


RESEARCH ARTICLE

Correlation Analysis between Tibial Tuberosity-Trochlear Groove Distance and Other Patellar Stability Parameters in Young and Middle-aged Populations

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Objective: The exact mechanism of patellofemoral instability has not been clearly clarified. The current study aims to explore the correlation between the tibial tuberosity-trochlear groove (TT-TG) distance and other patellar stability parameters.

Methods: A total of 60 individuals aged 18 to 40 years who underwent knee computed tomography (CT) examination between September 2014 and December 2017 were retrospectively recruited. Five reference sites were selected on the femoral trochlear articular surface in every CT image. The TT-TG distance and the trochlear groove angles (TGA) at the five reference sites were measured. The patellar ligament length (PLL), patellar length (PL), medial patellar retinaculum length (MPRL) and lateral patellar retinaculum length (LPRL) were quantitatively analyzed. The TT-TG distances on different knee sides or in different sexes were compared. The relationships between the TT-TG distance and TGA, PLL/PL, MPRL, and LPRL were analyzed by Spearman's method. Comparison analysis among patellar stability parameters was analyzed using ANOVA or two-tailed Student's *t* test.

Results: Variance analysis revealed no significant differences in the TT-TG distances among the five positions of the femoral trochlea ($F = 0.67$, $P = 0.62$) but significant differences among the five femoral TGAs at the five reference sites ($F = 380.37$, $P < 0.01$). Notably, an increasing tendency of the TT-TG distance was observed in the sexes (male, range 16.61–19.68 mm; female, range 14.37–17.38 mm) and knee sides (left knee, range 14.37–18.43 mm; right knee, range 15.80–19.68 mm). The TGA at site 1 of the femoral trochlear cartilage was the largest, with an angle of $151.97^\circ \pm 10.4^\circ$, and then gradually decreased to the smallest when the cartilage disappeared at site 5, with an angle of $92.05^\circ \pm 10.01^\circ$. Interestingly, there was a positive relationship between the TT-TG distance at site 1 and TGA in the right knees of males ($r = 0.490$, $P = 0.033$) as well as LPRL in the left knees of males ($r = -0.420$; $P = 0.046$). There were no correlations between the TT-TG distance and the other patellar stability parameters, including TGA, PLL/PL, MPRL, and LPRL.

Conclusion: Among young and middle-aged populations, patella surgeries should be carefully determined based on the comprehensive consideration of these patellar stability parameters rather than the TT-TG distance alone. Differences in sex and knee side should also be considered.

Key words: Correlation analysis; Patellar stability; Tibial tuberosity-trochlear groove; Young and middle-aged population

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Introduction

Patellofemoral instability is a common disease in orthopedics and sports medicine and is an extremely limiting pathology in young and active patients.¹ Patellofemoral instability is defined as a disease characterized by the patella bone pathologically disarticulating out from the patellofemoral joint. Multiple factors can result in patellofemoral instability, such as bony malalignment, chronic ligamentous laxity, acute trauma, connective tissue disorder, or anatomical pathology, such as trochlear dysplasia, patellar alta, a laterally placed tubercle, patellar tilt and medial patellofemoral ligament rupture.^{2,3} First-time patellar dislocations were observed in most individuals aged 10 to 19 years, accounting for 69% of all patients with patellar dislocation, and most cases of first-time dislocations without loose bodies or articular damage are treated conservatively.^{4,5} The incidence of patella dislocation in the general population was 7 per 100,000 annually⁵ and 43 per 100,000 in the <16-year-old age group in a Finnish study.⁶ Having a history of patellar dislocation was closely related to a high risk of persistent patellar instability later in life. Adolescent instability may herald a lifelong condition leading to chronic disability and arthritis.⁷ Long-term patellar instability may lead to premature degeneration of the patellofemoral joint, synovial hyperplasia, quadriceps atrophy and other serious adverse consequences.

The tibial tuberosity-trochlear groove (TT-TG) distance is one of four anatomical risk factors and can be regarded as the gold standard radiological measurement for patellofemoral instability.⁸ TT-TG showed a significant correlation with the Q angle but was more accurate in evaluating patellofemoral stability than the Q angle.⁹ Although the Q-angle has been widely used as an indicator for patellofemoral joint dysfunction, there is considerable disagreement on the reliability and validity of clinical Q-angle measurements.¹⁰ CT scan examination is considered to be the gold standard of TT-TG measurement for observing the anatomical structure with better spatial resolution of the knee at multiple levels and angles, despite controversial views related to various measurement methods.¹¹ For example, due to the small tunnel diameter, even slight artifacts on magnetic resonance imaging (MRI) images caused by screws could affect the precise measurement of the tunnel width and position.

However, in most existing studies focused on TT-TG distance, the subjects were European and American populations, and 20 mm was used as the threshold,¹² even in studies from China.¹³ Theoretically, the abnormal TT-TG distance of the Chinese population being shorter than the critical value reported in the literature is due to the different sizes and shapes of the bones and muscles of knee joints. Although few studies have focused on the TT-TG distance in Chinese subjects,^{14,15} more clinical data are needed to verify the differences in TT-TG distance between Chinese and foreign populations due to bias and limitations in measurement methods. Furthermore, the exact mechanism of patellofemoral instability has not been clearly clarified. There is still a lack of comprehensive and quantitative research on the main pathogenic factors of patellofemoral instability. Therefore, we

performed this study to: (i) compare the differences in the TT-TG distance of different knee sides and sexes; and (ii) investigate the correlation between the TT-TG distance and other patellar stability parameters in young and middle-aged populations.

Materials and Methods Inclusion and Exclusion Criteria

The inclusion criteria were as follows: (i) adults aged 18 to 40 years old; (ii) no history of knee surgery; (iii) no signs of patella dislocation or subluxation by imaging; and (iv) no fracture around the knee, tumor, inflammation, metabolic bone disease, rheumatic disease or congenital disease. The exclusion criteria were as follows: (i) obvious deformities in the knee; (ii) severe bone hyperplasia and degeneration; (iii) joint cavity effusion; (iv) soft tissue injury (ligament injury); and (v) old knee fracture. This study was approved by the Committee for Human Research of Tianjin Hospital (No. 2022131).

Subjects and Data Collection

A total of 60 individuals undergoing knee joint CT examination between September 2014 and December 2017 were recruited for the study, including 42 males and 18 females, aged 18–40 years, with a mean age of 31.87 ± 7.28 years. Sixty CT images were obtained from the knees of 60 individuals. The TT-TG distance, TGA, PLL, PL, MPRL and LPRL were quantitatively analyzed (Fig. 1).

CT Protocol and CT Imaging Analysis

CT imaging was performed using a high-definition CT (HDCT) scanner (GE Discovery CT750, HDCT, GE-Healthcare, Milwaukee, WI, USA). The imaging protocol was as follows: after routine scanning and positioning, a plain scan was performed (tube voltage 100–120 kV, tube current 180–230 mAs, pitch 1.375:1, layer thickness 3–5 mm, reconstruction layer thickness 0.625 mm). The scan range was centered on the patella, from 5 cm above the upper edge of the patella to 5 cm below the lower edge of the tibial tubercle to completely reflect the patella, femoral trochlear and tibial tubercle. The subject lay on the CT table with both knee joints in a straight position, lower limb muscles in a relaxed state, and feet in a rotating neutral position. The scanning direction was from the foot side to the head side.

All CT images were imported into a GE ADW 4.6 workstation (ADW 4.6, GE-Healthcare, Milwaukee, WI, USA) and postprocessed by multiplanar reformation and volume rendering. In the median sagittal plane of the knee on the multiplanar reformation image, five equidistant points were obtained from the appearance to the disappearance of the femoral trochlear cartilage (Fig. 2(A)), and the corresponding axial images of these five points were stored (Fig. 2(B)–(F)). The axial image corresponding to these five points was used as the proximal reference plane, with marked sites 1–5. The most prominent center point of the tibial tubercle was intuitively selected through the reconstructed VR image of the knee, and its corresponding axial image was

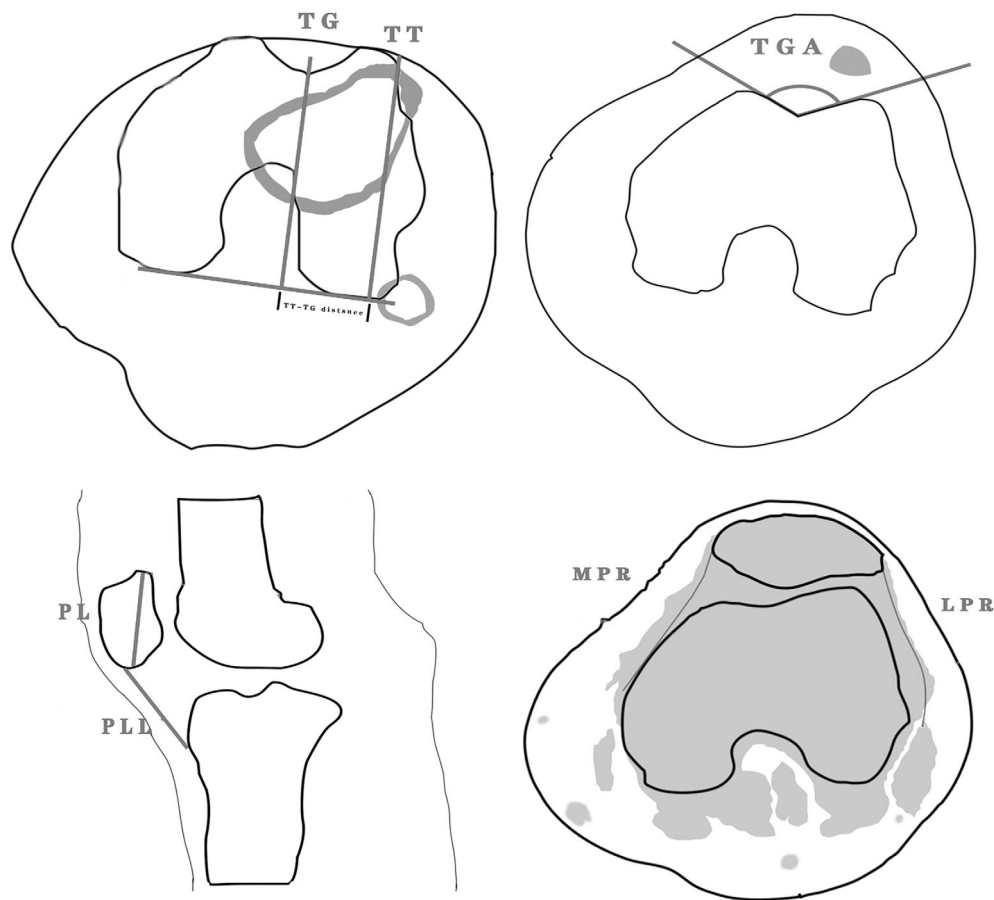


Fig. 1 An illustrative diagram shows the measurement of indicators, including Tibial tubercle–trochlear groove (TT-TG) distance, the trochlear groove angles (TGA), Patellar ligament length (PLL) and patellar length (PL), Medial patellar retinaculum length (MPRL) and lateral patellar retinaculum length (LPRL)

used as the distal reference level and marked as TT. All CT images were independently reviewed by two experienced musculoskeletal radiologists. The measurement was performed independently by each radiologist, and the repeated measurement was performed 2 weeks after the completion of the last measurement.

The Tibial Tuberosity-Trochlear Groove (TT-TG) Distance

The TT-TG distance is considered one of four anatomical risk factors and can be regarded as the gold standard radiological measurement for patellofemoral instability. To measure the TT-TG distance, a reference line was first drawn tangentially to the posterior femoral condyles at the deepest point of the trochlear groove (Fig. 3(A)). Then, two lines perpendicular to the reference were drawn at the deepest point of the trochlear groove and the anterior-most point of the tibial tuberosity (Fig. 3(B)). The TT-TG distance may be used as a relevant anatomic factor and an indication for a distal realignment procedure in patients with patellar instability.

The Trochlear Groove Angle (TGA)

TGA was used to assess the shape of the femoral trochlear groove. The larger the TGA, the lower the femoral trochlea.

The TGAs were measured in the corresponding axial images of the five points (Fig. 3(C)). TGA measurement is particularly important to evaluate the femoro-patellar joint.

The Insall-Salvati Ratio

The Insall-Salvati ratio is the first widely used index to be relatively independent of knee flexion and is widely used for the assessment of patellar height. The Insall-Salvati ratio is calculated as the ratio of the patellar ligament length to the patella length (PLL/PL). The patella length (PL) was measured in the central sagittal plane of the knee from the articular surface of the patella to the most distal end of the lower edge of the patella (Fig. 3(D)). Osteophytes were not included, that is, the maximum oblique length of the patella in the sagittal plane. The patellar ligament length (PLL) was measured in the same sagittal plane with PL from the patellar ligament to the connection point between the patella and tibia (Fig. 3(D)). The Insall-Salvati ratio is important for detecting the following two common clinical signs of knee disease: patella alta and patella baja.

Medial Patellar Retinaculum Length (MPRL)

The medial patellar retinaculum is considered the most important structure for static stabilization. MPRL was the

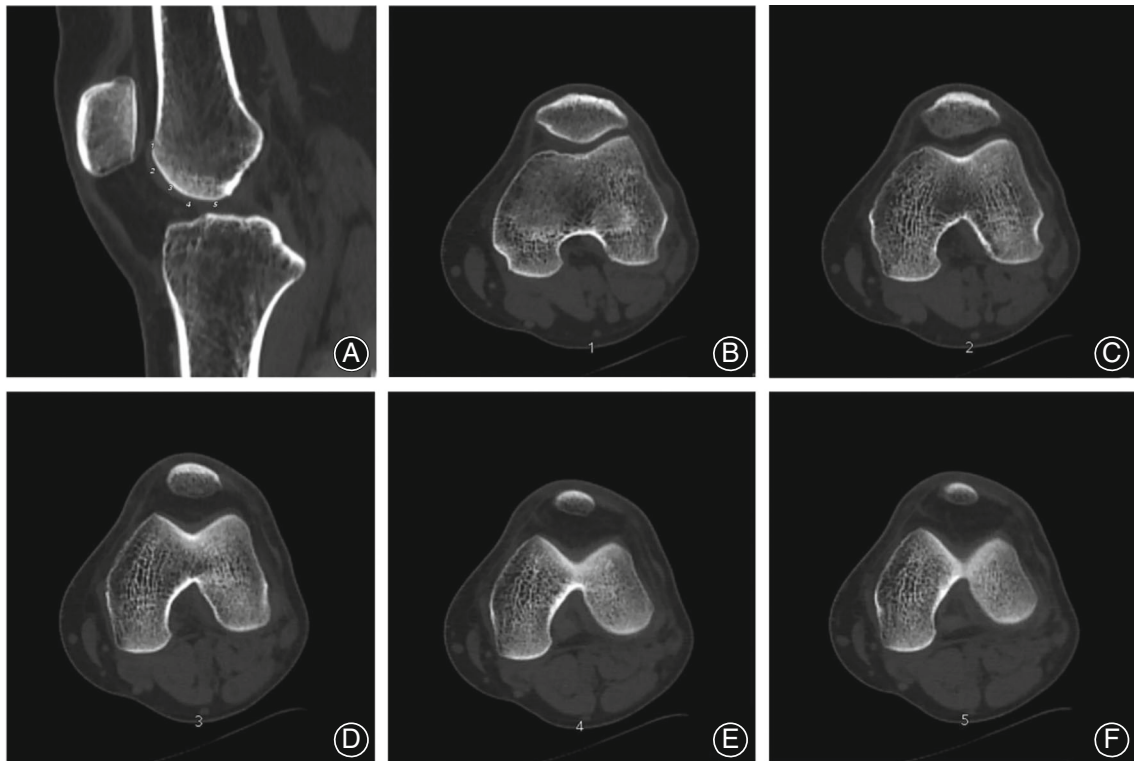


Fig. 2 Five reference sites were selected in the median sagittal plane of the knee on the multiplanar reformation image. (A) Five equidistant points can be obtained from the appearance to the disappearance of the femoral trochlear cartilage; (B–F) The corresponding axial images of these five points

distance from the most convex point of the medial edge of the patella to the most convex point of the femoral medial condyle. The lateral patellar retinaculum is located on the outer side of the patella and is a bundle of fibrous connective tissue that restricts the inward movement of the patella. MPRL was measured on the axial image of the middle layer of the patella using the workstation's curve length measuring tool (Fig. 3(E)). Injury of the patella medial stabilizing structure can lead to lateral dislocation or subluxation of the patella, thereby changing the normal trajectory of the patella and causing patellofemoral joint pain or dyskinesia.

Lateral Patellar Retinaculum Length (LPRL)

LPRL is the distance from the most convex point of the patella medial edge and the most convex point of the femoral medial condyle. LPRL was also measured on the axial image of the middle layer of the patella using the workstation's curve length measuring tool (Fig. 3(E)). Release of the lateral patellar retinaculum can be used to treat patellofemoral instability and to balance the extensor mechanism during knee replacement operations.

Statistical Analysis

All quantified data were obtained from at least three independent experiments and analyzed using SPSS 17.0 software

(Chicago, IL, USA). Data are expressed as the mean \pm SD. The differences in the TT-TG distances and the TGAs among the five sites were analyzed using ANOVA. The differences in the TT-TG distance between the two sides of the knee or different sexes were analyzed using a two-tailed Student's *t* test. Spearman's method was applied to analyze the relationship between the TT-TG distance and other patellar stability parameters, such as TGA, PLL/PL, MPRL and LPRL. A *P* value <0.05 was considered statistically significant.

Results

TT-TG Distance Analysis in Young and Middle-aged Populations

As shown in Table 1, the TT-TG distances at the five sites showed mean distances of 18.15 ± 5.65 mm, 16.83 ± 4.86 mm, 17.13 ± 4.81 mm, 17.82 ± 5.02 mm and 17.75 ± 5.10 mm. There were no significant differences in the TT-TG distances at the five selected sites ($F = 0.67$, $P = 0.62$).

Furthermore, the differences in the TT-TG distance between the two sides of the knee or different sexes were analyzed. The TT-TG distances of the left knee (range 14.37 mm to 18.43 mm) in both males and females were shorter than the TT-TG distances of the right knee (range 15.80 mm to 19.68 mm), but no significant differences were observed

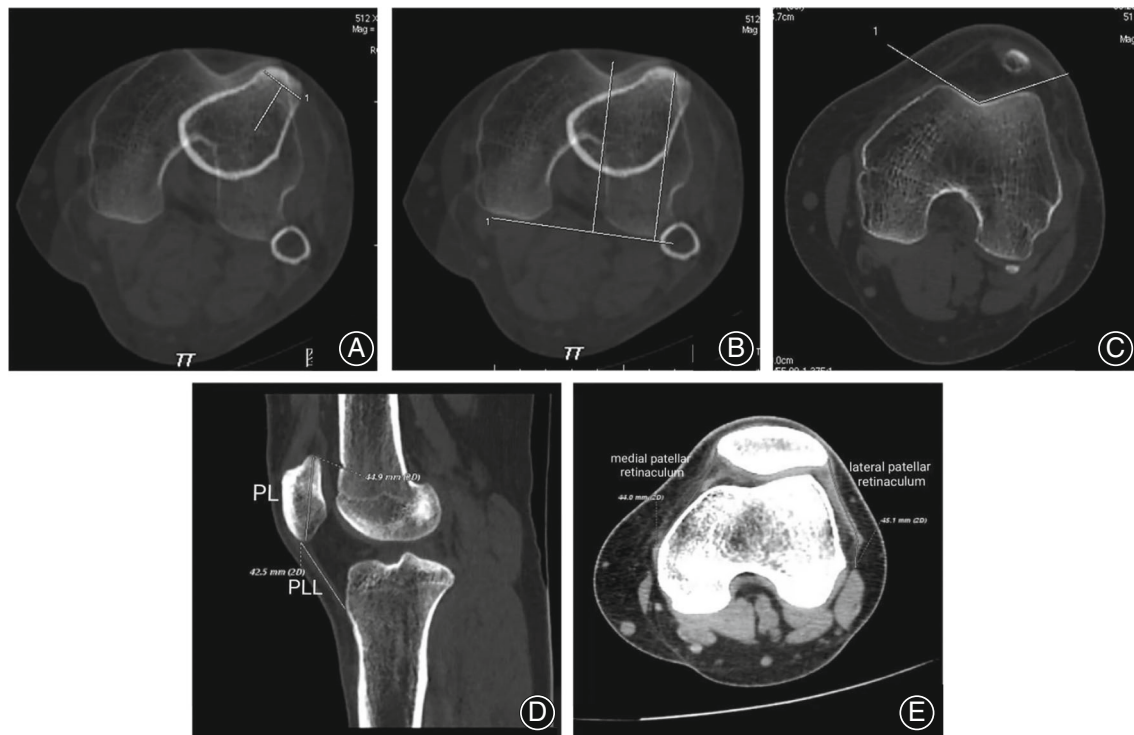


Fig. 3 Radiographs showing patellar stability related parameters measurement. (A) The center point of the tibial tubercle was selected as the reference point; (B) Tibial tubercle–trochlear groove (TT-TG) distance; (C) The trochlear groove angles (TGA); (D) Patellar ligament length (PLL) and patellar length (PL); (E) Medial patellar retinaculum length (MPRL) and lateral patellar retinaculum length (LPRL)

TABLE 1 TT-TG distance analysis in young and middle-aged population (mm, \pm s)

Groups	Site 1	Site 2	Site 3	Site 4	Site 5	F value	P value
Total (n = 60)	18.15 \pm 5.65	16.83 \pm 4.86	17.13 \pm 4.81	17.82 \pm 5.02	17.75 \pm 5.10	0.67	0.62
Male-R (n = 19)	19.68 \pm 4.69	18.47 \pm 3.81	18.58 \pm 3.53	19.37 \pm 3.71	19.37 \pm 3.96	0.86	0.54
Male-L (n = 23)	17.96 \pm 6.56	16.61 \pm 5.94	17.09 \pm 5.79	18.43 \pm 5.65	18.17 \pm 5.92	1.15	0.46
Female-R (n = 10)	17.38 \pm 6.16	15.80 \pm 3.91	16.60 \pm 4.03	16.00 \pm 4.57	16.40 \pm 4.12	0.17	0.63
Female-L (n = 8)	16.30 \pm 4.47	14.88 \pm 4.22	14.50 \pm 4.75	14.63 \pm 5.09	14.37 \pm 4.90	0.71	0.33

between males and females. In males, the TT-TG distances of the right knee at site 1 to site 5 (19.68 \pm 4.69 mm, 18.47 \pm 3.81 mm, 18.58 \pm 3.53 mm, 19.37 \pm 3.71 mm, 19.37 \pm 3.96 mm) showed no significant differences from the TT-TG distances of the left knee (17.96 \pm 6.56 mm, 16.61 \pm 5.94 mm, 17.09 \pm 5.79 mm, 18.43 \pm 5.65 mm, 18.17 \pm 5.92 mm) (all P s > 0.05). In females, the differences in the TT-TG distances between the right knee and left knee at site 1 to site 5 were also not obvious (all P s > 0.05). Meanwhile, there were no significant differences between the left knee and right knee. Compared with the TT-TG distances of the right knee in males, no obvious differences were observed in the TT-TG distances of the right knee in females (all P s > 0.05). Compared with the TT-TG distances of the left knee in males, no obvious differences were observed in the TT-TG distances of the left knee in females (all P s > 0.05).

Interestingly, there was an increasing tendency in the TT-TG distance from the female knee to the male knee and from the left knee to the right knee.

Quantitative Measurements of TT-TG-related Patellar Stability Parameters

The TT-TG-related patellar stability parameters, including TGA at five sites, PL, PLL, PLL/PL MPR and LPR, were measured (Fig. 4). Variance analysis revealed significant differences in the TGAs, with the largest at 151.97° \pm 10.4° at site 1 and the smallest at site 5, where the cartilage disappeared (F = 380.37, P < 0.01). Meanwhile, the 60 individuals in the young and middle-aged population had a PLL of 50.09 \pm 5.79 mm, PL of 42.55 \pm 3.46 mm, PLL/PL of 1.18 \pm 0.14, MPRL of 47.08 \pm 5.02 mm and LPRL of 50.80 \pm 5.04 mm.

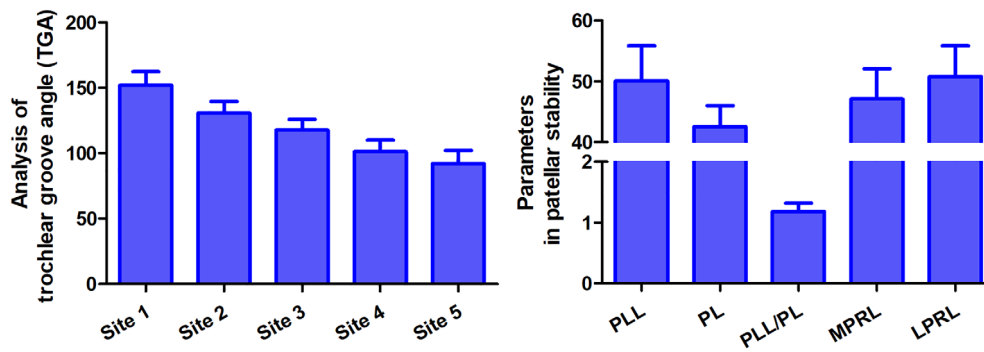


Fig. 4 Measurement of patellar stability related parameters. (A) Analysis of the trochlear groove angle (TGA); (B) Patellar ligament length (PLL), patellar length (PL), medial patellar retinaculum length (MPRL) and lateral patellar retinaculum length (LPRL). The Insall-Salvati ratio was calculated by PLL/PL

TABLE 2 Correlation analysis between TT-TG distance and TGA

Groups	Variables	Site 1	Site 2	Site 3	Site 4	Site 5
Total (n = 60)	r	0.089	0.094	0.107	0.010	0.097
	P value	0.497	0.473	0.417	0.940	0.459
Male-R (n = 19)	r	0.490	0.067	0.255	0.341	0.214
	P value	0.033	0.785	0.292	0.153	0.379
Male-L (n = 23)	r	0.025	0.212	0.042	-0.144	-0.064
	P value	0.910	0.332	0.850	0.512	0.772
Female-R (n = 10)	r	0.198	-0.073	0.347	-0.196	0.003
	P value	0.584	0.840	0.326	0.588	0.993
Female-L (n = 8)	r	-0.516	0.307	0.288	-0.149	0.135
	P value	0.190	0.460	0.489	0.724	0.750

Abbreviation: Trochlear groove angle (TGA).

The Relationship between the TT-TG Distance and TGA

The relationship between the TT-TG distance and TGAs at the five sites was analyzed (Table 2). Overall, no significant correlations were observed between the TT-TG distance and TGAs ($r = 0.089$, $p = 0.497$; $r = 0.094$, $p = 0.473$; $r = 0.107$, $p = 0.417$; $r = 0.010$, $P = 0.940$; $r = 0.097$, $P = 0.459$). Interestingly, a positive correlation was only observed between the TT-TG distance and TGA at site 1 from the right knees in males ($r = 0.490$, $P = 0.033$). No significant correlations were observed at site 2 to site 5 in different side knees and sexes (all P s > 0.05).

The Relationship between the TT-TG Distance and PLL/PL

Pearson analysis showed that there were no significant correlations between the TT-TG distance and PLL/PL among all the subjects ($r = -0.066$, $P = 0.616$; $r = -0.015$, $P = 0.909$; $r = -0.05$, $P = 0.705$; $r = -0.045$, $P = 0.735$; $r = -0.081$, $p = 0.541$; Table 3). There were no significant correlations between the TT-TG distance and PLL/PL at site 1 to site 5 in different side knees and sexes (all P s > 0.05).

TABLE 3 Correlation analysis between TT-TG distance and PLL/PL

Groups	Variables	Site 1	Site 2	Site 3	Site 4	Site 5
Total (n = 60)	r	-0.066	-0.015	-0.05	-0.045	-0.081
	P value	0.616	0.909	0.705	0.735	0.541
Male-R (n = 19)	r	-0.074	0.112	0.159	0.177	0.078
	P value	0.764	0.648	0.515	0.468	0.752
Male-L (n = 23)	r	-0.289	-0.333	-0.336	-0.348	-0.345
	P value	0.181	0.120	0.117	0.103	0.107
Female-R (n = 10)	r	0.528	0.542	0.322	0.384	0.484
	P value	0.117	0.105	0.365	0.273	0.157
Female-L (n = 8)	r	-0.102	0.208	0.165	0.264	0.047
	P value	0.810	0.622	0.697	0.527	0.912

Abbreviation: The patellar ligament length to the patella length (PLL/PL).

TABLE 4 Correlation analysis between TT-TG distance and MPRL

Groups	Variables	Site 1	Site 2	Site 3	Site 4	Site 5
Total (n = 60)	<i>r</i>	0.055	0.164	0.151	0.220	0.126
	<i>P</i> value	0.674	0.211	0.249	0.091	0.336
Male-R (n = 19)	<i>r</i>	0.353	0.213	0.118	0.195	0.133
	<i>P</i> value	0.138	0.381	0.630	0.423	0.586
Male-L (n = 23)	<i>r</i>	0.196	0.230	0.220	0.161	0.160
	<i>P</i> value	0.370	0.291	0.312	0.464	0.466
Female-R (n = 10)	<i>r</i>	-0.409	-0.444	-0.428	-0.459	-0.477
	<i>P</i> value	0.240	0.198	0.217	0.182	0.163
Female-L (n = 8)	<i>r</i>	0.240	0.539	0.291	0.571	0.084
	<i>P</i> value	0.567	0.168	0.484	0.140	0.844

Abbreviation: Medial patellar retinaculum length (MPRL).

TABLE 5 Correlation analysis between TT-TG distance and LPRL

Groups	Variables	Site 1	Site 2	Site 3	Site 4	Site 5
Total (n = 60)	<i>r</i>	0.039	0.156	0.147	0.237	0.153
	<i>P</i> value	0.770	0.232	0.263	0.068	0.244
Male-R (n = 19)	<i>r</i>	0.216	0.030	-0.073	-0.010	-0.020
	<i>P</i> value	0.374	0.901	0.765	0.967	0.935
Male-L (n = 23)	<i>r</i>	-0.420	-0.245	-0.233	-0.219	-0.315
	<i>P</i> value	0.046	0.261	0.286	0.316	0.143
Female-R (n = 10)	<i>r</i>	0.358	0.362	0.196	0.206	0.286
	<i>P</i> value	0.310	0.303	0.588	0.568	0.422
Female-L (n = 8)	<i>r</i>	0.077	0.500	0.491	0.542	0.265
	<i>P</i> value	0.856	0.207	0.217	0.165	0.526

Abbreviation: Lateral patellar retinaculum length (LPRL).

The Relationship between the TT-TG Distance and MPRL

As shown in Table 4, the results showed that there were no significant correlations between the TT-TG distance and MPRL ($r = 0.055$, $P = 0.674$; $r = 0.164$, $P = 0.211$; $r = 0.151$, $P = 0.249$; $r = 0.220$, $P = 0.091$; $r = 0.126$, $P = 0.336$). Using subgroup analysis, there were no significant correlations between the TT-TG distance and MPRL at the five sites from the right knees in males, from the left knees in males, from the right knees in females and from the left knees in females (all P s > 0.05).

The Relationship between the TT-TG Distance and LPRL

Meanwhile, Table 5 shows that there were no significant correlations between the TT-TG distance and LPRL from the 60 knees ($r = 0.039$, $P = 0.770$; $r = 0.156$, $P = 0.232$; $r = 0.147$, $P = 0.263$; $r = 0.237$, $P = 0.068$; $r = 0.153$, $P = 0.244$). Meanwhile, except for the TT-TG distance showing a negative relationship with LPRL at site 1 in male left knees ($r = -0.42$, $P = 0.046$), no significant correlations were observed between the TT-TG distance and PLL/PL from the five sites in different side knees and sexes.

Discussion

Though intensive studies have been reported on TT-TG distance, there is still a lack of comprehensive and quantitative research on the main pathogenic factors of patellofemoral instability. In our study, a reference range for the TT-TG distance of young and middle-aged individuals was provided. Among young and middle-aged populations, patella surgeries should be carefully determined based on the comprehensive consideration of these patellar stability parameters rather than the TT-TG distance alone, including sex and knee side.

Status of Research in the Field

Patellar instability is the most common disease in orthopedics, and the TT-TG distance is a predominant indicator for evaluating it. The TT-TG distance has been proven to be the gold standard diagnostic measurement for patellofemoral instability,⁸ which accounts for approximately 56% of patients with patellar dislocation.¹⁶ A study also demonstrated that TT-TG could accurately reflect the valgus vector applied to the knee and indirectly reflect the trajectory of the patella in the femoral trochlea under the traction of the patellar ligament when the knee joint was moved.¹⁷ Although intensive studies focused on patellofemoral instability have been reported, there is still a lack of

comprehensive and quantitative research on the main pathogenic factors among the Chinese population. In our clinical practice, patients with patellar instability often cannot be diagnosed and treated at an early stage, and the effectiveness of treatments is usually not very good. The current study presented a CT-based assessment of the TT-TG distance in the young and middle-aged population and explored the correlation between the TT-TG distance and other patellar stability parameters.

Analysis of the TT-TG Distance in the Young and Middle-aged Population

The exact upper limit of the TT-TG distance is controversial. A TT-TG distance between 10 and 15 mm is usually considered normal.¹⁸ Charles *et al.* reported that a TT-TG distance <15 mm may predispose patients to patellofemoral malalignment.¹⁹ In Dejour *et al.*'s study, a distance ≥ 20 mm was an indicator of symptomatic patients.¹⁸ Tibial osteotomy and medialization were also recommended when a threshold of 15 mm was exceeded.²⁰ The TT-TG distance was widely measured in the neutral position with knee extension to minimize the impact of different knee flexion states. In this study, five equidistant points corresponding to the axial images of the femoral trochlear bony articular surface in the mid-sagittal plane were used as the proximal femur reference plane. Our results demonstrated that there were no significant differences in the TT-TG distances (i.e., the vertical distance between the deepest point of the femoral trochlear groove and the center point of the tibial tubercle) in the selected five different reference sites ($P = 0.62$). The range of the TT-TG distances was 16.83 mm to 18.15 mm, and the maximum value was less than the threshold value of 20 mm. Furthermore, our results revealed no significant differences in the TT-TG distance between the two sides of the knee or by sex. However, the TT-TG distance showed an increasing tendency in males compared with females or in the right knee compared with the left knee in the selected five different reference sites. The side difference may mainly result from the right-side limb advantage during a long evolutionary process. The difference in the movement of the knee on both sides, the weight bearing, and the strength of the quadriceps may result in bone shaping variation. The gender difference may mainly result from the sample population variation of evolution. Alemparte *et al.* revealed an average TT-TG distance in males that was significantly larger than that in females using approximately 60 knees and CT,²¹ and the subjects were of the Caucasian population. Similar to our result, a CT-based analysis of TT-TG distance in the Indian population showed a mean TT-TG distance with no significant differences between different sexes.²² Thus, our findings provide new insights into TT-TG measurements, which at any point under the femur pulley ditch can be used as a parameter to evaluate patellofemoral stability. A reference range for the TT-TG distance of young and middle-aged population was provided, and the TT-TG threshold value should be reduced when assessing patellofemoral stability among the Chinese population. Different sexes and different sides of the knee should also be considered.

Correlation Analysis between the TT-TG Distance and Other Patellar Stability Parameters

To date, it is challenging for surgeons to clearly locate anatomical anomalies resulting in malfunctioning patellofemoral kinematics affected by multiple factors. Interestingly, the TT-TG distances showed no change in patients with or without knee osteoarthritis in Namik *et al.*'s study.²³ The knee rotation angle has been proven to be closely correlated with TT-TG, and the knee rotation angle is the cause of an increased TT-TG distance. However, a contrary result was observed in Tensho *et al.*'s study²⁴ and Prakash *et al.*'s study.²⁵ Tensho *et al.* revealed that the TT-TG distance depended on the knee rotation angle rather than tubercle lateralization.²⁴ In Prakash *et al.*'s study, the patella-dislocated group had increased lateralization of the tuberosity and no correlation between the knee rotation angle and the TT-TG distance.²⁵ In our study, the relationships between the TT-TG distance and TGA, PLL/PL, MPRL, and LPRL were analyzed. TGA is used to assess the anatomical morphology of the femoral trochlear groove, and a larger TGA indicates a lower femoral trochlear groove. The TGAs at the five reference sites showed a significant difference, with the largest value of $151.97^\circ \pm 10.74^\circ$ and the smallest value of $90.05^\circ \pm 10.01^\circ$. Merchant AC measured a TGA of $138 \pm 6^\circ$ in a normal population and proposed trochlear dysplasia if $TGA \geq 150^\circ$,²⁶ which was consistent with our study. However, our study showed no correlation between the TGA and TT-TG distance. It is noted that a positive relationship was observed between the TT-TG distance of 19.68 ± 4.69 mm (the largest value among the five sites) and TGA with the largest value of $151.97^\circ \pm 10.74^\circ$. This may be explained by the variance among the five TGAs ($F = 380.37, p < 0.01$). Thus, the TGA should also be measured as an independent parameter for evaluating patellofemoral instability. Femoral trochlear dysplasia, quadriceps dysplasia, high-riding patella and abnormal TT-TG distance were four risk factors for patella instability.³ An abnormally high-riding patella has been proven to correlate with patellofemoral instability and patellofemoral pain.²⁷ An abnormally high-riding patella was >1.20 , and a low-riding patella was <0.80 .²⁸ The Insall-Salvati ratio (PLL/PL) in our study was 1.18 ± 0.14 and showed no correlation with the TT-TG distance. This may be due to the normal knee joints recruited in our study.

In addition, we analyzed the relationship between TT-TG and MPRL and LPRL. Currently, the medial patellofemoral ligament (MPFL) is considered the most important structure for static stabilization, which provides 60% of the static restraint to dislocation of the patella in the normal knee.^{29,30} Due to its safety and good clinical outcomes, MPFL reconstruction is widely used in the treatment of patellofemoral dislocation,³¹ which is also recommended in the simultaneous use of tibial tubercle osteotomy and lateral retinaculum release (LRR).³² The lateral patellar retinaculum is located on the outer side of the patella and is a bundle of fibrous connective tissue that restricts the inward movement of the patella. Injury of the patella medial stabilizing structure can lead to lateral dislocation or

subluxation of the patella, thereby changing the normal trajectory of the patella and causing patellofemoral joint pain or dyskinesia.³³ Combining LRR with different surgical procedures has been extensively adopted, and the role of the lateral patellar retinaculum in patellofemoral instability is still debated.³⁴ In our study, the 60 knees showed a mean MPRL of 47.08 ± 5.02 mm and a mean LPRL of 50.80 ± 5.04 mm. There was no correlation between the TT-TG distance and MPRL or LPRL, except for a negative relationship observed in the left knees of males. Our results suggested that MPRL and LPRL were also independent parameters for evaluating patellofemoral instability.

Limitations

There were several limitations of the present study. The sample size was small, even though we revealed the average TT-TG distance to be 16.83 mm to 18.15 mm, which may also cause bias to the result. As we described previously, multiple factors, such as knee rotation, tubercle malposition, patella index, trochlear dysplasia, patellar alta, and patellar tilt, can be indicators of patellofemoral stability. We only explored the relationship between TT-TG and the other three parameters. These are the issues we will explore next. Analysis should be further performed between different factors, such as age, sex, and follow-up time. Despite these shortcomings, we believe that our preliminary attempt will

support the diagnosis of patellofemoral instability and related diseases, thus reducing the incidence of misdiagnosis.

Conclusion

Our findings provide a reference range for the TT-TG distance of young and middle-aged individuals, and the TT-TG threshold value should be reduced when assessing patellofemoral stability. Differences in sex and knee side should also be considered. The patellar stability parameters, such as the TT-TG distance, TGA, Insall-Salvati ratio (PLL/PL), MPRL, and LPRL, were independent of each other. In clinical practice, patella surgeries should be carefully determined based on the comprehensive consideration of the TT-TG distance, TGA, PLL/PL, MPRL, and LPRL rather than the TT-TG distance alone. Further studies with large sample size are needed to explore the potential mechanism of patellofemoral instability.

Ethical Statement

This study was approved by the Committee for Human Research of Tianjin Hospital.

Authors' Contributions

Conception: Z Wang; Interpretation or analysis of data: Y Qi and JY Liu; Preparation of the manuscript: Y Qi and M Sun; Revision for important intellectual content: Y Qi and Z Wang; Supervision: Z Wang.

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