Original Article

Patellar Height Correlates Modestly With Trochlear Dysplasia: A Magnetic Resonance Imaging Analysis

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Purpose: To evaluate whether there is a correlation between the position of the patella and trochlear morphology in patients with and without patellar instability using exclusively MRI measurements. **Methods:** MRI scans of knees in patients with patellofemoral instability and knees of patients with an ACL (anterior cruciate ligament) tear as a control group were reviewed. Measurements of patellar position (Canton-Deschamps ratio, Patellar Trochlear Index, and lateral patellar inclination) and trochlear morphology (lateral trochlear inclination and sulcus angle) were obtained from each scan. Bivariate and multivariate analysis was performed to identify correlations between study group, demographics, and patellofemoral joint measurements. **Results:** There were 70 knees in the patellofemoral instability group and 60 knees in the control group. Bivariate analysis showed a significant difference in all measurements between the patellar instability group and the control group. Multivariate analysis showed modest correlations between patellar position and trochlear morphology. The Caton-Deschamps (CD) ratio correlated with patellar trochlear index ($P < .001$) and lateral trochlear inclination ($P < .001$). The respective R-square goodness of fit was 41.1%. Patellar trochlear index correlated with CD ratio ($P < .001$), lateral trochlear inclination ($P < .001$), lateral patellar inclination ($P < .001$), and patellar instability group ($P = .011$). The R-sq goodness of fit was 37.3%. Lateral patellar inclination correlated with patellar trochlear index ($P <$ .001), Lateral trochlear inclination ($P < .001$), and age at first dislocation or injury ($P = .02$). The R-sq goodness of fit was 68.56%. **Conclusions:** Using MRI-based measurements of the patellofemoral joint, we identified modest, but significant, correlations between measures of patellar height (patellar trochlear index, CD ratio, and lateral patellar inclination) and trochlear dysplasia. This correlation is unclear and is likely multifactorial, but on the basis of this work, a causal relationship between trochlear dysplasia and patella alta cannot be established. **Clinical Relevance:** Radiographic evaluation of the patella and how it relates to the surrounding boney anatomy provides important information regarding our understanding of patella instability and its treatment.

Introduction

Patellar instability is a common and substantial problem among adolescents and young adults that is usually associated with underlying pathoanatomic risk factors, such as trochlear dysplasia, patella alta, patellar dysplasia, and coronal and rotational plane malalignment.[1-6] Although trochlear dysplasia has consistently been found as having the strongest association with recurrent patellar instability, its etiology remains unclear.[2,7,8] Some studies argue that trochlea morphology is determined very early in utero and, therefore, trochlear dysplasia is genetically determined.[9-13] Other studies in rabbits demonstrate that mechanical forces from the patella may play a large role in shaping the trochlea during early skeletal development.[14-16] This has led to further investigation on the relationship between patellar position, chiefly height, and trochlear morphology.[17]

Patellar height can be measured a variety of ways frequently with radiographs computed tomography (CT) scans or magnetic resonance imaging (MRI).[18-21] Studies have shown that these measurements are not reliable and depend heavily on the bony architecture

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used for reference.[22] These measurements also fail to account for the functional overlap between the patella and the trochlea, which may be of more importance in determining the patella—trochlear relationship. One way to assess the functional overlap is via the patellar-trochlear index described by Biedert and Albrecht,[23] which measures the cartilage overlap between the patella and the trochlea on sagittal MRI. Although their study was performed on patients without patellofemoral complaints, it may be even more pertinent to patients with patellar instability due to trochlear dysplasia, which has a more proximally distributed articular surface.[24]

Similarly, trochlear dysplasia has been classically described by Dejour, based off of findings on lateral radiographs and axial CT/MRI.[8] Although widely accepted and commonly used, it is more qualitative in nature and has low interobserver and interobserver reliability.[25,26] Another more advantageous measurement is the lateral trochlear inclination (LTI) angle, which provides a reliable, representative, and quantitative analysis of trochlear dysplasia.[27,28]

Our group previously looked at the influence that trochlear dysplasia had, as measured via the lateral trochlear inclination, on other radiographic parameters of patellar instability, such as the TT-TG distance, sulcus angle (SA), lateral patellar inclination (LPI), and the Caton-Deschamps (CD) ratio. Interestingly, we found a significant, but unclear, relationship between trochlear dysplasia and CD ratio. As the lateral trochlear inclination increased (less dysplasia), so did the CD ratio (more alta).[29] This result was in conflict with other studies showing a more direct relationship between trochlear dysplasia and patellar position[17,30] and, therefore, warranted further investigation.

It is possible that there are other factors that have not been evaluated that could have an influence on patellar height measurements. Given that the patella is often laterally tilted and translated in the setting of patellar instability, it is typically out of plane with the trochlea. This could misrepresent evaluation of patellar-trochlear overlap (patellar trochlear index evaluation) and also create variation with regard to its relationship to the proximal tibia (CD ratio).

The purpose of this study was to evaluate whether there is a correlation between the position of the patella and trochlear morphology in patients with and without patellar instability using exclusively MRI measurements. Our hypothesis is that there would be no clear relationship between the two entities and that other factors, such as patellar tilt, may have a relationship to patellar height measurements.

Methods

After obtaining institutional review board approval, a database of patients treated at our tertiary referral center between January 2014 and August 2017 was queried. Patients treated surgically for patellar instability were extracted, as well as age- and sex-matched patients with ACL tears to be used as a control group. Exclusion criteria included patients with patellar instability that required surgical intervention to correct coronal plane or rotational malalignment (gene valgum and femoral anteversion) determined both clinically and radiographically. Other exclusion criteria included patients with prior knee surgery, those undergoing treatment for a different diagnosis, lack of MR imaging, sagittal MR imaging with $>10°$ of knee flexion (Fig 1) and patients with a genetic syndrome predisposing them to abnormal skeletal abnormalities.

Demographic data were obtained, including age at first dislocation or injury and body mass index (BMI). MRI examinations were evaluated, and multiple measurements were obtained consistent with previously reported methods.[23,29] The patellotrochlear index, lateral trochlear inclination, lateral patellar inclination, and sulcus angle measurements were made on axial and sagittal MRI proton density fat saturation (PD FS) sequences. T2 fat saturation (T2 FS) sequences were used when the prior sequence was not available. Caton-Deschamps (CD) ratio was measured on sagittal MRI.

Lateral trochlear inclination and lateral patellar inclination measurements were performed using a 2-slice technique that references the orientation of the fully formed posterior femoral condyles. The intrarater and interrater reliability of these measurements are near perfect and have been reported elsewhere.[28,31] Measurement protocols were established by the principal investigator and distributed to the other authors for reference before measurement. All measurement protocols are detailed below. All measurements were then made by two independent observers; a fourth-year medical student (CC) and an orthopaedic sports medicine fellow (JH).

"Patellotrochlear Index"

The patellotrochlear index was measured using the technique described by Biedert and Albrecht.[23] First, the sagittal MR image through the portion of the patella with the thickest articular cartilage and maximal length is identified. The length of the patellar articular cartilage is then measured and recorded. Next, the amount of trochlear cartilage that overlaps with the patella is measured and recorded as the trochlear length. This measurement consists of a line drawn parallel to the patellar length starting at the most proximal articular trochlear cartilage extending distal to the distal extent of the patellar height line. The patellar trochlear index is calculated as a ratio between the trochlear length and patellar length (Fig 2). The interobserver correlation for this measurement has been reported to be high and significant (.663-.983; $P = .0001$).[23]

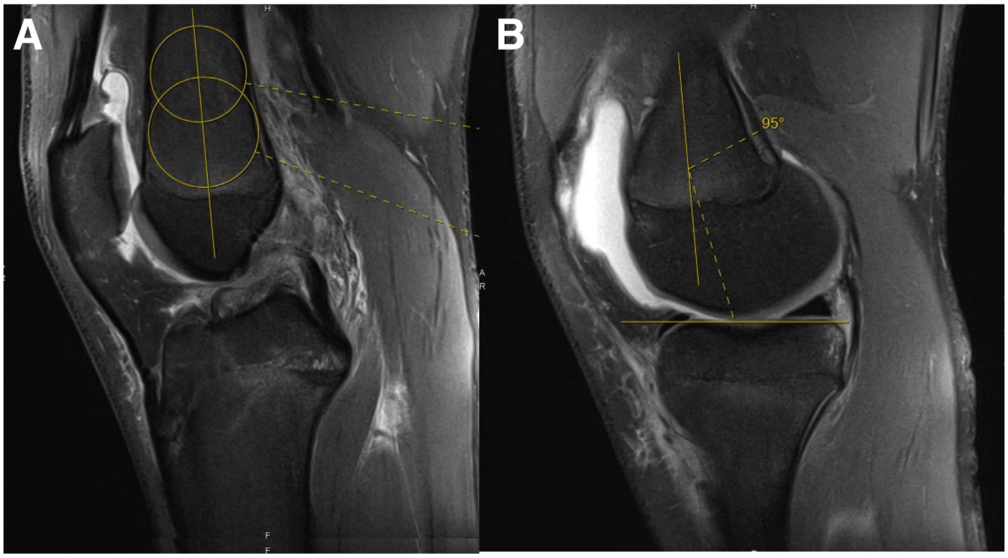

Fig 1. Measuring degree of flexion on sagittal magnetic resonance imaging (MRI). (A) Mid-sagittal MRI slice at the intercondylar notch is used to establish the axis of the femoral shaft. Two circles are placed along the distal femoral shaft, so that the anterior and posterior cortices are tangential to each circle. A line is then drawn through the center of each set of circles signifying the center of the femoral shaft. (B) Once the femoral shaft line is established, the image is scrolled to the medial compartment where the medial tibial plateau is flat. An angle is then measured between the flat medial tibial plateau and the axis of the femoral shaft. An angle of 90° corresponds to neutral position (0° of flexion). Only knees within 10° of neutral were used for patellofemoral position analysis.

"Lateral Trochlear Inclination"

The lateral trochlear inclination was performed as described by Joseph et al. using a 2-MRI-slice technique.[28] Briefly, this measurement is obtained by identifying the first axial image where the proximal lateral trochlear cartilage is seen. This image should be cross referenced with a PD FS or T2 FS sagittal image to ensure the measurement is at the most proximal aspect of the trochlea. An angle is then measured between the lateral trochlear cartilage surface and the horizontal. If the angle slopes up medially (convex trochlea), it is given a negative number. If it slopes down medially, the number is recorded as positive. Next, a more distal image is obtained where the posterior femoral condyle is fully formed and well defined. An angle between a line drawn along the posterior condyles and the horizontal is obtained and recorded. If angular measurements show internal rotation, the angle is recorded as positive. If the measurement shows external rotation, the angle is recorded as a negative number. The lateral trochlear inclination is then determined as the difference between the lateral trochlear angle and the posterior condylar angle.

"Lateral Patellar Inclination"

The lateral patellar inclination measurement was performed as described by Fucentese et al.,[32] with similar modification using a 2-MRI-slice technique used in the LTI measurement.[28] First, an angle was measured between the major axis of the patella and the horizontal on the axial image that shows the patella at its maximum width. This angle is then subtracted from an angle between the fully formed posterior femoral condyle and the horizontal to obtain the lateral patellar inclination.

"Sulcus Angle"

The sulcus angle was measured on the first axial slice of the MRI that showed the medial and lateral facets of the trochlea.

Caton-Deschamps Ratio

The CD ratio was measured on sagittal MRIs, showing the longest length of the patellar articular cartilage was consistent with the protocol described by Yue et al.[33] The length of the patellar cartilage was measured as was the distance from the inferior aspect of the patellar articular cartilage to the most proximal and anterior aspect of the tibial plateau.

Statistical Analysis

Means and standard deviations were obtained for all continuous variables overall and within groups. Two-sample *t*-tests were used to determine significance between groups. Correlation between continuous variables was measured using Pearson correlation. Contingency tables and related chi-square tests were

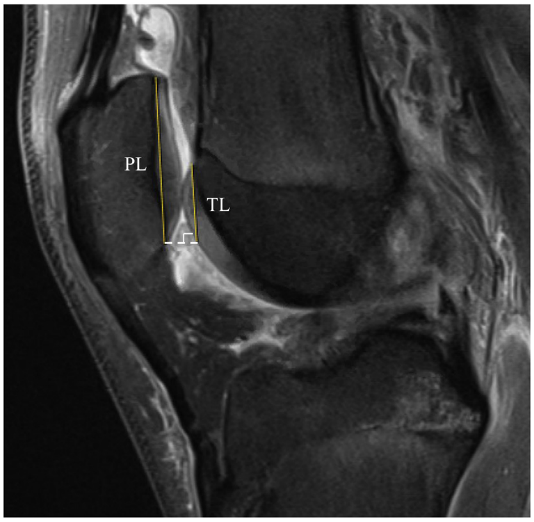

Fig 2. Patellotrochlear Index Measurement. Midline sagittal MRI through the patella with the thickest articular cartilage and maximum length of the patellar bone. The patellar length (PL) is measured from the superior most aspect of the articular cartilage to the inferior most articular cartilage. The trochlear length (TL) is measured from the superior most aspect of the trochlear articular cartilage to the level perpendicular to the inferior most aspect of the patellar cartilage. The ratio TL:PL is determined and reported as a percentage.

used to assess associations among discrete variables. Linear models and ANOVA were used to develop predictive models for continuous response variables. Statistical testing was performed with the R statistical package and STATA version 16. Significance was set at a P value <.05.

Results

A total of 70 knee MRIs of patients with patellar instability (patellar instability group) and 60 knee MRIs of patients with ACL tears (control group) were identified and met our inclusion criteria for this study. The patellar instability group had 33 females and 27 males. The control group had 35 females and 35 males. There was no statistical difference in gender between the groups (P = .569). The average age of patients at the time of their first dislocation or at the time of their ACL injury was 13.7 ± 2.6 (range: 6.5−19.7 years) and 14.5 + 2.2 (range: 9.4 − 22.1 years), respectively. Patients in the patellar instability group had a slightly higher BMI with a mean of 26.9 ± 6.53 compared to the control group (24.4 + 6.1) (P = .03) (Table 1). All imaging measurements were significantly different in the patellar instability group compared to the control group in bivariate analysis (Table 2).

Table 1. Demographics

	Control Group	PI Group	P Value
Number of knees	60	70	.06
Average age (years) at time of first injury	14.5	13.7	
Sex			
Male	35	27	.57
Female	35	33	
BMI (average)	24.4	26.9	.03

BMI, body mass index; PI, patella inclination.

Table 2. Patellofemoral Imaging Measurements Bivariate Analysis

	Control Group (n = 70)		PI Group (n = 60)		
Variable	Mean	SD	Mean	SD	P Value
CD Ratio	1.04	.14	1.23	.18	<.001
PTI	.40	.13	.31	.16	.001
LTI (degrees)	18.96	6.33	2.48	11.55	<.001
LPI (degrees)	8.89	6.24	23.87	9.96	<.001
SA (degrees)	140.80	6.69	157.28	8.77	<.001

CD, Caton-Deschamps; LPI, lateral patellar inclination; LTI, lateral trochlear inclination; PTI, Patellotrochlear Index; SA, sulcus angle; SD, standard deviation.

Multivariate analysis was performed to identify relationships between measures of patellar height and tilt (CD Ratio, Patellar Trochlear Index, lateral patellar inclination) and trochlear morphology (lateral trochlear inclination and sulcus angle). Demographic variables and group identity (control vs patellar instability) were included in the modeling, as well to see whether there were any significant differences attributed to BMI, age at first dislocation or injury, and/or patients with patellar instability.

CD ratio had significant although modest correlation with patellar trochlear index (P < .001) and lateral trochlear inclination (P < .001). A best-fitting regression model was obtained using patellar trochlear index and lateral trochlear inclination variables. The respective R-sq goodness of fit was 41.1%. There was no significant correlation between CD ratio and BMI (P = .517), age at first dislocation or injury (P = .604), or sulcus angle (P = .118). There was also no difference between the control and patellar instability groups (P = .544).

Analysis for patellar trochlear index gave a best fitting regression model with CD ratio (P < .001), lateral trochlear inclination (P < .001), lateral patellar inclination (P < .001), and patellar instability group (P = .011). The respective R-sq goodness of fit was 37.3%. Again, there was no significant correlation between patellar trochlear index and BMI (P = .286), sulcus angle (P = .211), or the age at first dislocation or injury (P = .798).

Lateral patellar inclination was significantly correlated with patellar trochlear index (P < .001), lateral trochlear inclination (P < .001), and age at first dislocation or injury (P = .02). The best fitting regression model included patellar trochlear inclination, lateral trochlear inclination, and age at first dislocation or injury. The R-sq goodness of fit was 68.56%. There was no significant correlation between lateral patellar inclination and BMI ($P = .127$), CD ratio ($P = .592$), or sulcus angle ($P = .149$). There was also no difference between groups ($P = .297$).

Discussion

The most important finding of our study was that although there was some correlation between patellar position measurements and trochlear morphology measurements, the correlations were not strong and do not provide significant evidence that patellar position is intimately related to trochlear morphology. Further, the strongest relationship found was that patellar tilt was influenced by trochlear dysplasia and patellar height, as measured by the PTI.

Although the importance of the patella-trochlea relationship to patellofemoral stability and overall knee biomechanics is well established, the developmental association between the two remains unclear. Some studies suggest that trochlear morphology is influenced via mechanical stress from the patella[15,34]; whereas, others contend[15,34] that the trochlear morphology is already well developed at birth and, therefore, determined more by genetics than influence from the patellar articulation.[9,13,35] More recently, Ferlic et al.[17] found an association between trochlear morphology and patellofemoral joint alignment measurements, concluding that increased patellar height is correlated with trochlear dysplasia. The authors[17] compared CT scans from patients with patellar instability to CT scans from patients without patellar instability to determine whether the position of the patella relative to the trochlea correlated with radiographic parameters characterizing the form of the trochlea. They determined the position of the patella relative to the trochlea by measuring the distance between where the patella showed its widest diameter (P) to the level of the proximal chondral entrance of the trochlear groove (TE), as described by Hingelbaum et al.[36] on axial CT images. They then compared this measurement to trochlear measurements taken 5 mm distal to the TE. They found significant correlation between the P-TE distance on all trochlear parameters, concluding that patellar position and trochlear morphology are intimately related. Their study has some limitations that are worth noting. Although their measurements are trochlear based as opposed to tibial based, their measurements may be too distal to accurately capture the more proximal extension of the trochlear cartilage that is common in trochlear dysplasia.[24,28] This may be more difficult to correctly identify using axial CT imaging that does not image the chondral surface as accurately as MRI. It is also curious that their patellar instability cohort had an average sulcus angle of 141.3°, which is similar to the sulcus angle of our control group (140.8°, Table 2). This is likely due to where the measurement was obtained. Our measurement was obtained on the first axial image where there was a formed medial and lateral facet. This typically represents a transitional zone from the more proximal, and more severe, location of dysplasia and the more normal distal trochlea. The average sulcus angle of our patellar instability group was much higher 157.28° (Table 2) and more consistent with what has previously been described in the literature for patients with patellar instability.[1] Our study used MRI-based measurements to try and better evaluate the interplay between the trochlea and patella chondral surfaces. Also, we looked to quantify trochlear dysplasia, in addition to the well-known sulcus angle, using the reliable and representative two-image lateral trochlear inclination measurement that evaluates dysplasia at the most proximal aspect of the cartilaginous trochlea.[28]

Stefanik et al.[30] evaluated 566 knees and compared patella height and trochlear morphology measurements to patellofemoral joint alignment measurements. They found a weak correlation between the patellar height measured via the Insall-Salvati ratio and patellar tilt and displacement measured via axial MRI. Similarly, they found weak correlations between patellar position (tilt and displacement) and trochlear morphology (sulcus angle and lateral trochlear inclination). Of note, the authors measured trochlear morphology at the level of fully formed posterior condyles on axial MRI. Again, these measurements are likely distal to where trochlear dysplasia would be of significance. Interestingly, they did not study whether or not their patellar height measurements correlated with their trochlear morphology measurements. The findings of the present study were similar in that we found a mild correlation between patellar height via the patellar trochlear index and trochlear morphology (two-image lateral trochlear inclination) and patellar tilt (modified lateral patellar inclination). Our findings that showed models of patellar height being influenced by patellar tilt and vice versa are consistent with these studies. This lends credence to the notion that the medial to lateral position of the patella, and potentially its axial orientation, can have an influence on patellar height measurements.

Close examination of our results in comparison to similar studies demonstrates the variety of patellofemoral measurements used in the literature with varying conclusions regarding correlations between the position of the patella and the trochlea. The lack of consistent findings is likely multifactorial. There is inherent difficulty in measuring the dynamic three-dimensional patellofemoral joint based on two-dimensional imaging. Specifically, using sagittal based imaging to measure patellar height in the setting of patellar instability is likely to be flawed given that the patella is usually translated out of the plane of the central trochlea and intercondylar notch. Further study into improved patellofemoral joint measurements using 2-image measuring in multiple planes or three-dimensional (3D) modeling techniques is warranted. Not only are our measuring techniques not ideal, but it is difficult to measure and account for every variable that may alter the static image being studied such as limb position and pull of the quadriceps on the superior patella.

Our study has several strengths. Although measurements of the patellofemoral joint are most important in the setting of patellar instability, our study included a control group consisting of patients with similar imaging who suffered ACL tears. This allowed bivariate analysis of our measurements between control and PI patients. There was a significant difference in all measurements between the groups, highlighting the importance of studying patellar instability cohorts in trying to make correlations between measurements of patellar instability risk factors. We also used measurements based solely on MRI, which provide the best detail of the chondral surface of the patellofemoral joint, in which most of our measurements were based on. Lastly, we tried to account for the inherent difficulty of measuring the 3D patellofemoral joint with two-dimensional imaging by using 2-image techniques for the lateral trochlear inclination and lateral patellar inclination measurements.[28,31]

Limitations

Our study is not without limitations. Torsional and coronal plane abnormalities were not optimally excluded from our study. Our aptitude to exclude these patients was based on chart review and imaging review. It is possible that some of our sample cohort had undiagnosed femoral anteversion or genu valgum that contributed to their patellar instability that was not accounted for in our analysis. Another potential limitation of the study is possible variability in the patellar trochlear index measurement method. Although this was shown to be an overall reliable measurement method, there was some intraobserver variability noted in one of the three reviewers in the original article.[23] We were meticulous in all of our measurements, but we paid particular attention to the patellar trochlear index measurement. Prior to performing the measurement on the dataset, multiple test reads were performed using a handout that was constructed by the senior author (J.L.P.). These measurements were compared against the senior author's measurements and were found to agree nicely. Thus, we think any measurement error here was minimized. Lastly, our cohort was almost exclusively adolescent patients, and therefore, the potential for selection bias exists. However, 75% of first-time patellar instability events occur in patients under the age of 25, so we believe our cohort is a good representation of the patellar instability population.[37]

Conclusion

Using MRI-based measurements of the patellofemoral joint, we identified modest, but significant, correlations between measures of patellar height (patellar trochlear index, CD ratio, and lateral patellar inclination) and trochlear dysplasia. This correlation is unclear and is likely multifactorial but, on the basis of this work, a causal relationship between trochlear dysplasia and patella alta cannot be established.

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