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Association of Femoral Trochlear Dysplasia and Tibiofemoral Joint Morphology in Adolescent

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Background: Trochlear dysplasia (TD) often leads to anatomic variations of the knee. Little is known about the association of TD and tibiofemoral joint morphology in adolescent.

Material/Methods: Computed tomography scans of 35 knees with TD and 55 knees with well-developed patella-femoral joint were analyzed randomly and retrospectively. Two researchers evaluated the posterior tibial slope (PTS), distal femoral rotation, proximal tibia varus angle, and femoral anteversion between the 2 groups. The independent Student's *t*-test was used to evaluate the statistical significance of variables.

Results: The study group had a smaller lateral PTS (4.7±2.97) than the control group (6.96±3.05) ($P<0.01$), while the medial PTS showed consistent values between the control and the study group (non-significant). Patients with TD had smaller external rotation of the distal femur (2.69±0.93) compared to the control group (3.77±1.46) ($P<0.01$). In addition, the study group showed a bigger proximal tibia varus angle (4.46±1.09) compared to the control group (3.35±0.76) ($P<0.01$). The femoral anteversion in the study group (17.46±9.95) was increased compared to the control group (12.22±5.39) ($P<0.01$). The femoral anteversion and distal femoral rotation in patients with TD showed a positive correlation ($r^2=0.326$; $P<0.001$).

Conclusions: Patients with TD had flatter lateral PTS compared to those without TD, but there were no differences in the medial PTS between the two groups. Patients with TD had smaller distal femoral rotation and bigger proximal tibia varus angle. The femoral anteversion in patients with TD was bigger than those without TD,and there was a positive correlation between the femoral anteversion and the external rotation of the distal femoral in the study group.

MeSH Keywords: Knee • Patellar Dislocation • Tomography, Spiral Computed

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Background

Trochlear dysplasia (TD) is a major predisposing factor related to patellar instability [1]. A previous study found that 96% of patients with TD had a history of patellar dislocation [2]. TD of the femur is not only manifested as morphological changes of the trochlear, but also as geometric morphology of the distal femur [3]. Although many researchers have studied the characteristics of TD, certain anatomical abnormalities related to TD are still not well explored. The purpose of this study was to explore the association of femoral TD and tibiofemoral joint morphology.

Distal femoral rotation has been extensively researched in recent years [4-6]. There have been many distal femoral rotational reference axes used to determine the rotation angle of the femoral component in knee replacements [7,8]. However, there has been little literature available on the relationship between TD and distal femoral rotation. Concomitantly, many recent studies have identified that patellar dislocation is related to many complex factors such as the bone structures and soft tissue malformation. Excessive femoral anteversion is one of the most important bony anatomical malformations [9–11]. However, there have been few studies that have examined the relationship between femoral anteversion and distal femoral rotation in patients with TD.

In recent years, the influence of the geometric shape of the tibial plateau on the biomechanics of the knee joint have been receiving significantly attention. A large number of investigations have shown that the geometric shape of the tibial plateau has a significantly effect on the biomechanics of the knee, knee rotation, screw-home mechanism, and biomechanical nature of the cruciate ligaments [12–14]. In the clinical practice of total knee replacement, many studies have indicated that the external rotation angle of a femoral prosthesis should be equal to the varus angle of the tibia plateau [15–17]. When common anatomical markers cannot be estimated due to excessive wear, it is difficult to determine the rotation angle of a femoral prosthesis, so the varus angle of the tibia plateau can be used to help determine the rotation angle of a femoral prosthesis. However, few previous studies have specifically examined the variation of varus angle of the tibia plateau in patients with TD. In addition, the posterior tibial slope (PTS) has been investigated as a vital factor in knee arthroplasty and anterior cruciate ligament injury [18–21]. Although the importance of the geometric structure of the tibial plateau has been well demonstrated in previous studies, few studies can help us understand the changes of PTS in patients with TD.

Therefore, the purpose of this research was to assess the geometry of PTS, the distal femoral rotation, the proximal tibia varus angle, and the femoral anteversion in patients with and without TD, and to evaluate a possible correlation between femoral anteversion and distal femoral rotation in patients with TD.

Material and Methods

This present study was approved by our Institutional Review Board, and informed consent was obtained from all participants. Computed tomography (CT) scans of 35 knees in 30 patients with TD (12 male patients and 15 female patients) were randomization and included in the study group. All the patients had a history of lateral patellar dislocation. Exclusion criteria were prior surgery of the lower extremity, trochleoplasty, distal femur or proximal tibia fracture, knee ligament injury, and arthritis.

CT scans of 55 knees of 43 patients (18 male patients and 25 female patients) without TD were included as the control group. CT scans of the control group and the study group were performed during the same time period. The reason for a CT scan of a patient in the control group was soft tissue injury or cartilage lesion of the tibiofemoral joint. Exclusion criteria were osteoarthritis or other pathological changes associated with the patellofemoral joint, as well as anterior cruciate ligament tear, which is usually related to an increased PTS [14].

All of the CT scans were performed by the same technician under standard conditions. All the patients were in a supine position with knee joint fully extended and feet placed in external rotation of 15° to ensure the patellar was exposed to anterior view. A 5 mm thick section was taken from the superior part of the trochlear to the tibia tuberosity. Sagittal, coronal, and transverse CT images were obtained and used to evaluate the grade of TD, the external rotation angle of the distal femur, and the medial and lateral tibial slope. All measurements were performed using RadiAnt DICOM software. To reduce measurements error, all measurements were taken by 2 researchers (DYK and KHJ). After an interval of 1 week, all samples were measured again by a third researcher, LFQ. In order to study the reliability between intra-observer and inter-observer, the intra-class correlation values of investigated parameters were calculated.

Trochlear dysplasia (TD)

Trochlear dysplasia (TD) was measured as described by Dejour et al. and classified as type A–D [9], with type A having morphology of femoral trochlear presented as a fairly shallow sulcus; type B having flat or convex sulcus of trochlear; type C having asymmetry of femoral trochlear with convex lateral and hypoplastic medial condyle; and type D having asymmetry of femoral trochlear and hypoplastic medial condyle.

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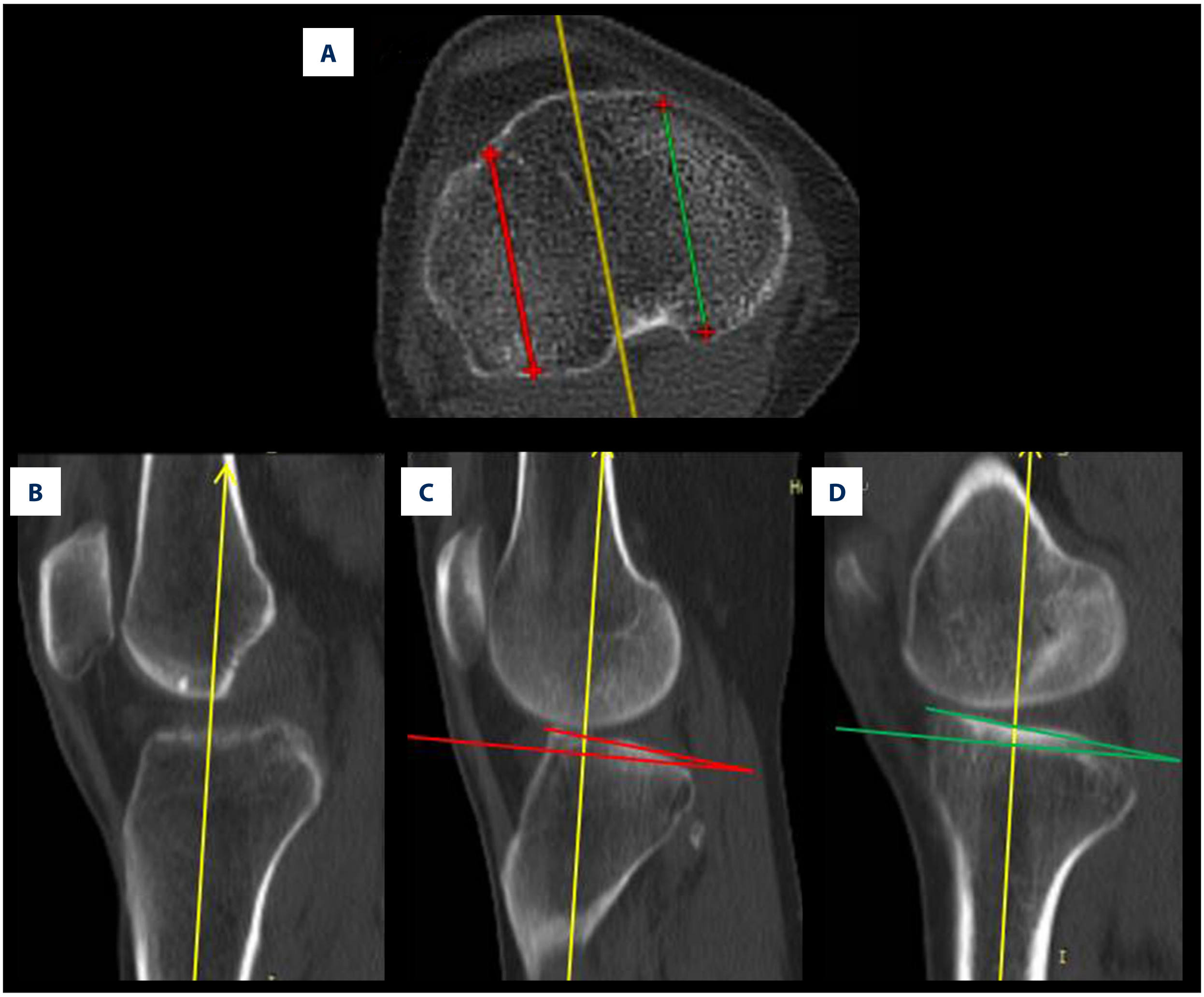

Figure 1. Measurement of the posterior tibia slope. (**A**) First transverse computed tomography image shows the entire tibia head. Yellow line: the central tibia head. Green line: the central of the medial plateau. Red line: the central of the lateral tibia plateau. (**B**) The longitudinal axis of the tibia diaphysis was the midpoint of the anterior-posterior distance at 2 locations (4–5 cm distal to the joint line and as distally as possible). (**C**) The central of the lateral plateau. (**D**) The central of the medial plateau. The line perpendicular to the longitudinal axis was used as the reference line. The angle between the reference line and the posterior inclination of the tibia was defined as the posterior tibial slope.

Posterior tibial slope (PTS)

The medial and lateral posterior tibial slope (PTS) was measured on transverse and sagittal CT images according to the measurement introduced by Hashemi et al. [22]. First, in the proximal-distal direction, the first transverse CT image in an axial scan that revealed the whole tibia head was selected (Figure 1A). The center of the tibia head was determined by this transverse image (yellow line in Figure 1A), then the corresponding sagittal plane was identified, which is shown in Figure 1. In the sagittal section, the longitudinal axis of the tibia, was defined as the line connecting the 2 midpoints of the anterior-posterior part of the tibia diaphysis (4–5 cm distal to the tibia plateau) (Figure1B). Then, the longitudinal axis was shifted to the medial and lateral center of tibia head (green and red lines in Figure 1A). The medial and lateral posterior angle of tibial slope measured the corresponding sagittal section (Figure 1C, 1D). Then, the posterior inclination of the tibia was measured between the peak anterior and most posterior points of the lateral and medial tibial plateau on this sagittal slice. Similarly, a marked line was measured to perpendicular to the longitudinal axis. The angle between the posterior inclination of the tibia and the marked line was defined as the PTS. The tibial slope was defined as positive when the anterior highest point was above the posterior highest point. When the posterior point was above the anterior point, it was defined as negative.

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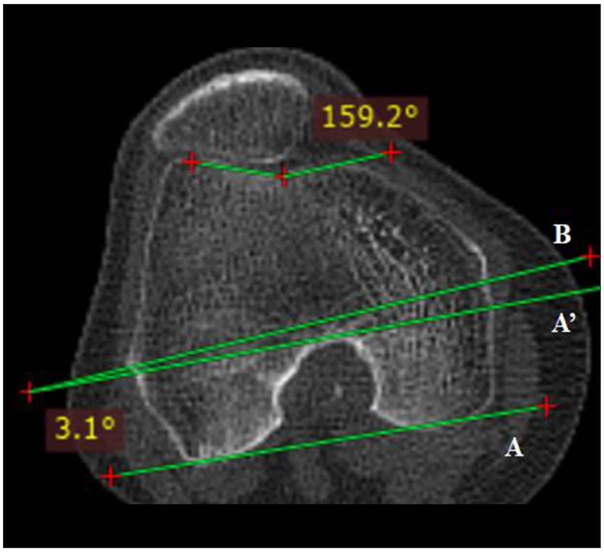

Figure 2. Measurement of the distal femoral rotation. The distal femoral rotation is determined by the angle between the transepicondylar axis (TEA) and posterior condylar axis (PCA). Line A – PCA. Line A' – a line parallel to the PCA. Line B – TEA.

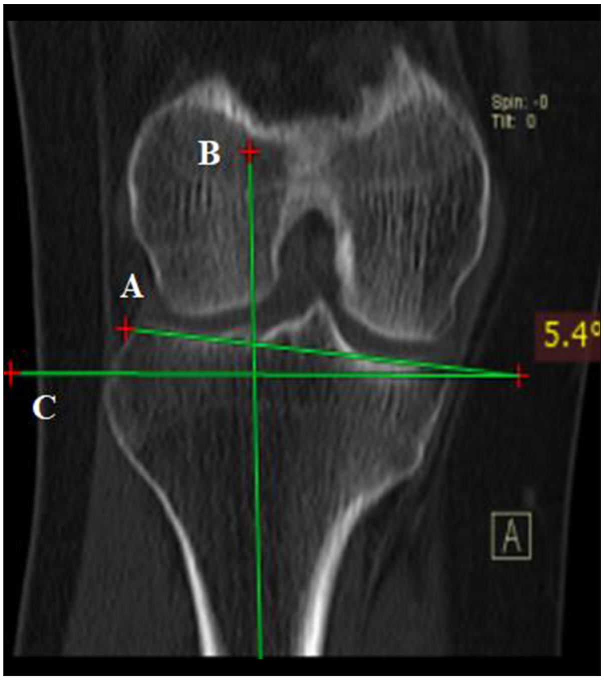

Figure 3. Measurement of the proximal tibia varus angle. Proximal tibia varus angle means an angle between tibial articular margins and a line perpendicular to the tibial mechanical axis. Line A – tibial articular margins. Line B – tibial mechanical axis. Line C – a line perpendicular to the tibial mechanical axis.

Distal femoral rotation

In order to measure the distal femoral rotation, 2 distal femoral reference axes needed to be identified and marked: transepicondylar axis and posterior condylar axis. The transepicondylar axis is a line joining the most prominent point of the lateral epicondyle and the groove of the medial epicondyle which is derived in a transverse CT image (Figure 2). The posterior condylar axis is a line tangent to the posterior side of posterior femoral condyles (Figure 2). The distal femoral rotation is the angle between the transepicondylar axis and the posterior condylar axis [7,8].

Proximal tibia varus angle

Proximal tibia varus angle is the angle between the tibial articular margins and a line perpendicular to the mechanical axis of tibia (mechanical axis of the tibia was drawn by a line connecting the center of tibial spine and the center of talar dome) [16] (See Figure 3).

Femoral anteversion

The anteversion of the femur neck is the angle formed by the posterior femoral condyles line (a line tangent to the posterior side of posterior femoral condyles) and a line connecting the center of the neck and femoral head [9] (See Figure 4.)

Statistical analysis

All statistical analyses were performed using SPSS 17.0 software (IBM, Chicago, IL, USA). Experimental data were checked for Gaussian distribution and were expressed as mean ± standard deviation. The 95% confidence interval was used to calculate all values of both groups. Linear regression analysis was used to determine the relationship between the femoral anteversion and the distal femoral rotation. The researchers compared the values of the study group and the control group with a Student's *t*-test. *P* value <0.05 was set as a significant difference.

Results

The demographic characteristics of the study group and the control group are presented in Table 1. In terms of sex, age, and side, there were no significant differences between the study group and the control group. In all measurements, the repeatability of intra-observer and inter-observer was high (Table 2). In the study group, the lateral PTS of patients with TD was decreased compared to the control group ($P<0.01$). However, the medial PTS between the study group and the control group showed no significant difference (Table 3, Figure 1). As a result,

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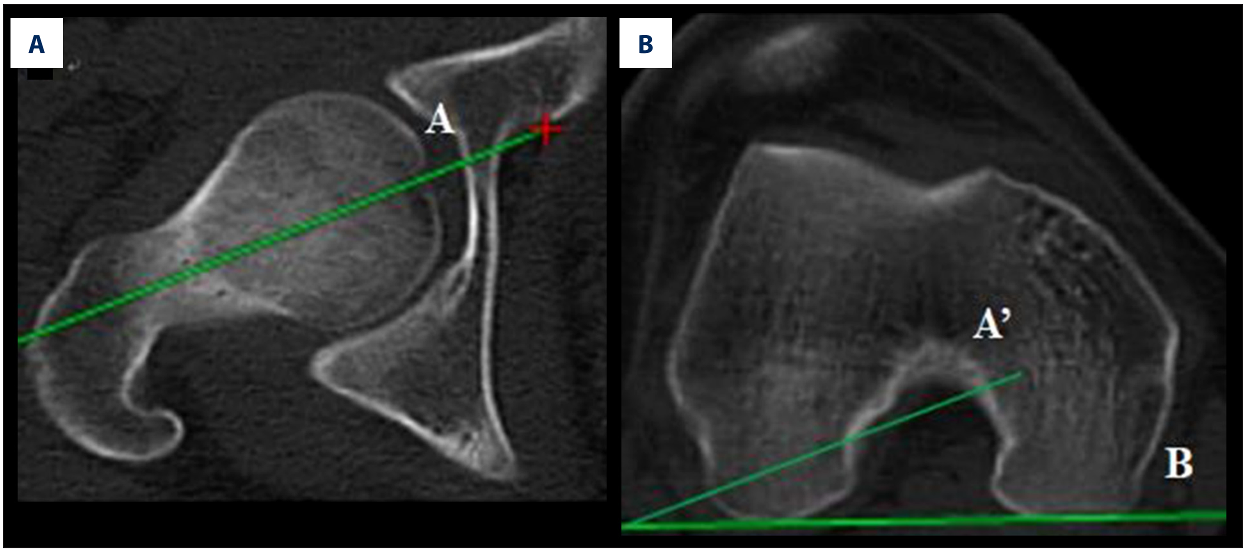

Figure 4. Measurement of the femoral anteversion. The anteversion angle of the femur neck is the angle formed by the femoral condyles plane (bicondylar plane) and a plane passing through the center of the neck and femoral head. (**A**) Line A – a line passing through the center of the neck and femoral head. (**B**) Line A' – a line parallel to the line A. Line B – posterior condylar axis.

Table 1. Demographic characteristics of the trochlear dysplasia group and the control group.

	Study (n=35)	Control (n=43)	*P*
Gender			ns
Female	18	25	
Male	17	18	
Age	19.73±5.66	19.95 ± 5.56	ns
Side			ns
Right	19 (54.29)	32 (59.26)	
Left	16 (45.71)	22 (40.74)	

n.s. – no significance.

Table 2. Intra-observer and inter-observer agreement of geometric measurements with 95% confidence intervals.

Measurement	Intra-observer ICC	95% CI for ICC		Inter-observer ICC	95% CI for ICC	
		Lower	Upper		Lower	Upper
Medial PTS	0.991	0.987	0.994	0.992	0.990	0.994
Lateral PTS	0.974	0.963	9.981	0.978	0.971	0.984
Femoral rotation	0.989	0.985	0.992	0.991	0.989	0.994
PTA	0.980	0.972	0.986	0.986	0.982	0.990
FA	0.985	0.979	0.989	0.987	0.983	0.991

PTS – posterior tibial slope; PTA – proximal tibia varus angle; FA – femoral anteversion angle.

the asymmetric posterior of the tibial plateau slope was significantly related to TD. Our study also showed that patients with TD had less external rotation of the distal femur compared to the control group (*P*<0.01) (Table 3, Figure 2). In addition, the study group showed a slightly increased varus deformity characterized as a slightly bigger proximal tibia varus angle compared

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Table 3. Parameter values of the trochlear dysplasia group and the control group.

	Study		Control		P
Medial PTS degree	7.87±3.49	(−3–17.3)	6.22±3.96	(0.7–16.7)	n.s.
Lateral PTS degree	5.23±2.65	(−2–14.1)	6.98±2.89	(1–14)	<0.01
Femoral rotation	3.02±1.10	(1–5.7)	4.03±1.33	(1–7)	<0.01
PTA	4.46±1.88	(3.2–7.6)	3.59±0.98	(1.8–9.1)	<0.01
FA	17.46±9.96	(2.2–28.5)	12.22±5.39	(3.2–20.5)	<0.01

Descriptive values are presented as mean ± standard deviation (minimum–maximum). n.s. – no significance; PTS – posterior tibial slope; PTA – proximal tibia varus angle; FA – femoral anteversion angle. Values are presented as median and range.

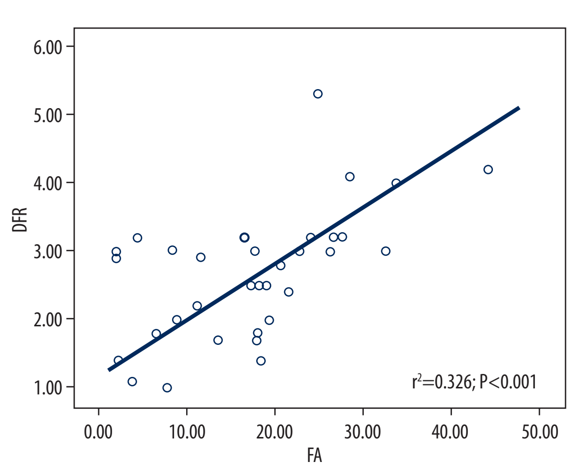

Figure 5. Linear regression analysis evaluating the relationship between the femoral anteversion (FA) and the distal femoral rotation (DFR) in the study group.

to the control group (*P*<0.01) (Table 3, Figure 3). Furthermore, the femoral anteversion was bigger in the study group compared to the control group (*P*<0.01) (Table 3, Figure 4), and a significant positive correlation was identified for the femoral anteversion and distal femoral rotation in patients with TD (r^2=0.326; *P*<0.001) (Figure 5).

Discussion

The first important finding of our research was that the posterior slope of the lateral tibial plateau gradually decreased, while the posterior slope of the medial tibial plateau was kept constant in patients with dysplasia of the femoral trochlear. In other words, the asymmetry of posterior tibial plateau slopes was gradually increased in patients with TD. In recent years, the characteristic of the tibial plateau has been well studied. The morphology of the tibial plateau has many influences on the biomechanics of the knee, such as translation of tibiofemoral joint, screw-home mechanism, position of the instantaneous center of rotation, and the biomechanics of the knee ligaments [12,23]. There is a direct relationship between the PTS and the anterior translation of tibia during weight-bearing activities. Javad Hashemi et al. studied the slopes of the tibial plateau using magnetic resonance imaging (MRI) and demonstrated that the increased PTS was related to the increased anterior shear force on the tibia surface, this force produced a corresponding anterior translation of the tibia [24]. This relationship was confirmed by the studies of Chan et al. They used mathematical models which identified that the stress of the anterior cruciate ligament increased when the PTS increased [25]. Thus, it can be argued that during activities, increased anterior force on the anterior cruciate ligaments is produced with increased posterior tibial slope, which will expose the anterior cruciate ligaments to the risk of injury. Our results supported an increased asymmetry of the posterior tibial plateau slope in patients with TD. Thus, we have to considered if the size of posterior condyle has some influence on the biomechanics of posterior tibial slope. A previous study reported that patients with TD might have a smaller lateral posterior condyle [26]. Frosch et al. reported similar findings in TD patients. They introduced a positive correlation between the PTS and the posterior condylar offset of the knee joint in patients with TD [27]. It can be argued that during weight-bearing activities, the smaller lateral posterior condyle decreases influences on the biomechanics of the lateral posterior tibial slope, so the lateral tibial plateau has a compensatory decrease in the posterior slope. Further studies may be needed in the future to assess the relationship between the increased asymmetry of the PTS and the risk of anterior cruciate ligament damage in patients with TD.

The other major finding of our study was that the distal femoral external rotation was smaller in TD patients compared to those patients without TD, which is defined as the angle between the transepicondylar axis and the line of posterior condyle (PCL) [28]. As previously reported in a study, patients with TD have a larger medial PCL and a smaller lateral PCL [26]. Thereby, the

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PCL' (the line of posterior condyle in TD patients) rotated internally compared to the PCL (the line of posterior condyle in normal patients), due to a larger medial PCL and a smaller lateral PCL. In other words, this change in the geometric shape of the PCL in patients with TD could lead to a more internal rotation of the distal femur and tend to dislocate the patella laterally, which could potentially aggravate TD [29]. In addition, the increased asymmetry of the posterior tibial plateau slope could in turn increase the internal rotation of the distal femoral during knee flexion. Concomitantly, the femoral anteversion in patients with TD was shown in our study to be slightly bigger compared to those without TD; this was also identified by some other studies [9–11]. Specifically, we identified a positive correlation between the femoral anteversion and the distal femoral external rotation in TD. We speculate that the reason for this finding is because the smaller external femoral rotation compensates for the bigger femoral anteversion, which contributes to a good alignment of the lower extremity.

In addition, our study identified that the proximal tibia varus angle was increased in patients with TD. We consider the reason for this finding is because the knee attempts to balance the medial and lateral collateral ligaments towards a rectangular space during flexion. A bigger proximal tibia varus angle is thus matched with a smaller distal femoral external rotation; this finding is similar to the findings reported by Ng et al. [30].

The findings of our study suggest that patients with serious TD might have associated non-traumatic anterior cruciate ligament damage due to changes in their posterior tibial plateau slope.

Furthermore, patients with TD have smaller external rotation of their distal femoral, which should be considered when determining the rotation angle of a prosthesis in knee arthroplasty for these patients. In total knee arthroplasty surgical procedures, the rotation of femoral prosthesis is extremely important, as it affects patellar tracking, ligament balance, and tibio-femoral congruity [31]. Smaller external rotation of the distal femoral is a potential risk factor for patellar maltracking [31]. Therefore, when total knee arthroplasty is performed on patients with TD, surgeons should appropriately increase the external rotation angle of prostheses to eliminate the adverse effects of such abnormal anatomy. Many studies have indicated that the external rotation angle of the femoral prosthesis should be equal to the varus angle of the tibia plateau [9,15,17]. Our study showed that patients with TD had an increased proximal tibia varus angle, which suggests an alternate method for surgeon to determine the optimal rotation angle of a prosthesis during total knee arthroplasty, especially when common anatomical markers cannot be estimated due to excessive wear. Thus, our findings indicate that the TD patients in our study had different anatomical and kinematic characteristics in their tibiofemoral joints. Surgeons should pay more attention to these differences with planning surgical procedures to replicate the biomechanics of the native knee joint.

There were many limitations of our research. First, while CT scans can be used to display the bone landmarks, the cartilage covering the surface cannot be clearly described using CT scans [32]. Second, the patients in our study came from a single hospital and the sample size was small; multi-center and large sample size studies are needed in the future. Third, we did not subdivide TD into the A-D subtypes due to the small sample size; the changes and relationships between each subtype should be analyzed when a larger sample size is studied in the future.

Conclusions

This study provided insight into the anatomic variability of femur and proximal tibia of TD. Patients with TD had flatter lateral PTS compared to those without TD, but there were no differences in the medial PTS between patients with TD and patients without TD. Patients with TD had smaller external rotation of the distal femoral and a bigger proximal tibia varus angle. In addition, our study identified that the femoral anteversion in patients with TD was bigger than in patients without TD; and our study revealed a positive correlation between femoral anteversion and external rotation of the distal femoral in patients with TD.

Conflict of interest

None.

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