Reliability of the TT-TG Index Versus TT-TG Distance on MRI

Morphometric Analyses in Asian Children and Adolescents

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Background: The tibial tuberosity–trochlear groove (TT-TG) distance measured on magnetic resonance imaging (MRI) is commonly used to decide the treatment for patellar instability; however, the patient's joint size is not considered in this measurement. The TT-TG index has been proposed as a knee size–adjusted measurement for tibial tuberosity location.

Purpose: To evaluate the reliability of the TT-TG index compared with the TT-TG distance by analyzing variations in measurement according to age and sex in a pediatric Asian population.

Study Design: Cohort study (diagnosis); Level of evidence, 3.

Methods: A total of 698 knee MRI scans were collected in patients between 4 and 18 years of age who did not have any patellofemoral problems. Patient age, sex, height, and weight were recorded. The scans were divided into 5 groups according to patient age (4-6 years, 46 scans; 7-9 years, 56 scans; 10-12 years, 122 scans; 13-15 years, 185 scans; and 16-18 years, 289 scans); MRI scans were also divided by sex (497 male, 201 female). Three independent observers measured the TT-TG distance and TT-TG index on each scan, and age- and sex-based differences in the measurements were evaluated after adjusting for body mass index (BMI). The reliability of the measurements was calculated with the intraclass correlation coefficient (ICC).

Results: Good to excellent inter- and intraobserver agreement was found for TT-TG distance (ICC, 0.74) and TT-TG index (ICC, 0.88). The TT-TG distance was significantly different among the groups and increased with age, while variations in the TT-TG index were minimal between age groups and sexes. This finding was also consistent after compensating for the effect of BMI.

Conclusion: The TT-TG distance changed with age, while the TT-TG index was relatively constant. Therefore, the TT-TG index may be more reliable and effective for diagnosing and planning treatment, especially in children and adolescents.

Keywords: tibial tuberosity; trochlear groove; distance; index; morphometry

The incidence of patellar instability is approximately 49 per 100,000 people.[12,25,28] The recurrence rate is as high as 44% after nonoperative management of the first patellar dislocation.[4,5,19,24] Compared with adults, the incidence is higher in girls aged 10 to 17 years.[9,15,31] The risk factors for recurrent patellar instability include increased tibial tuberosity–trochlear groove (TT-TG) distance (>20 mm), trochlear dysplasia, patella alta, torsional abnormality, medial patellofemoral ligament insufficiency, vastus medialis obliteration dysplasia, and iliotibial band contracture.[11,14,36] The osseous features of the tibial tuberosity and the femoral trochlea are the main factors causing patellar instability.

Several parameters can be used in evaluating the femoral trochlear morphology and tibial tuberosity, including sulcus angle, lateral trochlear inclination, trochlear facet symmetry, trochlear depth, and TT-TG distance.[6] Among these, TT-TG distance is most commonly used to decide the treatment for patellar instability.[3,7,22] Traditionally, this measurement assesses the mediolateral distance between the anterior tibial tubercle and the deepest part of the trochlear groove on an axial view using computed tomography (CT). When the TT-TG distance is >20 mm, tibial tubercle osteotomy/transfer is often considered as the surgical treatment of choice.[1,11,18] This measurement has been validated in many studies. It has a high prognostic

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value in predicting future recurrent patellar instability and guides surgical decision making.[26]

However, most of the above parameters, including TT-TG distance, are absolute values and do not consider the individual's age, sex, and joint size. In this context, a previous study reported a correlation between the TT-TG distance and joint size. The TT-TG index was able to show the relationship by calculating the ratio between the TT-TG distance and the proximodistal distance from the entrance of the chondral trochlear groove to the height of the tibial tubercle.[16]

Several studies have reported the relationship between these parameters and age and sex.[17,23,30] However, most reports evaluated the patellofemoral morphology parameter using magnetic resonance imaging (MRI) data from the knees of pediatric White patients, with no studies performed on pediatric Asian patients. Some anatomic structural differences depending on race have been found.[35,39] Furthermore, most reports used data from CT scans, and only a few used data from MRI scans.[‖] Compared with CT, MRI has better reliability in evaluating patellofemoral morphology and is currently the gold standard for knee joint evaluation.[10,32] Only limited information is available on the TT-TG distance and TT-TG index in Asian patients using MRI.

In this study, we compared the reliability of the TT-TG index versus the TT-TG distance measured on MRI by analyzing variations in measurement according to age and sex in a pediatric Asian population. We hypothesized that the TT-TG index, a size-adjusted measurement for tibial tuberosity location, would be more valid than TT-TG distance in this population.

METHODS

Study Population

This study was performed after gaining institutional review board approval. Informed consent was waived because of the retrospective nature of this study. A total of 836 knee MRI scans were collected from patients aged 4 to 18 years between 2000 and 2017. Data from patients who were 0 to 3 years of age were not included because of the small sample size and difficulty of measurement due to poor image resolution. The exclusion criteria for this study were as follows: missing or incomplete data due to poor image quality or imaging errors and insufficient demographic data; a history of any patellofemoral problem, including patellofemoral instability; a history of a previous surgical procedure on the involved extremity, including fractures around the knee; and a history of any skeletal disease that can affect the normal knee anatomy, including osteomyelitis. After applying exclusion criteria, 698 knee MRI scans were included (Figure 1).

The MRI scans were divided into 5 groups according to patient age (4-6 years, 46 scans; 7-9 years, 56 scans; 10-12 years, 122 scans; 13-15 years, 185 scans; and 16-18 years, 289 scans) and sex (497 male, 201 female) (Table 1). Patient height, weight, and body mass index (BMI) were also recorded.

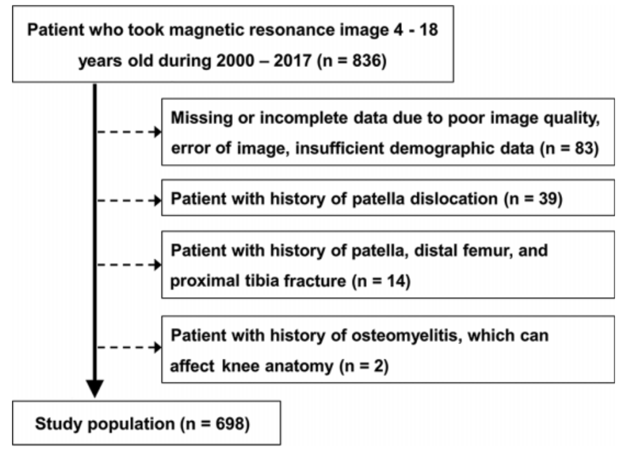

Figure 1. Flowchart of study inclusion and exclusion criteria.

TABLE 1
Number of MRI Scans According to Age Group and Sex[a]

Age Group	MRI Scans	Male Patients	Female Patients
4-6 y	46 (6.59)	25 (5.03)	21 (10.45)
7-9 y	56 (8.02)	37 (7.44)	19 (9.45)
10-12 y	122 (17.48)	84 (16.9)	38 (18.91)
13-15 y	185 (26.5)	125 (25.15)	60 (29.85)
16-18 y	289 (41.4)	226 (45.47)	63 (31.34)
Total	698 (100)	497 (100)	201 (100)

[a]Data are reported as n (%). MRI, magnetic resonance imaging.

‖References 2, 8, 13, 21, 27, 29, 34, 37, 38.

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Ethical approval for this study was obtained from CHA Bundang Medical Center (IRB No. 2020-06-030).

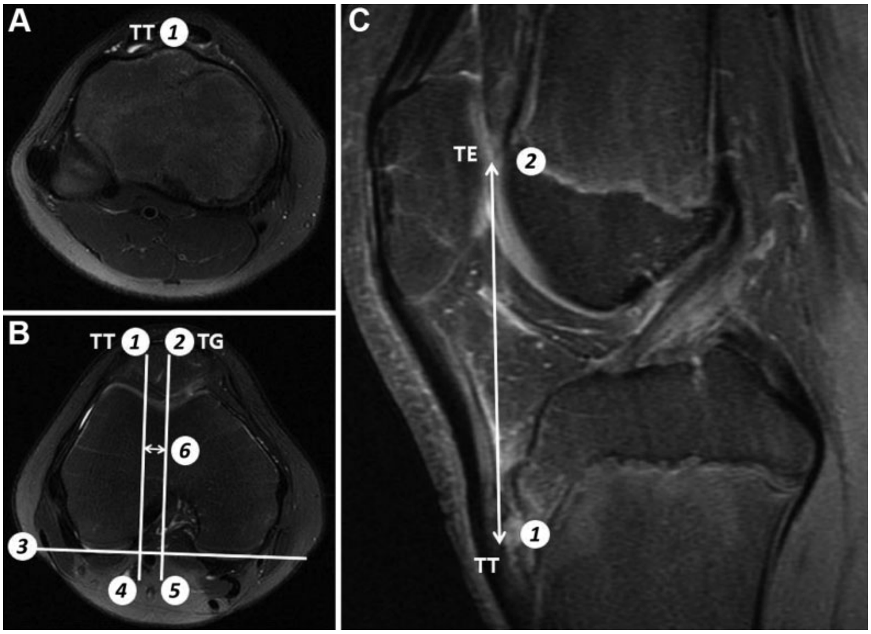

Figure 2. Measurement of the tibial tuberosity–trochlear groove (TT-TG) distance and TT-TG index. (A) The location of TT (*1*) was identified from the axial view of magnetic resonance imaging. (B) Next, a line was drawn between the deepest bony point of TG (*2*) and a superimposed perpendicular line (*5*) tangent to the bony borders of the posterior condyles (*3*), and a second line (*4*) was drawn parallel to the trochlear line through the most anterior portion of the tibial tubercle. The distance between these 2 parallel lines was the TT-TG distance (*6*). (C) The deepest point of the chondral trochlear entrance of the trochlear groove (TE) in the axial sequence was transferred to the sagittal T2-weighted sequence (*2*). The most proximal point of complete attachment of the patellar tendon to the tibial tubercle in the axial sequence was transferred to the sagittal sequences (*1*). The proximodistal distance between the height of these transferred points was measured in the sagittal plane (TT-TE distance, line *1*-*2*). The TT-TG index was the cartilaginous tendon TT-TG distance divided by the TT-TE distance between the tibial tubercle and the proximal chondral entrance of the trochlear groove.

MRI Evaluation and Measurement of Parameters

Magnetic resonance axial imaging was performed using a 3.0-T Signa Scanner (General Electric Healthcare). Patients were evaluated with the knee in full extension.

The age and sex differences in the measured parameters were evaluated. The TT-TG distance was measured as previously described by Schoettle et al.[32] The first line was drawn between the deepest bony point of the trochlear groove and a superimposed perpendicular line tangent to the bony borders of the posterior condyles in an axial MRI. The second line was drawn parallel to the trochlear line through the most anterior portion of the tibial tubercle. The distance between these 2 parallel lines is the TT-TG distance.[11] The deepest point of the chondral trochlear entrance of the trochlear groove (TE) in the axial sequence was transferred to the sagittal T2-weighted sequence. The most proximal point of complete attachment of the patellar tendon to the tibial tubercle in the axial sequence was transferred to the sagittal sequences. The proximodistal distance between these transferred points was measured in the sagittal plane (TT-TE distance), and the TT-TG index was calculated as the cartilaginous tendon TT-TG distance divided by TT-TE distance (Figure 2).[16]

Three independent observers, including 2 orthopaedic residents and 1 senior orthopaedic surgeon (S.L., J.O., W.A.), measured the TT-TG distance and TT-TG index of each scan blindly. One of them measured all parameters twice with an interval of 2 weeks between to analyze intra- and interobserver reliability. Then the TT-TG distance and TT-TG index were measured.

Statistical Analysis

All data were expressed as means and standard deviations. The inter- and intraobserver reliability of the measurements were assessed with the intraclass correlation coefficient (ICC). Comparison of the parameters, including TT-TG distance between sexes, was performed using an independent Student t test or Mann-Whitney U test for continuous variables. Analysis of variance and the post hoc Tukey honestly significant difference test was utilized to compare continuous variables for intergroup differences according to age. We performed a simple linear regression model with adjustments for the BMI. Significance was set at $P < .05$. Data manipulation and statistical analyses were performed using R software (Version 3.6.3; The R Foundation for Statistical Computing).

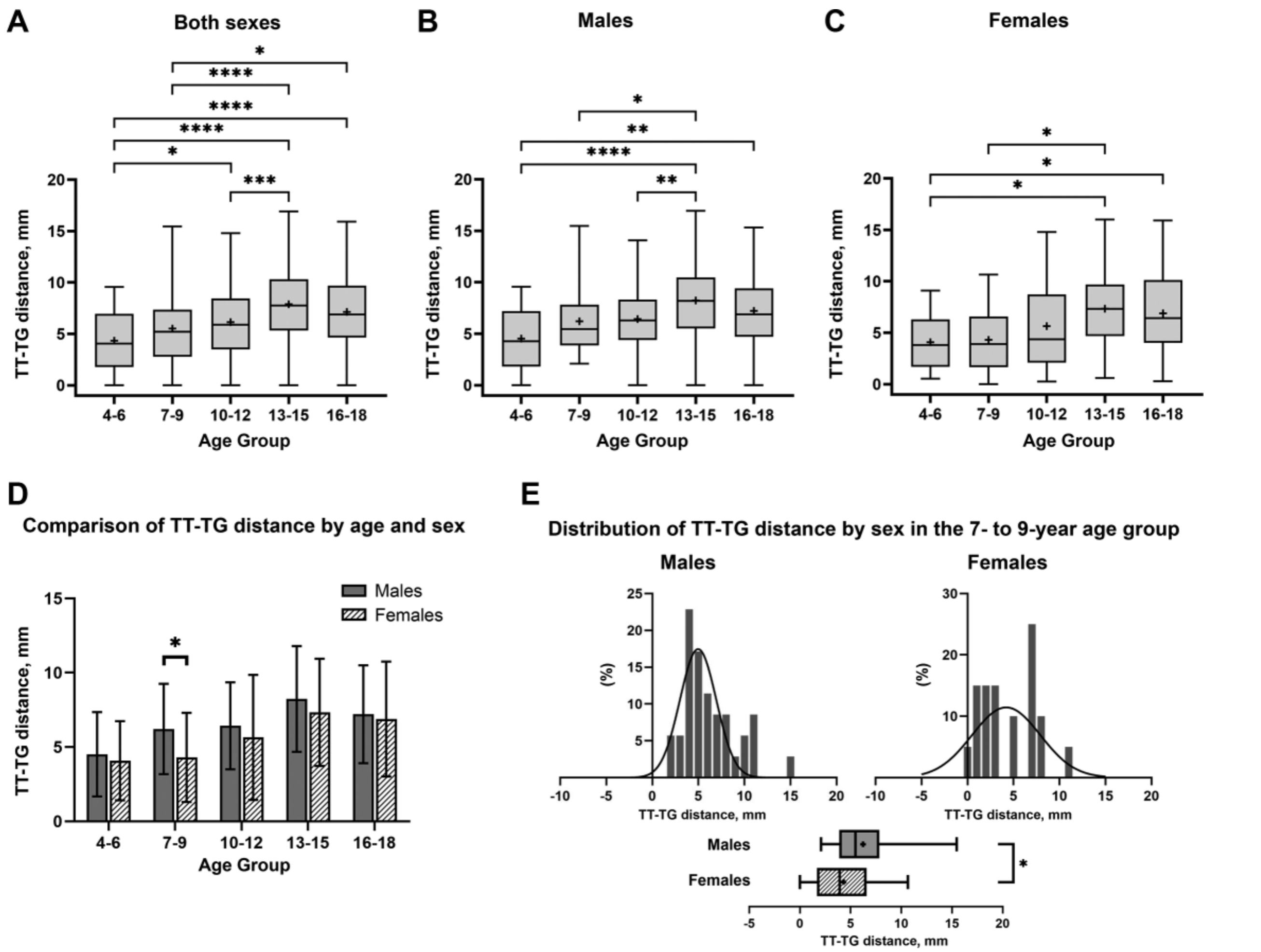

Figure 3. Changes in tibial tuberosity–trochlear groove (TT-TG) distance by age group and sex. The TT-TG distance was significantly different between age groups and increased with age: (A) both sexes, (B) boys, and (C) girls. The line indicates the median and the plus sign indicates the mean. (D, E) In the 7- to 9-year age group, the TT-TG distance was significantly different between boys and girls. Statistically significant difference: *$P < .05$, **$P < .01$, ***$P < .001$, ****$P < .0001$.

RESULTS

Inter- and intraobserver reliability of measurement showed good to excellent agreement for TT-TG distance (ICC, 0.74) and TT-TG index (ICC, 0.88). The TT-TG distance was significantly different between the groups and showed an increase with aging irrespective of sex (Figure 3). The TT-TG distance by age group was as follows: 4.34 ± 2.74 mm (4-6 years), 5.52 ± 3.13 mm (7-9 years), 6.15 ± 3.44 mm (10-12 years), 7.89 ± 3.59 mm (13-15 years), and 7.14 ± 3.44 mm (16-18 years). Although the 16- to 18-year age group had a lower TT-TG distance than the 13- to 15-year age group, the post hoc analysis revealed that the difference was not statistically significant. Boys had a greater TT-TG distance than girls (7.11 vs 6.32 mm). Comparison after age group matching showed a statistically significant difference between male and female TT-TG distance in the 7- to 9-year age group (Figure 3).

In contrast to TT-TG distance, there was no statistically significant change in the TT-TG index with age in both sexes in general (Figure 4). The mean TT-TG index increased from 0.09 (± 0.06) and 0.09 (± 0.05) in the 4–12 y age group to 0.11 (± 0.05) in the 13–15 y and 0.10 (± 0.06) in the 16–18 y age groups. However, significance was poor between the 10- to 12-year and 13- to 15-year age groups ($P = .03$). The TT-TG indices were 0.10 ± 0.05 for boys and 0.11 ± 0.06 for girls, which meant that girls had the higher value, although the result of TT-TG distance was the opposite. Details of the statistical results are summarized in Supplemental Tables S1 to S8 (available online).

After adjusting for each participant's BMI by simple linear regression analysis, we found that TT-TG distance was positively correlated with BMI (β coefficient, 0.01; $P = .0395$), whereas TT-TG index was not influenced by BMI (β coefficient, 0.0000834; $P = .275$) (Table 2).

DISCUSSION

The principal findings of this study indicated that there are variations in measurements for relative tibial tuberosity

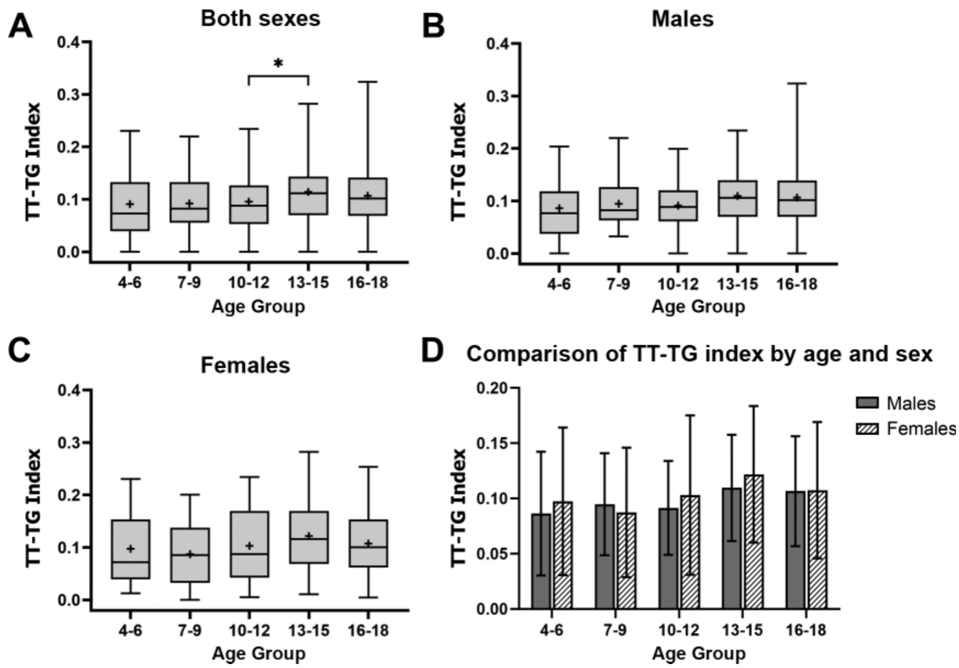

Figure 4. Change of tibial tuberosity–trochlear groove (TT-TG) index with aging. (A) In both sexes, the TT-TG index was significantly different between the 10- to 12-year and the 13- to 15-year age groups (*$P < .05$). The line indicates the median and the plus sign indicates the mean. (B-D) There were no significant differences in the TT-TG index in or between male and female patients.

TABLE 2
Results of Simple Linear Regression Test of TT-TG Distance and TT-TG Index[a]

Model	Unstandardized Coefficient β (95% CI)	SE	*t*	*P*
TT-TG distance				
Constant[b]	6.402 (5.9403 to 6.8630)	0.235	27.291	**<.001**
BMI	0.01 (0.0005 to 0.0203)	0.005	2.067	**.0395**
TT-TG index				
Constant	0.1003 (0.0932563 to 0.1072667)	0.003562	28.149	**<.001**
BMI	0.0000834 (–0.0000667 to 0.0002335)	0.0000763	1.093	.275

[a]Boldface *P* values indicate statistical significance ($P < .05$). BMI, body mass index; TT-TG, tibial tuberosity–trochlear groove.
[b]Y intercept.

location or trochlear morphology according to age and sex. TT-TG distance in the pediatric population showed wide variation, which increased with age. Meanwhile, the TT-TG index was relatively constant compared with the TT-TG distance. With this, we could present a normal range of TT-TG distance (4-8 mm) and TT-TG index (0.09-0.11) for the MRI of a juvenile and adolescent Asian population.

The strength of this study is that we compared the TT-TG index between age groups and evaluated the difference of the TT-TG index between boys and girls after adjusting for BMI. We also used MRI for measuring TT-TG distance and TT-TG index instead of CT. With the recent development of imaging technology, most patients with patellar instability undergo preoperative MRI. MRI has some advantages compared with CT. There is no exposure to radiation in MRI, while CT may expose growing patients to radiation. In addition, MRI yields better cartilage and soft tissue detail than CT and allows the use of both bony landmarks and cartilage to evaluate patellofemoral morphology.[32]

Schoettle et al[32] evaluated the reliability of the TT-TG distance on MRI compared with CT. They showed excellent interrater (82%), intermethod (86%), and interperiod (91%) quantitative reliability. Skelley et al[33] studied the intra- and interobserver reliability in the measurement of the TT-TG distance and the determination of the trochlear dysplasia index between musculoskeletal radiologists and orthopaedic surgeons. The study results showed that intra- and interobserver reliability in the MRI measurement of the TT-TG distance and trochlear dysplasia index are high. In our study, inter- and intra-observer reliability of measurement also showed good to excellent agreement for each parameter (0.74-0.88).

Richmond et al[30] evaluated several measurement techniques associated with patellofemoral instability as they relate to patellofemoral morphologic development. A total of 31 skeletally immature fresh-frozen cadaveric knees of patients aged 2 to 11 years were evaluated using CT scans. The authors revealed that the TT-TG distance increased with age. Mundy et al[23] evaluated the femoral trochlear morphology of 144 children using MRI. They also showed that TT-TG distance significantly increased with age. In our study, TT-TG distance was significantly different between the age groups and showed an increase with age in patients with no history of patellar instability. This finding was also consistent after considering height and weight.

Balcarek et al[7] evaluated the value of TT-TG distance in patellar instability in young athletes. TT-TG distance differed significantly between patients with and without patellar dislocation. Furthermore, multiple logistic regression analysis showed that the increased TT-TG distance was a significant risk factor for patellar dislocation, which was not correlated with the patient's age or femoral width. Pennock et al[26] assessed variations in TT-TG distance as a function of the patient's age and size in a population of patients with patellar instability compared with those with no instability. They showed that age does not appear to affect the TT-TG distance measurement in either male or female patients with a history of patellar instability. The age range was 10 to 47 years in the study by Balcarek et al[7] and 10 to 20 years in Pennock et al's report. The lack of children <10 years old may have caused an unfavorable distribution in the open physeal group. Thus, this contributed to the lack of statistical significance. In our report, the age range was 4 to 18 years.

Li et al[20] measured patellofemoral parameters, including TT-TG distance, using 3-dimensional reconstructed CT of 78 normal knees in a Chinese population. The TT-TG distance of the male participants was significantly larger than of the female participants. However, there were no significant differences in TT-TG distances after addressing the age bias and height and weight. Kim et al[17] determined the age- and sex-related differences in the osseous morphology of the patellofemoral joint in children during skeletal maturation. They revealed that the MRI measurements of osseous morphology, including TT-TG distance, were not significantly correlated with age, sex, or physeal patency. TT-TG index is the ratio of the TT-TG distance by the axial distance between the chondral proximal trochlear entrance and the height of the tibial tubercle. This allows the TT-TG distance to be adjusted to the patellofemoral joint size. Hingelbaum et al[16] showed that the pathological influence of the TT-TG distance in the case of patellar instability depends on an individual's joint size. They reported that the relative TT-TG index could facilitate a decision concerning an indication for the medial transfer of the tibial tubercle. In our study, TT-TG distance was significantly different between boys and girls in the 7- to 9-year age group (mean, 6.2 mm in boys vs 4.3 mm in girls). However, the TT-TG index–adjusted individual joint size and the TT-TG distance were similar between the sexes. The TT-TG indices were 0.10 ± 0.05 for boys and 0.11 ± 0.06 for girls, with no statistical significance.

Limitations

There are several limitations to this study. First, the numbers of each group were varied and the groups were predominantly male. Second, our data were not serial. Thus, we cannot evaluate the changes of each participant over time. Third, we associated TT-TG distance with chronologic age instead of skeletal age. Skeletal age would be a better predictor of skeletal maturation. However, because of the retrospective nature of the study, we could not obtain data about skeletal age. Fourth, we did not compare the TT-TG index of a pathologic population with recurrent patellar dislocation with the index of a normal population. We will do this in the future. Fifth, the purpose of investigating the TT-TG index was to determine whether tibial tuberosity transfer should be used to reduce the TT-TG index in patients with patellar instability and a high TT-TG index. Tibial tuberosity transfer cannot be performed in young patients, however, because they are still growing. However, our study suggests a normal value or cutoff value of the TT-TG index, and it can be helpful in predicting the probability of failure when operations without bone surgery, such as medial plication, are performed in young patients; predicting whether bone surgery will be required later; and setting a target for how much correction is needed.

CONCLUSION

The TT-TG distance changed with age, while the TT-TG index was relatively constant. Therefore, the TT-TG index may be a more reliable and effective factor in making diagnoses and planning treatment, especially in younger patients.

Supplemental material for this article is available at https://journals.sagepub.com/doi/full/10.117710.1177/23259671221145228#supplementary-materials.

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