, TT-TG Distance: tibial tubercle-trochlear groove distance, TSA: trochlear sulcus angle, TGD: trochlear groove depth, MT, and LT: medial and lateral trochlea length, MT/LT ratio, LPTA: lateral patellar tilt angle, QPA: quadriceps-patellar tendon angle, MTI and LTI: medial and lateral trochlear inclination. A p value less than.05 is considered as significant.

TSA value with the highest sensitivity and specificity in predicting the presence of effusion, fat-pad, and chondromalacia was found ≤131, ≤129.6, and >125.8, respectively. TSA values>133.6 and>138.9 show the highest sensitivity and specificity in predicting the presence of MM and LM tears, respectively. The patellar angle of ≤125.5 was predisposed risk 2.85 times (CI 1.539-5.277) higher for the presence of meniscal tear (p=.001), and a TSA of >138.9 was pose a significant risk of 2.43 times presence of meniscal tear (CI 1.427-4.012) (p=.001).



Graphic 1. *Relationship between Patella Angle and Trochlear Sulcus Angle*

It was observed that the TT-TG value was significantly lower in the group with MM tear (p=.001). There was no significant difference between TT-TG measurements in groups with ACL and PCL tear (p=.080). The MT/LT values

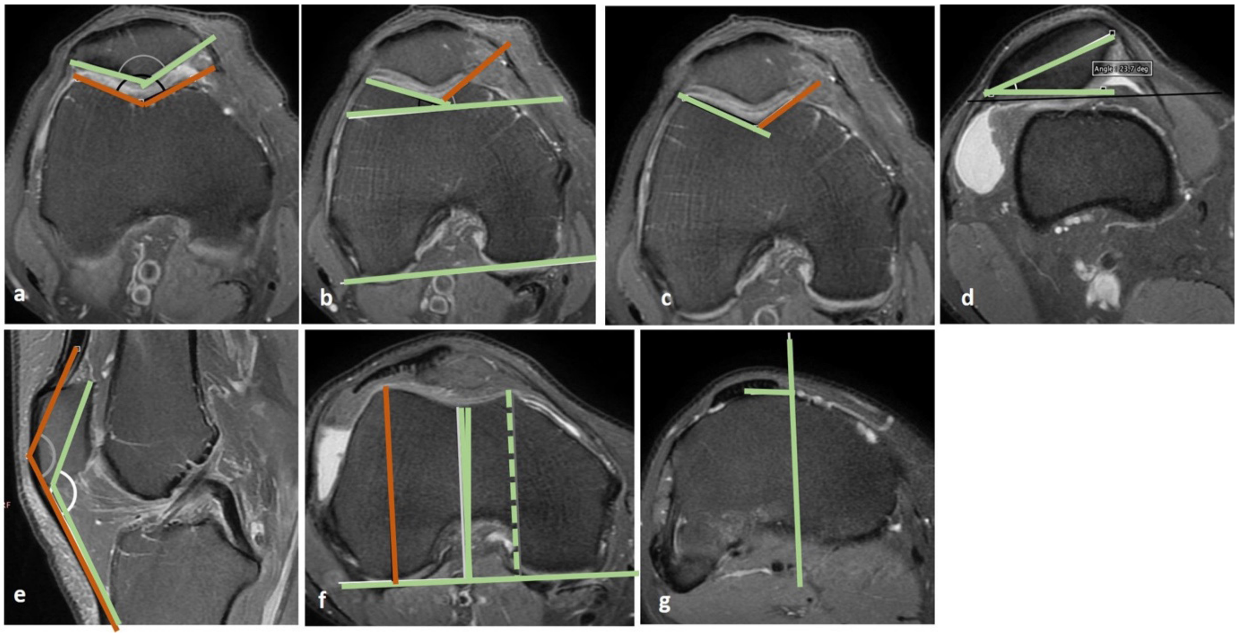


Figure 1. Measurement methods . On axial proton density images, a.) patella angle is measured as the crossing angle between the lines parallel to the medial and lateral patellar facets (green angle). TSA is measured as the angle of two lines parallel to the medial and lateral trochlear facets (orange angle). b.) MTI is obtained as the angle between the lateral trochlear facet and the transcondylar axis (green angle). LTI is measured as the angle between the lateral trochlear facet and the transcondylar axis (orange angle). c.) medial trochlea length is measured as 26,9 mm (green line) and lateral trochlea length is measured as 15,6 mm (orange line). d.) LPTA is measured as a line parallel to the lateral patellar facet and a line drawn across the posterior femoral condyles (green line). e.) QPA is measured as the angle between the quadriceps tendon and a line drawn from the patella upper pole in the midsagittal plane (green line). PPTA is measured as the angle the between the line connecting the upper-lower pole of the patella and the tuberosities tibia (orange line). f.) TGD is accepted as the width between the most anterior parts of the femoral trochlear facets and the deepest part of the trochlear groove. g.) TT-TG is measured as a distance from the apex of the tibial tuberosity to the base of the trochlear groove.

with the highest sensitivity and specificity in predicting the presence of MM tear were found to be ≤0.496 and ≤0.656 (p<.001 for both). While MT and LT were significantly higher in the group with fat-pad edema (p=.043, p<.001), no difference was found for TSA and TGD measurements. There was no significant difference in terms of TSA, TGD, MT, and LT measurements in the patellar chondromalacia group compared to the non-patellar chondromalacia group. No significant difference was observed between the groups with and without effusion in terms of TSA, TGD, MT and LT measurements.

In the group with quadriceps tendinosis, TT-TG distance, and MTI were significantly higher (p=.004, p<.001). In the group with quadriceps tendinosis, patellar tendon length, MT and LT were found to be significantly lower (p=.004, p=.012, p=.01, p=.01). No significant change was detected in terms of other measurements. The frequency of fat-pad edema was found to be significantly higher in the group with quadriceps tendinosis (p=.012). There was no difference in the frequency of effusion and patellar chondromalacia in the group with quadriceps tendinosis (p=.287 and p=.276). Increased TT-TG distance has posed a risk for quadriceps tendinosis 1.127 times (CI 1.026-1.237), increased MT has posed a risk for quadriceps tendinosis 1.167 times (CI 1.020-1.335), increased LT has posed a risk for quadriceps tendinosis 1.224 times (CI 1.074-1) (p=.013, p=.025, p=.002).

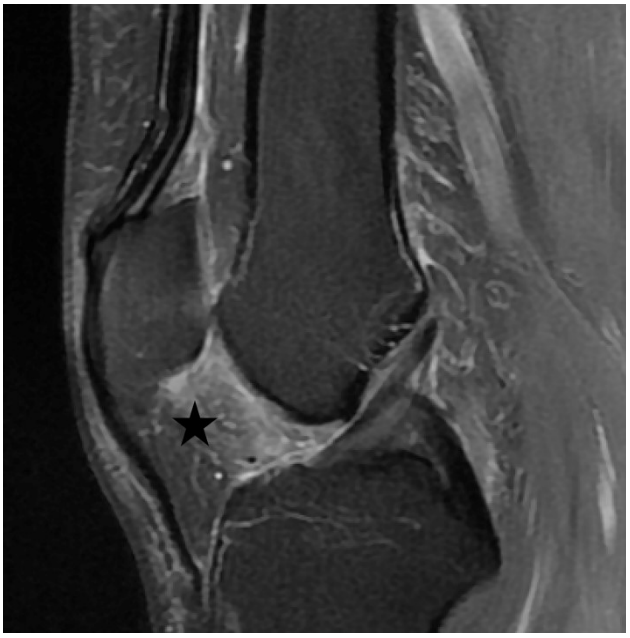


Figure 2. Hoffa's fat-pad edema. On mid-sagittal proton density images of a 46-year-old male, the high signal in Hoffa's fat-pad (star) and prefemoral fat-pad is seen.

4. DISCUSSION

This retrospective study examined the relationship between TSA values with the highest sensitivity and specificity in predicting the presence of effusion, fat-pad edema, and chondromalacia, and found that TSA values are associated with knee instability and injury.

Hypoplastic lateral femoral condyles accompanied by a shallow or flattened shaped groove in the trochlea favor trochlear dysplasia (11,12). Yang et al. (13) stated that in the presence of shallow trochlea, patellofemoral joint balance is impaired. A shallow trochlea decreases the stability of the patella from the lateral aspect and causes instability, dislocation, and cartilage loss. Kalichman et al. (14) found that increased sulcus angle creates excessive stress on the medial and lateral condyles. Damgacı et al. (5) suggested that patellar cartilage loss increases in knees with larger TSA and P-PTA and LPTA also decrease in patients with larger TSA. Paiva et al. (15) performed a systematic review through the literature. And they assessed known radiological measurements for trochlear dysplasia. LPTA, TT–TG, and TGD were suggested as useful measurements in evaluating trochlear dysplasia.

Many studies aiming to reveal trochlear dysplasia have determined measurement and angle values. A consensus is still lacking, however, as to which of these measurements is valuable enough to be used in practice. LTI, MTI, TSA and MT\LT ratios are the most commonly used measurements in these studies (15). It has been reported as the most preferred and reliable measurement is LTI. It has been reported that values of 11° and above for LTI can predict trochlear dysplasia with an accuracy of 93% and a specificity of 87% (16). Joseph et al. (17) measured LTI at two different images captured one from the most proximal aspect of trochlear cartilage and the second from the level of posterior condyles. They reported that 2-image LTI has higher reliability compared to single-image LTI and Dejour classification. They also concluded that 2-image LTI or classical LTI measurement demonstrated trochlear dysplasia perfectly with a 91% sensitivity. According to Keser et al. (18) recommended that LTI is above 11 degrees in a sizable proportion of patients with anterior knee pain but for whom no cause could be found, and that it would be beneficial to measure LTI in patients with knee pain of unknown origin. Carrillon et al. (16) suggested that the cutoff value of 11° for LTI was studied in studies that included only a limited number of populations, and therefore should be evaluated in a larger population, especially for patients with patellar instability.

TT-TG distance may be affected by the flexion angle and imaging modality. It has been stated that the intra – and inter-reliability for TT–TG distance is low (15). TT-TG distance greater than 15 mm is defined as pathological in a recent study (19). Imhoff et al. (20) reported that higher grades of trochlear dysplasia demonstrated higher values of TT–TG distance. In the group with quadriceps tendinosis, while TT-TG distance and MTI were significantly higher, the patellar tendon length, MT, and LT measurements were found to be significantly lower in the group with quadriceps tendinosis.

Among the measurements investigating trochlear dysplasia, there are these classically known measurements, and there is no diversity in the publications where different angles are evaluated. Biedert et al. (21) developed a measurement called the patella–trochlear index by dividing the lengths of the patella and trochlea to look at their compatibility, but there are quite a few publications examining the relationship between patella angle and TSA. In our study, the relationship between patella angle-TSA discrepancy was investigated. The compatibility of patella angle and TSA and its change were investigated. In our study, a low level and insignificant correlation were found between patella angle and TSA in the negative direction (R: – 0.023).

The different morphological shapes of the patella will result in the sum of the different kinetics and vectors forces in the patellofemoral joint. Changes in the shape of the patella or trochlear sulcus may restrict patella motion or full extension. The restriction of full extension of the patella may lead to soft tissue being forced to dominate patellofemoral kinematics. On the other hand, increased LTI causes increased patellar flexion and causes an extra load on the posterior part of the patella (22). Jimenez et al. (23) conducted a study investigating whether there is a significant relationship between the shape of the patella and the trochlea. In their study, they found that patellar morphology varied greatly among patients. And they stated that there was a weak correlation between patellar morphology and trochlear dysplasia.

The number of studies investigating how the shape of the patella affects the vectorial forces in the knee joint or the degeneration of ACL tear, PCL tear, MM tear, LM tear, and chondromalacia is extremely few. In addition, there is no study investigating how the importance and normal values of the patella angle change with the shape of the trochlea and how often it is seen with trochlear dysplasia. Damgacı et al. (5) measured normal patella angle values in their patients as 126.5±8.4 and stated that there were significant differences in patella angle in patients with severe chondromalacia. However, they did not examine the associations between patella angle and other variables that suggest trochlear dysplasia. Endo et al. (23) measured patella angle at three distinct levels (the superior, middle, and inferior portions of the patella) known as interfacet angle in a morphometric study. And in this study, no significant relationship was found between patella angle and chondromalacia. In our study, the patella angle value was found to be ≤120.9,>119.8, and <122.9 with the highest sensitivity and specificity in predicting the presence of effusion, fat-pad, and chondromalacia, respectively. The patella angle value with the highest sensitivity and specificity in predicting the presence of MM and LM degeneration-tear was found to be ≤117.8 and ≤125.5, respectively.

We acknowledge several limitations of the current study. First, the retrospective design might have introduced bias to our results. Second, the sample of the study, which included only patients who underwent knee MRI, is nor representative of the general population. Additionally, the exclusion criteria used may also have limited the sample size and population diversity. Thus, we acknowledge limited genaralizability of our results. Furthermore, the study only examined the association between certain measurements and knee pathologies and did not investigate other factors that may contribute to the development of knee pathologies. We believe that examining other factors that may contribute to the development of knee pathologies in patients with severe gonarthrosis and professional athletes may have beneficial results for knee trauma and rehabilitation and contribute to the literature. Finally, the study did not assess the inter-observer reliability of the measurements taken, which may affect the validity of the results.

5. CONCLUSION

We can conclude that certain cut-off values of patella angle and TSA may pose a risk for meniscal tear, effusion, fat pad oedema and chondromalacia. Although not significant, there was a negative correlation between patella angle and TSA. Patients with narrowed patella angle and shallow trochlear sulcus should be carefully evaluated for meniscal tear. Specific mal-alignancies may be the cause of knee pain and injury.

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Design of the study: GYO, FZA
Acquisition of data for the study: GYO, FZA
Analysis of data for the study: GYO
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Drafting the manuscript: FZA
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