Original Research

Comparing the Tibial Tuberosity–Trochlear Groove Distance Between CT and MRI in Skeletally Immature Patients With and Without Patellar Instability

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Background: The tibial tubercle–trochlear groove (TT-TG) distance was originally described for computed tomography (CT), but it has been measured on magnetic resonance imaging (MRI) in patients with patellar instability (PI). Whether the TT-TG measured on CT versus MRI can be considered equivalent in skeletally immature children remains unclear.

Purpose: To investigate in skeletally immature patients (1) the effects of CT versus MRI imaging modality and cartilage versus bony landmarks on consistency of TT-TG measurement, (2) the difference between CT and MRI measurements of the TT-TG, and (3) the difference in TT-TG between patients with and without PI.

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

Methods: We retrospectively identified 24 skeletally immature patients with PI and 24 patients with other knee disorders or injury but without PI. The bony and cartilaginous TT-TG distances on CT and MRI were measured by 2 researchers, and related clinical data were collected. The interrater, interperiod (bony vs cartilaginous), and intermethod (CT vs MRI) reliabilities of TT-TG measurement were assessed with intraclass correlation coefficients.

Results: The 48 study patients (19 boys, 29 girls) had a mean age of 11.3 years (range, 7-14 years). TT-TG measurements had excellent interrater reliability and good or excellent interperiod reliability but fair or poor intermethod reliability. TT-TG distance was greater on CT versus MRI (mean difference, 4.07 mm; 95% CI, 2.6-5.5 mm), and cartilaginous distance was greater than bony distance (mean difference, 2.3 mm; 95% CI, 0.79-3.8 mm). The TT-TG measured on CT was found to increase with the femoral width. Patients in the PI group had increased TT-TG distance compared with those in the control group, regardless of landmarks or modality used ($P > .05$ for all).

Conclusion: For skeletally immature patients, the TT-TG distance could be evaluated on MRI, regardless of whether cartilage or bony landmarks were used. Its value could not be interchanged with CT according to our results; however, further research on this topic is needed.

Keywords: tibial tubercle–trochlear groove; computed tomography; magnetic resonance imaging; patellar instability; immature

Patellar instability (PI), including recurrent instability, is a common condition affecting up to 49 people per 100,000.[18] Primary PI is usually associated with a traumatic event, and younger patients are more susceptible to recurrent injuries. Recurrent PI can result in considerable knee joint dysfunction with reduced quality of life.[12,22]

The tibial tubercle–trochlear groove (TT-TG) distance has been considered an important anatomic factor associated with recurrent PI.[3,5] TT-TG distance was originally evaluated by computed tomography (CT)[9] but recently has been evaluated on magnetic resonance imaging (MRI) in patients with PI, in order to reduce radiation exposure.[8,21,23,25] Studies in adults have found differences in TT-TG distances when measured by CT versus MRI, and whether measurements made by these 2 modalities are equivalent remains controversial.[2,8,14,15,19-21]

In pediatric populations with a high occurrence of PI, some researchers have investigated TT-TG measured on MRI and found that TT-TG may change with age or size of children.[4,6,10,17,25] Also, the relatively thick trochlear cartilage surface may obscure the anatomic landmarks of TT-TG. However, no research has

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compared TT-TG distance measured on MRI versus CT in these children.[2,8,14,15,19-21]

The aim of the current study was to investigate in skeletally immature patients (1) the effect of imaging modality (CT, MRI) and landmarks (cartilage, bone) on agreements of measurements of TT-TG, (2) differences in CT and MRI measurements of TT-TG, and (3) TT-TG distance in patients with and without PI.

METHODS

After obtaining institutional review board approval, we retrospectively reviewed patients younger than 14 years who underwent both CT and MRI for knee disorders in the department of pediatric orthopaedics in our hospital between 2014 and 2018. The patients with PI (including traumatic patellar dislocation or recurrent patellar dislocation) were assigned to the case group. The diagnosis of PI was verified through examination of the medical records (a clinical history of patellar giving way and related signs on physical examination, such as joint effusion, patellar apprehension, and tenderness along the medial facet of the patella, the medial retinaculum, or at the medial femoral condyle) and radiological findings (contusion of the lateral femoral condyle or medial portion of the patella, osteochondral fragment, and lesion of the medial patellofemoral ligament). The patients without PI, diagnosed as having other knee injury or disorders such as tibial spine fracture, anterior or posterior cruciate ligament injury, or bone tumor, were included in the control group. The patients selected for these groups were not specifically matched for any other clinical factors. All patients had complete related medical records, and all had both CT and MRI imaging data, performed according to the imaging protocols of our hospital, for the same knee within 1 month of clinical examination.

MRI Protocol

The patient was scanned in the supine position with the knee tightly fixed in the center of an HD Quad Extremity Coil (GE Healthcare) and supported by padding within the cylindrical coil to ensure patient comfort and avoid motion. The patients were scanned on 3.0-T GE MRI scanners (GE Healthcare) with axial T2-weighted fat-saturated imaging (repetition time/echo time, 4120/86 ms; field of view, 150 $\times$ 150 mm; 5-mm slice thickness; 5-mm spacing between slices; matrix, 256 $\times$ 384).

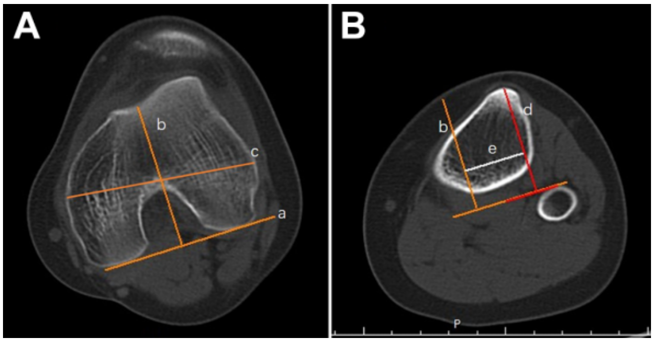

Figure 1. (A and B) Bony tibial tubercle–trochlear groove (TT-TG) distance on computed tomography (CT). Line connecting the posterior femoral condyles on axial CT (*a*); trochlear line: the line through the deepest point within the trochlear groove perpendicular to line *a* (*b*); femoral width (*c*); line parallel to line *b* through the most anterior point of the tibial tuberosity (*d*); bony TT-TG distance (*e*).

CT Protocol

All CT examinations were performed on an Aquilion 64 (Toshiba America Medical Systems). Patients were positioned supine with the legs in full extension and the right and left forefoot taped together at the level of the metatarsophalangeal joint. The patients underwent a higher resolution CT scan of their knee to approximately 10 cm above and below the joint line. The sequence of images from the scan, representing a slice thickness of 1 to 5 mm and an interval of 0 mm with a resolution of 512 $\times$ 512 pixels, were obtained using standard 120-kV and 93-mA parameters.

The TT-TG distance was evaluated using both bony and cartilaginous measurement in CT and MRI methods as described by Schoettle et al[19] and Camp et al[7] (Figures 1-4). The femoral width was measured as the distance from the medial epicondyle to the lateral epicondyle in the same craniocaudal image where the trochlear line was drawn[17] (Figures 1-4). The flexion angle of the knee was measured as angulation of the longitudinal midline axis of the distal femur and proximal tibia in the sagittal images of CT or MRI (Figure 5).

All the distances and angles were measured by a fellowship-trained orthopaedic surgeon (L.S.) and a graduate student (Z.-Z.D.) using the same workstation. For all 48 knees, each evaluator chose all landmarks from the beginning on each reading and stored the image series, devoid of patient identification, in numbered electronic folders. Each

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Ethical approval for this study was obtained from Xin Hua Hospital Affiliated to Shanghai Jiao Tong University School of Medicine (approval No. XHEC-D-2020-007).

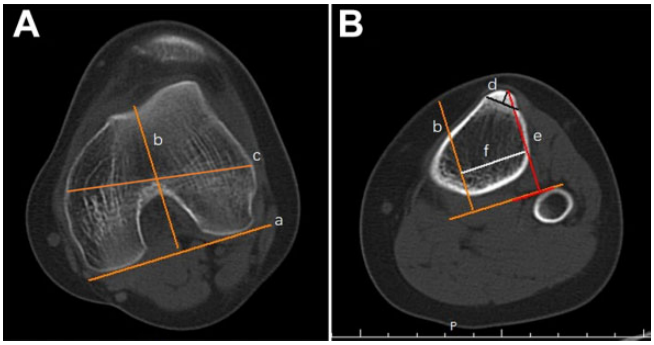

Figure 2. (A and B) Cartilaginous tibial tubercle–trochlear groove (TT-TG) distance on computed tomography (CT). Line connecting the cartilaginous posterior femoral condyles on axial CT (*a*); trochlear line: the line through the deepest point within the trochlear groove on the craniocaudal image that depicts complete cartilaginous trochlea perpendicular to line *a* (*b*); femoral width (*c*); a line starting at the midpoint of and perpendicular to the line that connects the 2 external points of the patellar tendon insertion to the tuberosity (*d*); line parallel to line *b* through the patellar tendon center (*e*); cartilaginous TT-TG distance (*f*).

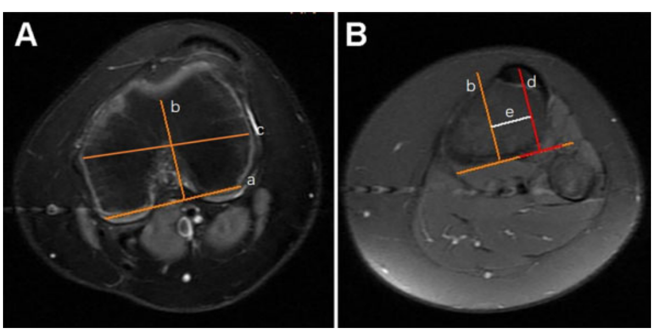

Figure 3. (A and B) Bony tibial tubercle–trochlear groove (TT-TG) distance on magnetic resonance imaging (MRI). Line connecting the posterior femoral condyles on axial MRI (*a*); trochlear line: the line through the deepest point within the trochlear groove perpendicular to line *a* (*b*); femoral width (*c*); line parallel to line *b* through the most anterior point of the tibial tuberosity (*d*); bony TT-TG distance (*e*).

evaluator made a total of 3 measurements with intervals of no less than 7 days to limit bias from previous measurements. The aggregate means for the TT-TG and angle were calculated.

Statistical Analysis

Continuous variables were compared using a paired *t* test and Wilcoxon signed-rank test. Categorical variables were compared using a chi-square test and Fisher exact test. The interrater, intermethod (CT vs MRI measurement), and interperiod (bony vs cartilaginous TT-TG) reliabilities of TT-TG measurement were assessed with intraclass

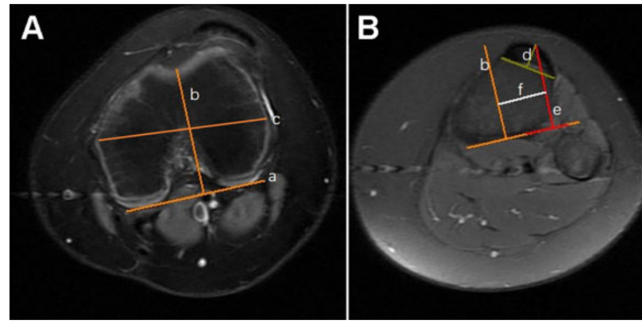

Figure 4. (A and B) Cartilaginous tibial tubercle–trochlear groove (TT-TG) distance on magnetic resonance imaging (MRI). Line connecting cartilaginous posterior femoral condyles on axial MRI (*a*); trochlear line: the line through the deepest point within the trochlear groove on the craniocaudal image that depicts complete cartilaginous trochlea perpendicular to line *a* (*b*); femoral width (*c*); a line starting at the midpoint of and perpendicular to the line that connects the 2 external points of the patellar tendon insertion to the tuberosity (*d*); line parallel to line *b* through the patellar tendon center (*e*); cartilaginous TT-TG distance (*f*).

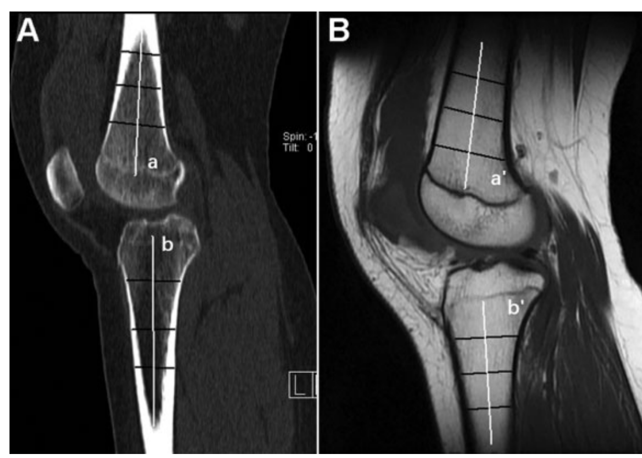

Figure 5. (A) Femoral shaft axis (*a*) and tibial shaft axis (*b*) on sagittal CT. (B) Femoral shaft axis (*a*′) and tibial shaft axis (*b*′) on sagittal T1-weighted MRI. For both CT and MRI, the method used to determine the femoral and tibial shaft axis was as follows: (1) draw 3 parallel lines from the anterior to the posterior aspect of the distal femur and the proximal tibia, (2) determine the midpoints of each of the 3 parallel lines, and (3) draw a line connecting the midpoints. The knee flexion angle was defined as the acute angle of the femoral and tibial shaft axis.

correlation coefficients (ICCs) and the Bland-Altman 95% limits of agreement (LOA). An ICC < 0.4 was considered poor agreement, $0.4 <$ ICC ≤ 0.75 was fair to good agreement, and ICC > 0.75 was excellent agreement. Relations between parameters, such as age, femoral width, flexion angle, and TT-TG distance, were assessed by use of the Spearman rank correlation test. Statistical analyses were

TABLE 1
Patient Characteristics and TT-TG Distance Between the Study Groups[a]

Characteristic	Total (N = 48)	Control Group (n = 24)	Patellar Instability (n = 24)	*P* Value[b]
Age, y	11.33 ± 1.99	10.83 ± 2.22	11.83 ± 1.63	.0826
Male sex, n (%)	19 (40)	9 (38)	10 (42)	.7680
Femoral width, mm				
CT	68.92 ± 7.99	67.42 ± 8.96	70.43 ± 6.73	.1956
MRI	69.33 ± 7.88	68.51 ± 9.12	70.15 ± 6.50	.4754
TT-TG distance, mm				
Bony TT-TG on CT	—	11.28 ± 4.07	17.35 ± 5.12	**<.0001**
Cartilaginous TT-TG on CT	—	12.74 ± 4.57	20.20 ± 5.14	**<.0001**
Bony TT-TG on MRI	—	8.40 ± 3.10	11.73 ± 3.73	**.0016**
Cartilaginous TT-TG on MRI	—	10.29 ± 2.96	14.87 ± 4.50	**.0002**

[a]Data are expressed as mean ± SD unless otherwise noted. CT, computed tomography; MRI, magnetic resonance imaging; TT-TG, tibial tuberosity–trochlear groove; —, values shown in Table 2. Boldface values indicate statistically significant difference ($P < .05$).
[b]Comparison between control group and patellar instability.

TABLE 2
Interrater Reliability and Bland-Altman Analysis of TT-TG Distance[a]

TT-TG Distance	Measurement, mean ± SD, mm	Difference, mean ± SD, mm	95% LOA, mm	ICC (Interrater)
Bony TT-TG on CT	14.32 ± 5.51	0.14 ± 0.92	–1.66 to 1.94	0.9858
Cartilaginous TT-TG on CT	16.47 ± 6.11	–0.19 ± 1.00	–2.15 to 1.77	0.9863
Bony TT-TG on MRI	10.06 ± 3.78	0.09 ± 1.06	–1.98 to 2.17	0.9613
Cartilaginous TT-TG on MRI	12.58 ± 4.42	–0.12 ± 0.84	–1.97 to 1.53	0.9817

[a]CT, computed tomography; ICC, intraclass coefficient; LOA, limits of agreement; MRI, magnetic resonance imaging; TT-TG, tibial tuberosity–trochlear groove.

carried out with statistical software Stata Version 15.0, all statistics were 2-tailed, and *P* values < .05 were considered significant.

RESULTS

The 48 selected children (mean age, 11.33 ± 1.99 years; range, 7-14 years; 19 boys and 29 girls) included 24 children in the PI group and 24 children in the control group (Table 1). No differences in age, femoral width, or sex proportion were seen between the PI group and the control group (Table 1).

Cartilaginous TT-TG distances measured on CT were larger than those measured on MRI ($P = .0006$); bony TT-TG distances measured on CT and cartilaginous TT-TG distances measured on MRI were larger than bony TT-TG distances measured on MRI ($P < .0001$ and $P = .0035$, respectively). No significant differences were seen between cartilaginous TT-TG distances and bony TT-TG distances when measured on CT ($P = .0734$) (Figure 6A).

All of the TT-TG measurements had an excellent interrater reliability, with mean differences (MDs) <0.19 mm (Table 2). For interperiod (bony vs cartilaginous TT-TG) reliability, measurements on MRI had good agreement of measurement (MD, 2.52 mm; 95% CI, 1.80-3.23 mm; ICC, 0.6917) and those on CT had an excellent agreement of measurement (MD, −2.15 mm; 95% CI, 1.55-2.75 mm; ICC, 0.8766) (Table 3 and Figure 6B). For intermethod (CT vs MRI measurement) reliability, bony TT-TG distance had poor agreement of measurement (MD, 4.25 mm; 95% CI, 2.87-5.64 mm; ICC, 0.3487) and cartilaginous TT-TG distance had fair agreement of measurement (MD, −3.89 mm; 95% CI, 2.36-5.41 mm; ICC, 0.4060) (Table 3, Figure 6B).

Overall, there was a mean difference of 4.07 mm (95% CI, 2.6-5.5 mm) between TT-TG distances measured on CT and those on MRI and a mean difference of 2.3 mm (95% CI, 0.79-3.8 mm) between cartilaginous TT-TG distances and bony TT-TG distances. The mean flexion angle of the knee on CT scan was –0.29° ± 7.85° (range, –16.5° to 16.6°), whereas that on MRI scan was 11.3° ± 8.07° (range, –12.5° to 29.9°). The mean flexion angle of the knee on CT scan was lower than that on MRI ($P < .001$).

Bony or cartilaginous TT-TG distance measured on CT or MRI did not change with the age or sex of patient. The femoral width measured on both CT and MRI increased with the age of the patient (CT, $r = 0.7874$; MRI, $r = 0.7996$) (Figure 7A). However, there was no difference in femoral width measured by CT and MRI (Table 1). TT-TG distance on CT increased with the femoral width (bony TT-TG, $r = 0.4333$; cartilaginous TT-TG, $r = 0.4467$) (Figure 7B), but TT-TG distance on MRI did not (Figure 7C).

Not surprisingly, TT-TG distance by any kind of measurement in the PI group was significantly greater than that in the control group (Table 1).

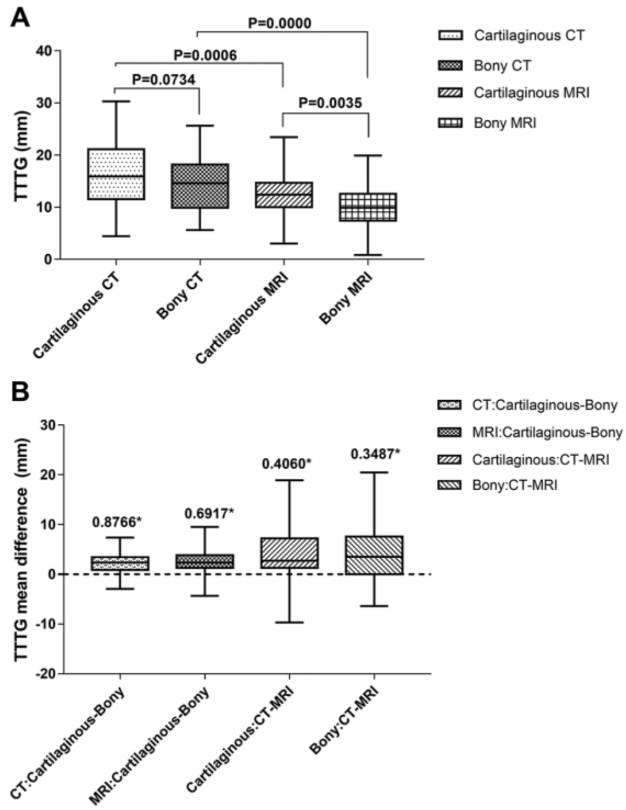

Figure 6. Box plots showing the overall mean and SD for (A) comparison of the different kinds of tibial tuberosity–trochlear groove (TT-TG) distance measurement and (B) difference in TT-TG between modalities (CT vs MRI) or landmarks (cartilaginous vs bony). Whiskers represent minimum and maximum values. *Intraclass correlation coefficient. CT, computed tomography; MRI, magnetic resonance imaging.

DISCUSSION

In the present study, we investigated TT-TG distance measurements in skeletally immature patients younger than 14 years and found that measurements had good or excellent interrater and interperiod (bony vs cartilaginous TT-TG) agreement but poor intermethod (CT vs MRI) agreement. Significant differences in TT-TG distances have been found between the 2 modalities. However, TT-TG distances measured on CT were found to increase with the femoral width in CT, but those on MRI did not. Compared with those in the control group, patients in the PI group had increased TT-TG distance.

Measurements made by CT and MRI have been investigated extensively in adults.[2,8,14,15,19-21] Some researchers have investigated TT-TG measured on MRI in skeletally immature patients, who have high occurrence of PI.[4,6,10,17,25] However, no research has compared TT-TG distance measured between the 2 modalities in a pediatric population.[2,8,14,15,19-21] In the present study, we found an MD of 4.07 mm (95% CI, 2.6-5.5 mm) in TT-TG distances measured by CT and MRI in skeletally immature patients.

TABLE 3
Intermethod and Interperiod Reliability of TT-TG Distance Measurements[a]

TT-TG Distance	Difference, mean ± SD, mm	95% LOA, mm	ICC (Interrater)
Bony vs cartilaginous TT-TG on CT	–2.15 ± 2.07	–6.22 to 1.92	0.8766
Bony vs cartilaginous TT-TG on MRI	2.52 ± 2.46	–7.34 to 2.31	0.6917
CT vs MRI bony TT-TG	4.25 ± 4.77	–5.10 to 13.61	0.3487
CT vs MRI cartilaginous TT-TG	–3.89 ± 5.26	–6.42 to 14.19	0.4060

[a]CT, computed tomography; ICC, intraclass coefficient; LOA, limits of agreement; MRI, magnetic resonance imaging; TT-TG, tibial tuberosity–trochlear groove.

In a meta-analysis of 5 studies, Tan et al[20] found an MD of 1.79 mm (95% CI, 0.91-2.68 mm) between CT and MRI for adults. The difference between the 2 modalities in children seems relatively greater than that in adults.

In adults, it remains controversial whether TT-TG distances measured by CT and MRI are interchangeable.[2,8,14,15,19-21] In the pediatric population included in the present study, TT-TG distances measured by CT and MRI were not interchangeable because of their poor or fair intermethod agreement (ICC < 0.4). This observation should be taken into consideration when MRI is used to evaluate recurrent PI in skeletally immature patients.

Patient position has been suggested to account for the difference between the 2 modalities, because the use of a knee coil in MRI increases knee flexion.[1,8,14-16] In our cohort, the knee flexion angle during MRI scanning was different from that used during CT, with an average of 11° (11.6 ± 9.9°); in adults studied previously, the difference was an average of 7° (7.46 ± 11.6°; $P < .0001$).[14] Although the same imaging protocols were applied during CT and MRI scanning, our study showed a relatively wide variability of knee flexion (range, –16.5° to 16.6° for CT; range, –12.5° to 29.9° for MRI). This may be due to passive posture in the knee of some children during the CT or MRI scan; those who had pain from acute trauma or immobilization. Some studies have focused on the effect of knee position on measurements of TT-TG[1,2,11,15,16]; however, few studies have analyzed in detail the variability of knee flexion angle in children with PI during MRI and CT scanning. Although further studies are warranted, differences in knee position should be taken into account in the interpretation of TT-TG measured by CT or MRI in children.

It remains controversial how TT-TG distance measured on MRI changes with the age or size of developing children.[4,6,10,17,25] Dickens et al[10] found that TT-TG distance measured on MRI changed with chronologic age in a pediatric population (n = 571; age range, 0-15.9 years) and suggested that it might be appropriate to devise an age-based approach for evaluating children. Bayhan et al[6] found that TT-TG distance increased with age only in children without PI but not in children with PI; that study has the largest

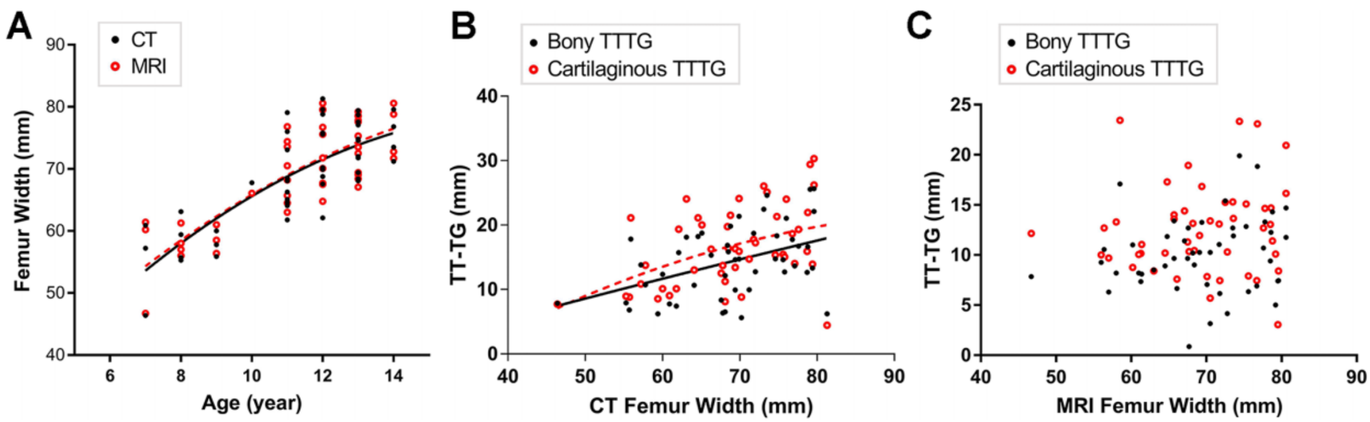

Figure 7. (A) Scatterplot showing the relationship between patient age and femoral width measured on CT (black dots) or MRI (red circles); the best-fit curve showed that femoral width on both CT (solid black line) and MRI (dashed red line) increased significantly with age (CT: $r = 0.7874$, $P < .0001$; MRI: $r = 0.7996$, $P < .0001$). (B) Scatterplot showing the relationship between tibial tuberosity–trochlear groove (TT-TG) distance (black dots, bony TT-TG; red circles, cartilaginous TT-TG) and femoral width measured on CT; the best-fit curve showed that both bony (solid black line) and cartilaginous (dashed red line) TT-TG increased significantly with femoral width measured on CT and MRI (bony TT-TG: $r = 0.4333$, $P = .0021$; cartilaginous TT-TG: $r = 0.4467$, $P = .0015$). (C) Scatterplot showing the relationship between TT-TG distance (black dots, bony TT-TG; red circles, cartilaginous TT-TG) and femoral width measured on MRI. There was no significant relationship between bony or cartilaginous TT-TG and femoral width measured on MRI (bony TT-TG, $P = .2348$; cartilaginous TT-TG, $P = .5818$).

sample size (n = 869; age range, 5-15 years) in the current literature. In contrast, Pennock et al[17] found that TT-TG distance decreased with the age of patients only in the PI group but increased with height in both the PI group and the control group (n = 180; age range, 10-19 years). Those investigators suggested that it might be appropriate to normalize TT-TG to patient height to evaluate patients of that age. Balcarek et al[4] reported that in young athletes (n = 245; age range, 5-47 years; <20% younger than 13 years), age did not correlate with TT-TG distance. Hernigou et al[13] found that TT-TG distance varied with the size of the knee in adults, and those investigators developed a nomogram to represent the normal values for a given size of the knee. Although all of these reports focused on TT-TG distance measured on MRI as a function of age or size, the heterogeneity in the populations, age ranges, and ethnicities makes it difficult to reach consistent conclusions. The present research did not confirm that TT-TG distance measured on MRI changed with age or size but found that TT-TG distance on CT increased with the femoral width of children.

Wilcox et al[24] and Hinckel et al[14] found that selection of bony or cartilaginous landmark affected the reliability of TT-TG distance measurements on CT or MRI. In their studies, patients investigated were older than 14 years. In children younger than that age, the relatively thick cartilage surface in the trochlea or tubercle may obscure the anatomic landmarks of TT-TG. However, our research found that TT-TG has a good or excellent measurement agreement (ICC > 0.69) between different landmarks for children. Our results were consistent with the research of Schoettle et al,[19] although their population selection was not described. Therefore, bony TT-TG and cartilaginous TT-TG could be interchangeable for evaluation of children.

As expected, the present article showed that children in the PI group had greater TT-TG distance on any kind of measurement than children in the control group. Some researchers have discussed possible cutoff values of TT-TG on MRI,[4,19] but the threshold of TT-TG on MRI has not been accepted widely and needs to be confirmed by future investigations that focus on natural history or long-term follow-up of treatment in skeletally immature patients with PI.

There are some limitations in the present research. First, the small sample size restricts the power of this study and precludes effective analysis of the effects of some factors, such as age, sex, body size, or body position, on the measurements of TT-TG. Second, the lack of standardization of knee position during CT or MRI scanning in the present research may affect measurements of TT-TG and does not allow us to investigate the relationship between knee position and TT-TG. However, in clinical situations, orthopaedic surgeons often must refer to imaging results performed elsewhere before referral. In the future, a specific experimental design should be used that standardizes knee position for children. Third, because this was a retrospective chart review, the skeletal age and growth metrics of the children (height, weight, etc) could not be collected. However, it is accepted that growth metrics are routinely associated with chronological age. Fourth, there is potential bias in that we assumed that young patients without a history of PI included in the control group would not develop patellar instability. Our data could be affected if some of the control patients develop symptoms of PI as they grow.

In conclusion, for skeletally immature patients, TT-TG distance could be evaluated on MRI, regardless of whether cartilage or bony landmarks were used. We found that this value could not be interchanged with TT-TG distance measured by CT, but this topic needs to be researched further.

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