Original Research

Association Between Femoral Anteversion and Distal Femoral Morphology in Patients With Patellar Dislocation and Trochlear Dysplasia

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Background: Increased femoral anteversion (FA) is reportedly associated with patellar dislocation (PD) and trochlear dysplasia (TD), and the increase in FA may occur at different segments of the femur. In addition, TD is associated with dysplasia of the posterior femoral condyle. Among patients with PD, whether FA is greater with or without TD remains unclear.

Purpose: To explore differences in FA and torsion distribution at different femoral sections among patients with PD and TD, patients with PD and no TD, and sex- and age-matched controls and to investigate the association between FA and distal femoral morphology.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: This study involved 132 knees: 44 knees with PD and TD, 44 knees with PD but no TD, and 44 control knees. FA, proximal torsion (PT), middle torsion (MT), distal torsion (DT), and distal femoral morphology were measured. Differences were investigated by 1-way analysis of variance. Pearson correlation analysis was conducted to explore the association between FA and each parameter.

Results: FA was significantly larger in the PD with TD group (25.4° ± 4.7°) than in the other groups (controls: 18.9° ± 5.6°; PD without TD: 19.9° ± 4.8°) ($P < .01$). DT was significantly larger in the PD with TD group (15.8° ± 2.9°) than in the other groups (controls: 9.0° ± 4.3°; PD without TD: 8.8° ± 3.9°) ($P < .01$). In all 3 groups, FA was strongly positively correlated with DT (control, PD without TD, and PD with TD, respectively: $r = 0.76$, 0.80, and 0.88; $P < .01$), strongly positively correlated with the posteromedial condylar length ($r = 0.48$, 0.48, and 0.70; $P < .01$) and negatively correlated with the posterolateral condylar length ($r = -0.30$, -0.35, and -0.78, respectively; $P < .05$).

Conclusion: The increased FA in knees with TD was due mainly to DT rather than PT or MT, which may provide a reference for choosing the optimal position for femoral derotation osteotomy.

Keywords: femoral anteversion; femoral torsion; patellar dislocation; trochlear dysplasia

Patellar dislocation (PD) is a common condition in adolescents, especially girls between the ages of 10 and 17 years; the incidence of PD ranges from 29 to 43 per 100,000 per year.[5,8,17,21] Nearly half of patients with primary PD develop recurrent patellar instability after nonoperative treatment.[8] Increased femoral anteversion (FA) has been considered a predisposing risk factor for PD because it generates increased tension of the medial patellofemoral ligament,[4,6,30] increased forces on the lateral patellar facet, and decreased forces on the medial facet,[13,19,22] resulting in abnormal patellofemoral loads and the tendency for lateral dislocation.[3,7,30] Increased FA has also been correlated with inferior clinical efficacy of PD treatment without correcting the abnormal torsion.[9,26,36]

Some studies have indicated that increased FA is correlated with trochlear dysplasia (TD), and TD was associated

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with dysplasia of the posterior femoral condyle.[15,33] However, among patients with PD, whether FA is greater in those with than without TD remains unclear. In addition, no study to date has explored the torsion distribution among different femoral sections between a control group, a group with TD, and a group without TD. It is important to determine the difference in the torsion distribution and the locations of the abnormal torsion among these groups to choose the optimal surgical plan for correction of the abnormal torsion.

The purpose of this study was to investigate the difference in the FA and the proximal torsion (PT), middle torsion (MT), and distal torsion (DT) of the femur between a control group, a PD group with TD, and a PD group without TD and to investigate the association between FA and distal femoral morphology.

METHODS

Before the study began, approval was obtained from the hospital's ethics committee. Informed consent was obtained from all participants. This was a cross-sectional study involving 3 groups of 44 patients each: (1) patients with TD who had experienced ≥2 episodes of PD with continued instability, (2) a sex- and age-matched group of patients with patellar instability without TD, and (3) a sex- and age-matched control group of patients who had experienced meniscal injuries with no history or objective signs of patellar instability and no TD. Computed tomography (CT) data were collected from March 1, 2015, to October 31, 2020. Patients were excluded if they met the following criteria: previous surgery or trauma of the lower extremity involved in the study, habitual PD, or Kellgren-Lawrence grade ≥2 patellofemoral osteoarthritis.[24] To ensure a rigorous selection process, the enrolled participants were rechecked independently and confirmed by the same senior orthopedist (F.W.), who has extensive experience in treating patellofemoral disorders.

Participants

The PD with TD group comprised patients with severe TD who were treated with trochleoplasty and medial patellofemoral ligament reconstruction in our hospital's orthopaedic surgery department from March 1, 2015, to October 31, 2020. We used a combination of the following criteria to select patients for enrollment: trochlear depth of <3 mm and Dejour TD types B to D.[11,16,23,32] The Dejour classification was chosen over the lateral trochlear inclination because the latter is affected by the posterior femoral axis, which also influences FA.[20] Patients in the PD without TD group were matched with patients in the PD with TD group through a search of inpatients who had been diagnosed with PD in our hospital's orthopaedic surgery department. Patient records were reviewed to confirm that ≥1 PD episode had occurred and that CT results were available. Patients in the control group were matched with patients in the TD group through a search of inpatients who had been diagnosed with meniscal tears in our hospital's orthopaedic surgery department. Patient journals were assessed to confirm that the patients had sustained a meniscal tear and had no history or objective signs of patellar instability.

CT Protocol

All patients underwent CT scans of the knee and hip on the affected side. They were placed in the supine position on the scanning table with the knee fully extended, with neutral or slight external rotation as needed for comfort. Straps were wrapped around the thigh and lower leg to minimize motion. A 16-detector row CT scanner (SOMATOM Sensation 16; Siemens Medical Solutions) was used. These axial CT scans of the lower limb were acquired using the following parameters: 512 × 512 matrix, 120 kV, 100 mAs, 1-second rotation time, and 1-mm slice thickness. CT images were then imported into a personal computer to carry out measurements using RadiAnt DICOM (Digital Imaging and Communications in Medicine) software (Medixant Ltd) with an accuracy of 0.1° and 0.1 mm.

Measurements

To investigate the position at which the torsion occurred, the following measurements were determined according to previous studies[15,33]: the femoral head-neck axis, a line passing through the lesser trochanter, the tangent line of the distal femur at the upper popliteal level, and the posterior condylar line. According to these anatomical landmarks, the following angles could be measured: FA, PT, MT, and DT (Figure 1).

The clinical transepicondylar axis was used as a basis to measure the morphology of the femoral trochlea and condyle in the transverse plane, which is a reliable reference point on the distal femur.[1,2,12,35] The axial image of the distal femur was selected in the section of the "Roman arch" (rounded intercondylar notch) to show the entire morphology of the femoral trochlea and femoral condyle.[27,33] The length of the anterior condyle and posterior condyle was defined as the vertical distance between the top point of the condylar cortex and the clinical transepicondylar axis. The anteromedial condylar length (AMCL), anterolateral condylar length (ALCL), posteromedial condylar length (PMCL), and posterolateral condylar length (PLCL) were measured (Figure 2). The height of the anteromedial condyle is difficult to measure in some hypoplastic knees; in such cases, measurements were taken from an inflection point or top point of the medial trochlear slope.[33]

All measurements were made independently by 2 experienced surgeons (X.C. and G.J.) twice using the same criteria at a 4-week interval, and the means of the data were taken as the final results for analysis. The interobserver and intraobserver agreement of the measurements was calculated.

Statistical Analysis

All statistical analyses were performed using SPSS software Version 24.0 (IBM Corp). The interobserver and intraobserver agreement of the measurements was

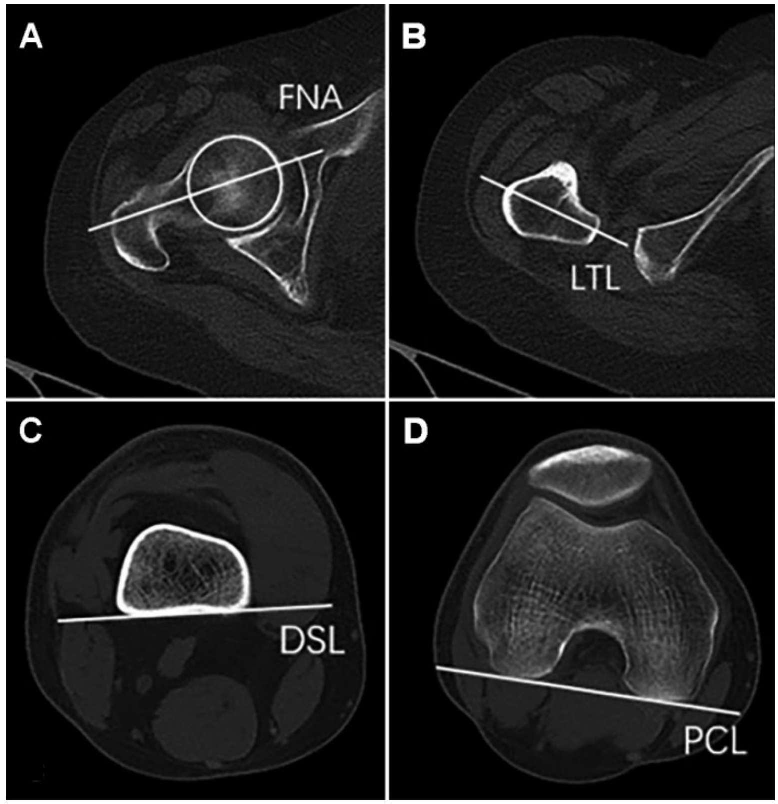

Figure 1. FA and torsion of different femoral sections. (A) FNA, defined as a line through the center of the femoral head and neck. (B) LTL, defined as a line through the center of the lesser trochanter. (C) DSL, defined as the tangent line of the posterior distal femoral shaft (popliteal level). (D) PCL, defined as the line at the posterior edge of the medial and lateral condyles; FA is the angle between FNA and PCL, PT is the angle between FNA and LTL, MT is the angle between LTL and DSL, and DT is the angle between DSL and PCL. DSL, distal femoral shaft line; DT, distal torsion; FA, femoral anteversion; FNA, femoral head-neck axis; LTL, lesser trochanter line; MT, middle torsion; PCL, posterior condylar line; PT, proximal torsion.

assessed with the intraclass correlation coefficient (ICC), and an agreement of $\geq$0.75 was considered excellent.

The related data for femoral torsion at different levels and the condylar length were tested for normality (Kolmogorov-Smirnov test), compared by 1-way analysis of variance among the groups, and analyzed using the Pearson correlation coefficient (r). The value of r ranged from -1 to 1 and was classified as follows according to absolute value: strong correlation (0.75-1.00), moderate correlation (0.45-0.75), mild correlation (0.30-0.45), or no correlation (0.00-0.30). The threshold for statistical significance was set at $P < .05$ for significant and $P < .01$ for highly significant. For estimation of the sample size, a power analysis was undertaken based on a confidence level of 95% ($\alpha = .05$), a power ($1 - \beta$) of 80%, an effect size $f = 0.3$, and number of groups = 3; this analysis showed that a total of 111 patients was needed.

RESULTS

The characteristics of the study patients are shown in Table 1. No significant differences in the patients' baseline information were detected among the 3 groups. Excellent interobserver and intraobserver reliability was found for all measurements, with an ICC of $\geq$0.75 (Table 2). All quantitative data in this study passed the test of normality.

The correlation analysis showed that FA had a positive correlation with DT and PMCL and a negative correlation with PLCL. In knees without TD, FA was not correlated with AMCL or ALCL. Interestingly, however, in knees with TD, FA was mildly correlated with AMCL and ALCL (Table 4).

DISCUSSION

The main strength of this study was that it provides direct evidence that FA is larger in knees with TD than in knees without TD. The increased FA in knees with TD is due to DT rather than PT or MT. To be more precise, the increase in FA in knees with TD is due mainly to a larger posteromedial condyle and a smaller posterolateral condyle. This increase in FA may be due largely to dysplasia of the posterior femoral condyles.

The pathological value of FA in patients with recurrent PD has been analyzed previously, but data were conflicting. Dejour et al[4] found that FA in patients with recurrent PD was 15.6° ± 9.0°, Diederichs et al[6] found that FA in patients with recurrent PD was 20.3° ± 10.4°, and Yang et al[33] found

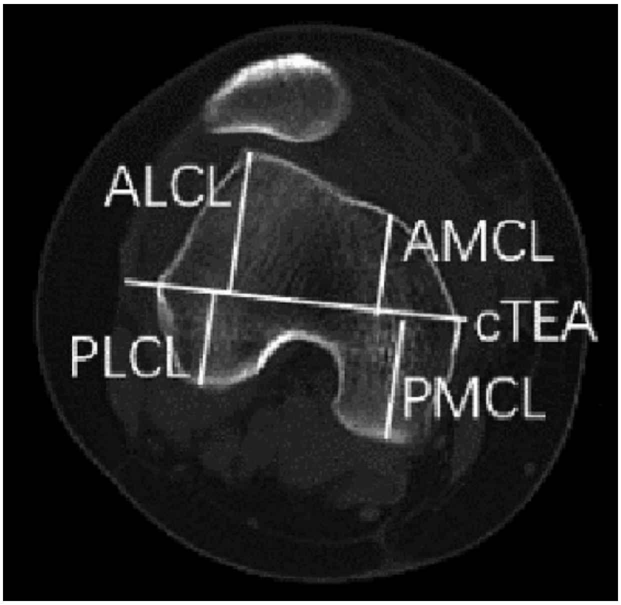

Figure 2. Measurement of distal femoral morphology. cTEA, defined as the line through the most prominent points of the bilateral epicondyles. AMCL, defined as the length of the anteromedial condyle with reference to the cTEA. ALCL, defined as the length of the anterolateral condyle with reference to the cTEA; PMCL, defined as the length of posteromedial condyle with reference to the cTEA; PLCL, defined as the length of posterolateral condyle with reference to the cTEA. ALCL, anterolateral condylar length; AMCL, anteromedial condylar length; cTEA, clinical transepicondylar axis; PLCL, posterolateral condylar length; PMCL, posteromedial condylar length.

TABLE 1
Participant Characteristics[a]

Variable	Control Group (n = 44)	PD Without TD (n = 44)	PD With TD (n = 44)
Sex, male/female	14/30	14/30	14/30
Age, years	25.5 ± 4.6	24.6 ± 5.1	26.2 ± 4.8
Side, left/right	24/20	23/21	25/19
BMI, kg/m^2	22.8 ± 4.1	23.1 ± 5.7	23.3 ± 5.2

[a]Data are presented as n or mean ± SD. BMI, body mass index; PD, patellar dislocation; TD, trochlear dysplasia.

TABLE 2
Intraobserver and Interobserver Reliability of Measurements[a]

Variable	ICC (95% CI) Interobserver	Intraobserver
FA	0.76 (0.69-0.85)	0.78 (0.73-0.81)
PT	0.79 (0.75-0.83)	0.75 (0.68-0.82)
MT	0.80 (0.76-0.84)	0.76 (0.71-0.82)
DT	0.81 (0.77-0.84)	0.79 (0.73-0.85)
AMCL	0.78 (0.75-0.82)	0.75 (0.68-0.80)
ALCL	0.79 (0.75-0.82)	0.78 (0.71-0.83)
PMCL	0.81 (0.76-0.84)	0.76 (0.72-0.82)
PLCL	0.80 (0.75-0.84)	0.75 (0.68-0.81)

[a]The FA and DT were significantly different among the groups ($P < .01$), but there was no significant difference in PT or MT among the groups ($P > .05$). The AMCL, PMCL, and PLCL were significantly different among the groups ($P < .01$), but there was no significant difference in ALCL among the groups ($P > .05$) (Table 3, Figure 3). The increase in FA in the TD group was due mainly to the increase in DT (Figure 4). ALCL, anterolateral condylar length; AMCL, anteromedial condylar length; DT, distal torsion; FA, femoral anteversion; ICC, intraclass correlation coefficient; MT, middle torsion; PLCL, posterolateral condylar length; PMCL, posteromedial condylar length; PT, proximal torsion.

TABLE 3
Comparison of Parameters[a]

Parameter	Control Group	PD Without TD	PD With TD	*P*
FA, deg	18.9 ± 5.6	19.9 ± 4.8	25.4 ± 4.7	<.01
PT, deg	39.2 ± 6.7	40.2 ± 6.1	40.6 ± 5.3	NS
MT, deg	29.8 ± 5.1	28.9 ± 5.5	29.4 ± 4.2	NS
DT, deg	9.0 ± 4.3	8.8 ± 3.9	15.8 ± 2.9	<.01
AMCL, mm	28.6 ± 4.4	28.1 ± 4.4	26.0 ± 3.7	<.05
ALCL, mm	35.6 ± 4.8	35.1 ± 4.7	35.1 ± 3.5	NS
PMCL, mm	25.7 ± 3.1	25.2 ± 3.2	27.4 ± 2.2	<.05
PLCL, mm	20.3 ± 2.7	19.8 ± 2.8	18.8 ± 2.6	<.05

[a]Data are presented as mean ± SD. ALCL, anterolateral condylar length; AMCL, anteromedial condylar length; DT, distal torsion; FA, femoral anteversion; MT, middle torsion; NS, not significant; PD, patellar dislocation; PLCL, posterolateral condylar length; PMCL, posteromedial condylar length; PT, proximal torsion; TD, trochlear dysplasia.

that the FA was 27.5° (range, 5° to 55°) in patients with lateral PD and TD. These variances may be due to the high heterogeneity of the recruited patients. To diminish such heterogeneity, we divided our study population into a control group, patients with PD and TD, and patients with PD but without TD. We detected a significant increase in FA in the TD group (25.4° ± 4.7°) compared with normal knees (18.9° ± 5.6°) and knees with PD but without TD (19.9° ± 4.8°). This suggests that, among patients with PD, FA is clearly different between those with and without TD. It should be noted that the standard deviation of FA in our study was smaller; the reason may be that population stratification reduces the variability, and our population may have thus been more precise and targeted than those in previous studies.

In addition, the mean values of FA in our study were larger than those in previous data, and the reasons may be the measuring methods used and variation in the population. FA reportedly varies by up to 30° in apparently healthy adults.[28] Different measuring methods can yield values of FA that differ by up to 20° in the same participant, based mainly on determination of the femoral head-neck axis.[10] Using the measurement method described by Liebensteiner et al,[15] and according to previous studies,[14,18] an increased FA may begin at >25°, and the

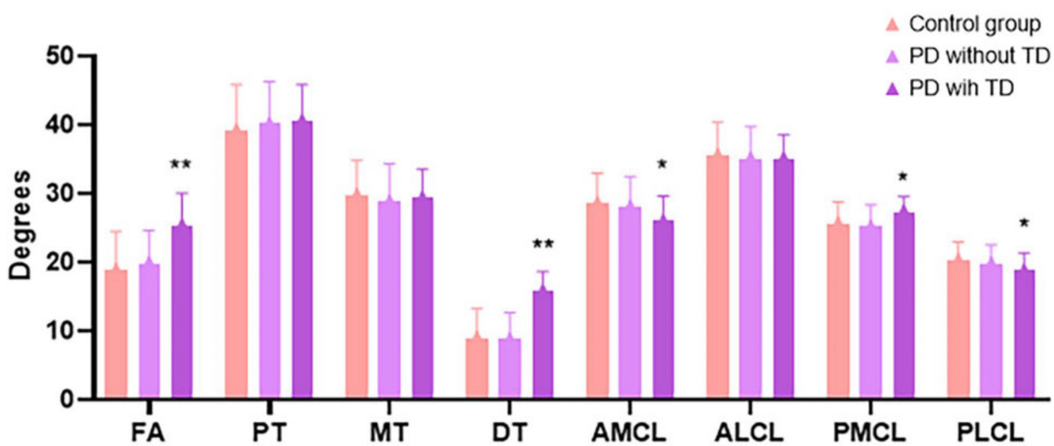

Figure 3. Comparison of parameters among the 3 study groups. Statistically significant difference between groups: *$P < .05$, **$P < .01$. ALCL, anterolateral condylar length; AMCL, anteromedial condylar length; DT, distal torsion; FA, femoral anteversion; MT, middle torsion; PD, patellar dislocation; PLCL, posterolateral condylar length; PMCL, posteromedial condylar length; PT, proximal torsion; TD, trochlear dysplasia.

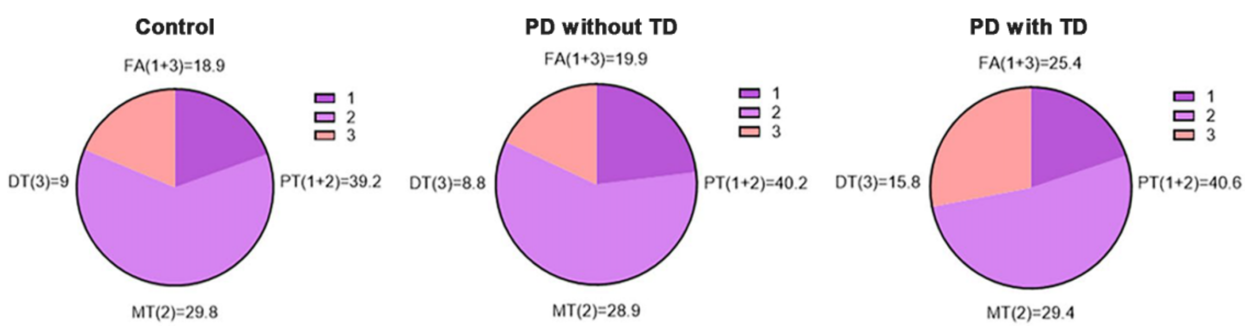

Figure 4. Composition of differences in FA among the 3 study groups. DT, distal torsion, represented by 3; FA, femoral anteversion, represented by 1+3; MT, middle torsion, represented by 2; PD, patellar dislocation; PT, proximal torsion, represented by 1+2; TD, trochlear dysplasia.

indication for distal femoral derotation osteotomy is also an FA of >25°. This has also been verified in other studies.[18,31,34] If severe femoral shaft deformity is not present, we suggest that there is no need for proximal or middle derotation surgery. We speculate that distal derotation surgery combined with patellar stabilizing surgery is sufficient for these patients.

Our study indicated that FA was greater in knees with TD than in knees without TD, and the increase in FA was due mainly to DT rather than to PT or MT. This conflicts with a previous study showing that an increased FA was attributed to PT and MT in addition to DT.[29] The reason for the conflicting findings may be due to the recruited samples. The authors of the previous study artificially divided the participants into low and high FA groups and investigated the sources of FA differences by comparing the torsion of different segments. In our study, however, the FA and the PT, MT, and DT of the femur were compared among normal knees, knees with PD and TD, and knees with PD but without TD. We found that the FA was significantly larger in knees with TD, and the cause of the increase was the increase in DT. This may provide a reference for the position chosen for femoral derotation osteotomy in patients with TD. In addition, in our study, an increased FA was attributed mainly to a larger posteromedial condyle and a smaller posterolateral condyle in knees with TD, which is partly consistent with the results reported by Roger et al,[25] who found that a short lateral posterior condyle is associated with TD and PD.

The correlation between FA and distal femoral dysplasia has been analyzed previously, but the conclusions were conflicting. Liebensteiner et al[15] found a correlation between FA and a flatter, more dysplastic trochlea, especially for FA located at the distal femur. Yang et al[33] reported that an increased FA was correlated with a prominent anterolateral condyle and a shorter posterolateral condyle compared with the medial condyle. By contrast, Diederichs et al[6] found no significant correlation between FA and trochlear morphology in a limited patient population. These conflicting findings may be attributed to the high heterogeneity of the recruited patients. Previous studies focused more on patients with TD or the general population[15,33]; studies involving patient stratification are not available. In the present study, we divided the patients into

TABLE 4
Correlation of FA With Study Parameters (Pearson r)[a]

Parameter	Control Group	PD Without TD	PD With TD	All Patients
PT, deg	0.26	0.11	0.10	0.14
MT, deg	-0.02	-0.12	-0.05	-0.06
DT, deg	0.76[b]	0.80[b]	0.88[b]	0.77[b]
AMCL, mm	-0.07	-0.08	-0.44[b]	-0.30
ALCL, mm	0.16	0.16	0.37[c]	0.17
PMCL, mm	0.48[b]	0.48[b]	0.70[b]	0.58[b]
PLCL, mm	-0.30[c]	-0.35[c]	-0.78[b]	-0.49[b]

[a]ALCL, anterolateral condylar length; AMCL, anteromedial condylar length; DT, distal torsion; FA, femoral anteversion; MT, middle torsion; PD, patellar dislocation; PLCL, posterolateral condylar length; PMCL, posteromedial condylar length; PT, proximal torsion; TD, trochlear dysplasia.

[b]Relationship significant at the $P < .01$ level.

[c]Relationship significant at the $P < .05$ level.

3 distinct groups to diminish the heterogeneity and found that FA had a positive correlation with DT, a positive correlation with PMCL, and a negative correlation with PLCL in the 3 groups. Interestingly, in knees without TD, FA was not correlated with AMCL or ALCL, while in knees with TD, FA was correlated with AMCL and ALCL. This may suggest that the deformities of the anterior and posterior condyles are combined deformities rather than isolated and individual deformities in patients with TD.[33]

Limitations

Several limitations of the present study should be noted. First, the patients in the control group were chosen from among those with meniscal tears, which may have increased patient selection bias. Second, although a standardized CT protocol was used, the study was performed in a blind and randomized manner, and the ICC showed that the data were reproducible, the data still had the possibility of measurement bias. Finally, although the number of patients in this study met the statistical requirements of the power study, a larger sample size and more data are still needed to further assess the quantitative relation between FA and features of condylar morphology.

CONCLUSION

The increased FA in TD knees is due mainly to DT rather than PT or MT, which may provide a reference for choosing the optimal position of femoral derotation osteotomy. Patients with TD are prone to developing recurrent patellar instability, which may be due to the malalignment of the patellofemoral joint caused by abnormal rotation in addition to the weakening of bony resistance. More evidence is needed to show that femoral derotation osteotomy may also achieve good clinical results in the treatment of recurrent patellar instability with TD.

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