SciMedCentral
Annals of Sports Medicine and Research

Research Article

Age-Based Patellofemoral Morphology in the Immature Knee

Mundy A[1], Ravindra A[1], Yang J[2], Adler B[2], Beran M[2], and Klingele K[2]*

[1]Department of Orthopaedics, Ohio State University, Columbus, USA
[2]Department of Orthopedic Surgery, Nationwide Children's Hospital, USA

***Corresponding author**
Kevin Klingele, Department of Orthopedic Surgery, Nationwide Children's Hospital 700 Children's Drive Suite A2630 Columbus, Ohio 43205-2696, USA, Tel: 614 -722-5175; Fax: 614-293-4755; Email: Kevin.Klingele@nationwidechildrens.org

Submitted: 14 June 2016
Accepted: 06 July 2016
Published: 07 July 2016
ISSN: 2379-0571

Keywords
• Patellofemoral; Trochlear groove; knee pain

Abstract

Purpose: Patellar instability (PI) is a common cause of anterior knee pain and disability in the pediatric population. The use of patellofemoral measurements on MRI provides a quantitative means for PI assessment and has now become an important diagnostic tool, but these techniques largely rely upon adult standards. Our goal is to describe morphologic trends in the skeletally immature knee and to predict the age at which adult norms can reliably be used in the evaluation of the pediatric knee.

Methods: We retrospectively reviewed 144 normal knee MRIs in 133 skeletally immature patients that presented between 2002 and 2014. Patients were equally distributed by age and gender with ages ranging from 1-16. MRI exclusion criteria included: moderate to severe effusions, cartilaginous defects, patellofemoral abnormalities, ligamentous injury, neoplasms, infection, congenital disease, or arthritic changes. All 1 and 2 year olds were included due to lack of MRIs and only females younger than 15 were used to account for anticipated physical closure. All measurements used cartilaginous landmarks and results were stratified based on age and gender. Each measurement was charted in a linear regression model or analyzed with Student's t test.

Results: Each measurement can reliably be performed at all ages with good inter- and intra observer reliability. All MR measurements were graphically represented in a linear regression model and are shown to approach adult norms with increasing age. The age at which there is no statistical difference between our pediatric patients and the adult norms is shown as the "regression cutoff". Further t-test analysis suggests a 2[nd] cutoff that serves as the age at which younger should not be compared to adult norms.

Conclusion: The measurements commonly used to evaluate for patellar instability in the adult population are subject to considerable variation throughout skeletal maturation. Based on our analysis, children < 10 years of age should not be compared to adult standards. Conversely, children ≥ 10 appear to have reached near patellofemoral maturation and show consistent and progressive development of patellofemoral morphology with increasing age.

Significance: The ability to predict morphologic abnormalities in the first decade of life may lend to earlier surgical intervention or realignment procedures. Surgical outcomes may be augmented by remaining patellofemoral growth and remodeling, especially in those patients under 10 years of age.

INTRODUCTION

Primary patellar dislocation is a multi factorial disorder that is estimated to occur in 5.8 in 100,000 individuals [1]. Although the underlying etiology is unclear, anatomical abnormalities involving the distal femur, patella, and the surrounding soft tissues have been shown to disrupt mechanical and structural mechanisms of the knee, resulting in patellar instabili [2,3]. Three of the most significant anatomical variants include trochlear dysplasia, patella alta, and tibial tubercle – trochlear groove distance [2,3].

Plain radiographs and computed tomography were first used to describe anomalous anatomical features associated with patellar instability [2]. More recently, MRI has become an important diagnostic tool, as it is able to visualize soft-tissue abnormalities and can differentiate between the cartilaginous and osseous contours of the patellofemoral joint [4-11]. Normative patellofemoral morphology has been established on MRI, but there remains a lack of data within the pediatric cohort [12]. Our objectives are to (1) describe age-based normative patellofemoral morphology in the pediatric population, and (2) to determine if adult measurements can reliably be used in the evaluation of the pediatric knee.

MATERIALS AND METHODS

Study Population

After institutional review board approval, we retrospectively reviewed "normal" knee MRIs in 131 pediatric patients (77 knee MRIs in 71 males, 67 knee MRIs in 60 females) ages 1 thru 16 with an open physic who presented from2002-2014. All these patients obtained a knee MRI to evaluate knee pain or clinically suspected knee pathology. For the purposes of this study, "normal" MRIs were defined as those with no developmental abnormalities (e.g.

nopatella alta, trochlear dysplasia, or tibial tubercle – trochlear groove distance greater than 20mm). Normal MRIs included baker's cysts, discoid menisci, and small effusions in this study. To account for anticipated physical closure, we included female knee MRIs from age 1to 14 and male knee MRIs from age 1 to 16. With the exception of 1-2 year olds (n=14 knee MRIs, 7 males and 7 females), knee MRIs from 5 males and 5 females were randomly selected to represent each age group from 3 to 14 ages, and additional 10 male knee MRIs (5 each) were randomly selected from boys ages 15 and 16. Thus, a total of 144 knee MRIs from 131 patients (11 had bilateral MRIs, while 2 had repeat ipsi lateral MRIs performed at a later age) were included and analyzed in this study. Each MRI was read by a pediatric-trained radiologist to ensure the knee MRI met "normal" defined in this study, without any other development abnormalities. The included knee MRIs were stored in our Picture Archiving and Communication Systems (PACS) for further analysis.

Exclusion criteria included presence of a closed physic, abnormal radiographic findings that may affect patellofemoral morphology, including moderate to severe effusions, cartilaginous defects, anatomic abnormalities, ligamentous injury, neoplasms, infection, or arthritic changes.

MRI Protocol

All MR imaging was performed at our institution utilizing a 1.5-3.0T imaging system with a knee coil. Each patient had routine knee images as per our hospital protocol. Knees were placed in extension with axial and sagittal measurements obtained from T2 or PD sequences for optimal cartilage visualization. Axial slice thickness varied between 3-5mm, whereas sagittal slices were 2-4mm in thickness. Each knee reviewed on MRI was shown to have an open physic.

MRI Measurements

After collaboration with a pediatric-trained radiologist, all measurements were recorded in PACS individually by two authors, both of whom were pediatric orthopaedic research residents at the time of the study and had extensive training on the study protocol and MRI imaging reading. Each was blinded to the other's results. All measurements were performed to include cartilaginous landmarks on the distal femur and patella Figure (1). To maintain reproducibility, five axial measurements (lateral trochlear inclination (LTI), trochlear facet asymmetry (TFA), trochlear depth (TD), tibial tuberosity-trochlear groove (TTTG), and sulcus angle (SA)) were taken at a single sequence where the distal femoral condylar width was the greatest. The sixth measurement, patellar height ratio (PHR), was assessed on the most midline sagittal sequence. The six measurements are outlined in Table (1).

The six adult patellofemoral measurements were selected based on published work that demonstrated reproducibility, as well as, predictability in assessing patellofemoral pathology [2,4,7,9,13-23]. Normative values as described by Charles et al. were utilized [4]. He and his colleagues compared 40 recurrent patellar instability patients to 81 control patients, and were able to delineate them based on patellar tilt measurements. (To the editor: No gender or age distributions were mentioned in the paper)

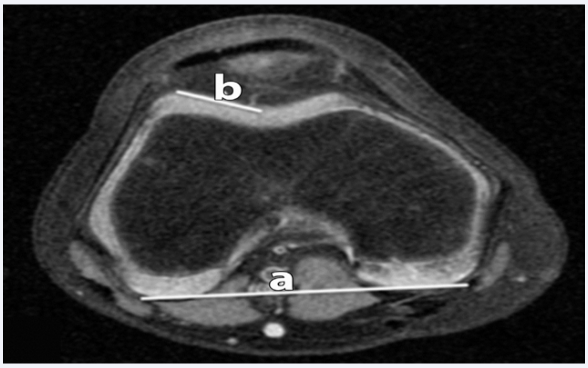

Figure 1 Lateral Trochlear Inclination (LTI). The angle between the lateral trochlear facet (b) and the line along the posterior condyles (a) is measured.

Table 1: Description of Measurements.

Lateral Trochlear Inclination (LTI):	A reference line (a.) is drawn along the posterior condyles with a second line (b.) placed tangential to the articular surface of the lateral facet. The angle formed between these two lines is then measured (Figure 1) [7]. A measurement of less than or equal to 11° is considered abnormal. [7,8].
Trochlear Facet Asymmetry (TFA):	Two lines are formed extending from the apex of the medial (a.) and lateral (b.) trochlear facets along the trochlear surface to the deepest part of the femoral sulcus (Figure 2). The distance of (a.) and (b.) was recorded. Facet asymmetry is the ratio of (a/b) x 100%. (9) A value less than 0.40 is considered abnormal [9].
Trochlear Depth (TD):	Three lines were drawn perpendicular to the posterior condylar reference line and extended to the apices of the medial (a.) and lateral (b.) facets, and to the deepest part of the femoral sulcus (c.) (Figure 3) [2,9]. The trochlear depth was calculated with the following equation: [(a+b)/2]-c [9]. Pathologic trochlear depth on MRI is suggested at less than 3mm [9].
Tibial Tuberosity – Trochlear Groove (TTTG):	The superior attachment of patellar tendon insertion at the tibial tuberosity was marked at its center (Figure 4A). This marker was then transposed to our standard axial image. A line was then formed through the femoral sulcus and extended down to the posterior condylar reference line. The distance between the transposed patellar tendon attachment site and the femoral sulcus line was measured (Figure 4B). [3]. Pathologic results are measurements greater than or equal to 20mm. [10].
Sulcus Angle (SA):	This is the angle formed by two lines tangential to the slopes of the medial and lateral facets intersecting at the femoral sulcus. (Figure 5) [11]. A sulcus angle > 150 is considered pathologic [4].
Patellar Height Ratio (PHR):	This measurement is performed on midline sagittal MR where patellar length is the greatest. At the most midline sequence, the patella is measured from the superior to the inferior poles, and the patellar tendon is then measured from the patellar attachment to the tibial tuberosity. (Figure 6) Per the Insall-Salvati (IS) ratio, the patellar tendon length/patellar height was recorded [12, 13]. Values greater than 1.3 are considered abnormal [13].

Lastly, we used the Insall-Salvati (IS) index as a measurement of patella alta, which can be shown in 24% of cases of patellar instability [12,16,17]. IS ratio is perhaps the most commonly used measurement technique and has been adapted to MRI, with a ratio of ≥ 1.3 considered abnormal [17].

Statistical Analysis

Each of the measurements taken by the two recorders were first averaged and then used to describe the distributions of each patellofemoral measurement across ages among pediatric participants. Linear regressions were used to model each of the six patellofemoral measurements against age, respectively. Predicted means of each of six measurements conditional on age were estimated, along with their 95% confidence intervals (CIs) Figure (2).

We treated each of the adult normative values (fixed values) as the population means and assumed that as age increased, the predicted pediatric means would approach the population mean Figure (3). The interval whereupon the population mean fell outside the 95% CI of the predicted pediatric mean was defined as statistically significant. To visualize the analysis, we plotted the regression lines along with their 95% CI lines, as well as, a reference line (population mean) in the scatter plot of each measurement versus age. The oldest age at which there is statistical significance is considered the "regression cutoff," or the first cutoff. We then used a t-test analysis to examine whether there were statistically significant differences between our observed age-based pediatric means. Assuming our regression cutoff to be most similar to population means, we compared the cumulative pediatric mean values at and above the regression cutoff to the age-based mean values below the cutoff. By doing so, we determined a "t-test cutoff", or the second cutoff, demonstrated by the oldest age at which statistical significance was first seen ($p < 0.05$) when these two groups were compared.

RESULTS

Of 144 knee MRIs analyzed, the average value for lateral trochlear inclination (LTI) was 19.7 degrees (SD=4.1 degrees), trochlear facet asymmetry (TFA) was 73.2 (SD=11.7), trochlear depth (TD) was 4.6 mm (SD=1.4 mm), tibial tuberosity-trochlear groove (TTTG) was 7.8 degrees (SD=4.0 degrees), sulcus angle (SA) was 146.2 mm (SD=7.4 mm), and patellar height ratio (PHR) was 1.0 (SD=0.2).No gender difference was observed for any measurement, except trochlear depth (TD), with males having a TD 0.66 mm greater than females (p=0.004). The six measurements were each plotted by age as a linear regression line, along with 95% confidence intervals (CIs). For each measurement, values from the regression line along with 95% CIs were compared with adult normative values Figure (4). The point at which the adult normative values first fall between the confidence limits is the age at which there is no statistical difference between adult and pediatric data points. The estimated "regression cutoff," or the first cutoff point based on the regression line, as well as the actual mean of the measurement at the cutoff, is shown in Table (2). For example, at age 14.94, the adult normative value of lateral trochlear in clination (LTI), which is 21.74, first falls between the 95%CI of the LTI regression line plotted, based on the child data from this study. The predictive mean of LTI at age 14.9from the regression model was 20.50. While the cutoff ages vary amongst the six measurements, it is seen that when children become approximately 9 years of age or older, the patellofemoral measurements start to show no statistical differences compared to their adult counterparts. Table (3) presents the "t-test cutoff," or second cutoff point based on results of t-tests. This assumes that children at or above the second cutoff are not statistically different. Again, the cutoff values differ across the six measurements, but it can be seen that children ≥ 10 years of age are not statistically different in each of the six measures Figure (5).

Figure 2 Trochlear Facet Asymmetry (TFA). The distances of the lateral facet (b) and medial facet (a) are recorded.

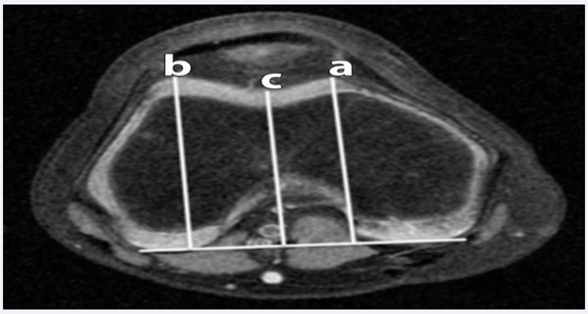

Figure 3 Trochlear depth (TD). Posterior condylar reference line is created (solid white line). Three lines are drawn from the reference line to the lateral facet apex (b), medial facet apex (a), and the deepest portion of the sulcus (c).

Our mean PHR was 1.04 +/- 0.17 in comparison to the adult standard of 1.08 +/- 0.2 [4]. The regression analysis cutoff age is 9 years old.

DISCUSSION

This study aimed to describe age-based normative patellofemoral morphology in the pediatric population through analysis of 144 normal knee MRIs of males and females ages from 1 to 16. The main findings showed that while the cutoff ages based on the regression models vary amongst the six measurements, it is seen that when children become approximately 9 years of age or older, the patellofemoral measurements start to show no statistical differences compared to respective adult normative values.

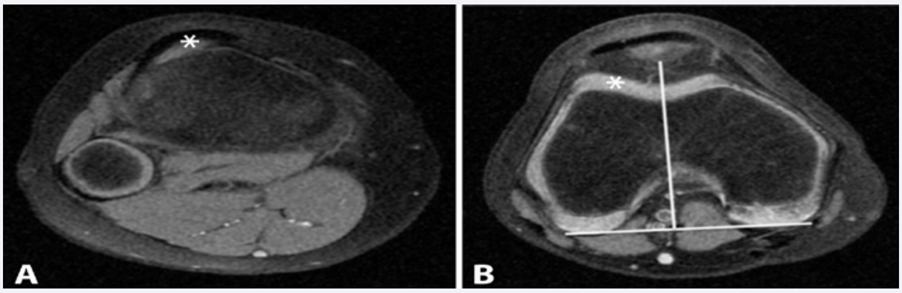

Figure 4 a (left) and 4b (right): Tibial Tuberosity – Trochlear Groove (TTTG) distance. Superior attachment of patellar tendon at tibial tuberosity is marked (left) and then transposed on our standard axial sequence (right). The distance between the marker (*) and solid white line that is extending through the deep sulcus to the reference line was recorded.

Table 2: First Cutoff Age Based on Predictive Mean from Regression Analysis.

	Cutoff Age[a]	Predictive Mean Values at Cutoff		Adult Values[b]	
	(Year)	Mean	SE	Mean	SE
Lateral Trochlear Inclination (°)	14.9	20.5	0.63	21.74	0.52
Trochlear Depth (mm)	12.5	5.78	0.11	5.87	0.15
Trochlear Facet Asymmetry	8.8	0.73	0.01	0.71[c]	0.02
Tibial Tuberosity - Trochlear Groove (mm)	14.6	10.01	0.56	10.96	0.39
Sulcus Angle (°)	15.3	139.72	0.97	137.57	0.93
Patellar Height Ratio	9.1	1.03	5.07	1.08	0.02

[a]Age at which there is no statistically significant difference when compared to adult normative data

[b]Mean values described by Charles et al.

[c]Originally shown as inverse ratio (1.4)

Table 3: Second Cutoff Age Based on T-Test on Observed Means

	Cutoff Age[a]	Observed Mean Values ≥ Cutoff Age		Observed Mean Values < Cutoff Age		p value[b]
	(Year)	Mean	SE	Mean	SE	
Lateral Trochlear Inclination (°)	9	20.62	0.47	17.26	1.18	0.0126
Trochlear Depth (mm)	10	5.84	0.13	4.79	0.30	0.0025
Trochlear Facet Asymmetry	4	0.71	0.01	0.80	0.02	0.0133
Tibial Tuberosity - Trochlear Groove (mm)	6	8.99	0.39	5.99	0.82	0.0186
Sulcus Angle (°)	10	140.90	0.77	145.50	1.86	0.0263
Patellar Height Ratio	8	1.12	0.02	1.00	0.05	0.0314

[a]Oldest age at which statistical significance is first seen when comparing the data points for children age at or above versus age below the second cutoff point

[b]$P < 0.05$

There are statistically significant differences in knee morphology between adults and children. Data suggest that children ≥ 10 years of age are close to adult norms across all data points. However, these cutoffs should not be considered as absolute values. Furthermore, the regression models exhibit the remarkable remodeling potential of the immature knee, especially among children ages 1 to 10; trochlear depth specifically shows an increase in depth with increasing age. The ability to predict morphologic abnormalities in the first decade of life may lend to earlier surgical intervention or realignment procedures. Surgical outcomes may be augmented by remaining patellofemoral growth and remodeling Figure (6). Patellar instability is typically associated with one of several anatomical abnormalities: 1) limb mal alignment, 2) disruption of soft-tissue stabilizers, 3) abnormal trochlear morphology, 4) patella alta, or 5) increased TTTG [2,24,25]. The diagnostic role of MRI in assessing patellar instability has become an important one: MRI is able to differentiate between soft-tissue disorders, osseous variants, and it allows for visualization of articular contours [12]. Additionally, MRI is often necessary when operative intervention is considered, as surgical restoration of anatomy is essential to patient outcomes [12]. In an effort to standardize pediatric patellofemoral morphology and predict trends, we compared our data to an adult study by Charles et al., which utilized the

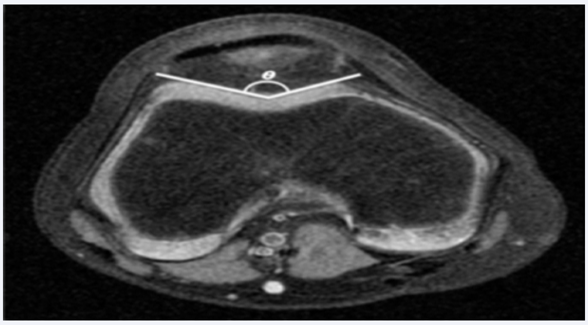

Figure 5 Sulcus Angle (SA). The angle (ɵ) between the lateral and medial facet is measured.

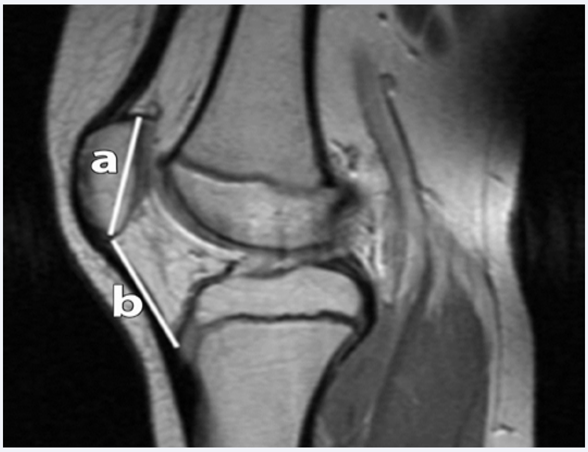

Figure 6 Patellar Height Ratio (PHR) according to Insall-Salvati. Two measurements were recorded, the distance between the superior apex (articular surface) and inferior apex (non- articular surface) (a), and the distance of the patellar tendon at its attachments from the inferior patellar apex to the tibial tuberosity (b).

same data points and measurement techniques as discussed below [4]. It is also important to highlight the use of cartilaginous landmarks in children as the immature ossification centers allow for significant variability between the osseous and cartilaginous structures [26]. Our comparison studies also utilized these, and provide the most similar data to our own [4,27,28]. The trochlea is located in the distal femur and is composed of a lateral and medial facet with a central trochlear groove that deepens distally [10]. With knee flexion angles greater than 20°, the larger lateral facet inhibits lateral translation and mal tracking of the patella [29]. Trochlear facet or groove abnormalities are termed trochlear dysplasia and can be seen in up to 85% of patellar instability patients [2]. To assess for these abnormalities, we used four measurements techniques commonly used in adults, and are shown to reliably predict trochlear dysplasia. Lateral trochlear inclination (LTI) and trochlear facet asymmetry (TFA) have been described to assess abnormal facet architecture, whereas trochlear depth (TD) and sulcus angle (SA) measure degree of trochlear concavity [2,19].

LTI has been studied on MRI, with a value less than 11° considered abnormal and predictive of trochlear dysplasia [13,14]. LTI has traditionally been measured at the first craniocaudal sequence where subtle dysplasia may be present; however, Charles et al., utilized proximal and distal MRI slices showing statistical significance between patellar instability patients and controls regardless of location of measurement ($p < 0.001$) [4]. Mean adult LTI was 21.74° compared to our value of 19.66° +/- 4.09 [4]. Kim et al., had a mean LTI of 19.8° +/- 4.6 in children with normal anatomy and an open physic, but used the most proximal sequence for measurement as described by Carillon [14,28]. We found that in younger children, slice thickness significantly impacted proximal trochlear visualization and could not be reliably reproduced. Therefore, we utilized the sequence with the largest condylar width, as it was easily reproducible even in the youngest children. Our linear regression model shows ages 14 and older to be statistically similar to adult norms, supporting the use of LTI in this age group. Additionally, t-test analysis suggests that ages less than 9 should not be compared to adult values. A second measure of trochlear depth, the sulcus angle, was originally described on plain radiographs but has alternatively been used on MRI [22]. The mean sulcus angle on plain radiographs is 138° +/- 6, with a value of > 145° considered abnormal [23]. Our total mean SA was 146.18° +/- 7.4. On adult controls, mean SA is 137.57° +/- 0.93 [4]. Linear regression analysis obtained a cutoff age of 15, with a t-test cutoff at 10 years old. Validating these cutoffs, the SA is found to be considerably higher in younger children and gradually plateaus as it approaches adult norms. This is demonstrated by a mean SA of 140.90° in children > 9 years old, which is more similar to the adult standard.

Trochlear facet asymmetry (TFA) and trochlear depth (TD) have also been studied on MRI and provide a quantitative analysis of patellar instability [19]. TFA can be determined by the ratio of the medial to lateral facet, with a ratio less than 2:5 considered dysplastic, whereas a TD less than 4mm is considered dysplastic [19]. Our mean TFA and TD, are 0.73 +/- 0.12 and 4.6mm +/- 1.41 respectively in comparison to adult norms of 0.71 and 5.87mm [4]. Pfirrman et al., depicted measurements at 3cm above the knee joint as the most sensitive and specific for predicting trochlear dysplasia, but values showed statistical significance at 1 to 2cm above the joint which would bear more resemblance to our measurement technique[19]. A study by Kim et al., found a mean TFA and TD of 0.72 and 5.1mm, respectively [28]. TD had a regression and t-test cutoff age of 12 and 10, respectively. Interestingly, TFA had significantly younger age cutoffs at both regression analysis (8 years old), and the t-test (4 years old). This is likely the result of a ratio used to calculate TFA, which resulted in a smaller slope angle on the linear regression model, thus less variation across all ages. This is further exemplified with one of our other measurements, patellar height ratio.

The lateral displacement or malalignment of the patellar tendon in relation to its inferior attachment at the tibial tuberosity is a well-known factor of patellar instability [2,30]. On plain radiographs, the abnormal lateral vector was first depicted by measurement of the Q angle, but CT and MRI use has generated additional measurement techniques, such as the tibial tuberosity-trochlear groove (TTTG) distance 20,30. Although TTTG values have significant variability in patellar instability patients, a value of > 20 mm is predictably abnormal [2,3]. In our study, the mean TTTG was 7.84mm +/- 4.02, in contrast to 5.6mm +/- 3.0 seen by Kim [28]. Dickens et al., singularly measured TTTG in children, with a mean of 8.6mm +/- 0.3 [27]. Although variability exists between studies, our comparative analysis suggests that TTTG may have a predictive value of adult measurements, in children as young as6 years of age. Our study is the first to describe age-based patellofemoral morphologic progression across multiple measurements. Furthermore, we selected measurements that assessed three distinct precipitating factors of patellar instability. Mundy et al., have shown excellent intra- and inter observer variability with such measurements [31, 32].

Some limitations were present with this study. Although bone age would be a better predictor of age-based norms, the retrospective nature of the study is prohibitive in obtaining this information. We also recognize the need for larger studies to corroborate our findings and to further delineate between normal and abnormal patellofemoral anatomy. We believe, however,that by obtaining adequate power and equal distribution of children, we were able to accurately represent morphologic progression.

CONCLUSION

A thorough understanding of normal patellofemoral anatomy is integral to the evaluation of patellar instability as the decision to treat conservatively versus operatively is complex and must account for anatomic derangements, severity of patellofemoral dysplasia, and the remodeling potential of such articulation. Patellofemoral morphology continues to evolve throughout childhood, especially among children ages 1 to 10.Our results suggest the six patellofemoral morphology measurements used in this study can reliably be performed at all ages with good inter- and intra observer reliability. While children ≥ 10 appear to have reached near patellofemoral maturation and are consistently shown to be within adult norms, children< 10 years of age should not routinely be compared to adult values.

ETHICAL APPROVAL

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent: Informed consent was waived by our IRB from all individual participants included in the study, as this was a retrospective review.

REFERENCES

1. Fithian DC, Paxton EW, Stone ML, Silva P, Davis DK, Elias DA, et al. Epidemiology and natural history of acute patellar dislocation. Am J Sports Med. 2004; 32: 1114-1121.
2. Dejour H, Walch G, Nove-Josserand L, Guier C. Factors of patellar instability: an anatomic radiographic study. Knee Surg Sports Traumatol Arthrosc. 1994; 2: 19-26.
3. Köhlitz T, Scheffler S, Jung T, Hoburg A, Vollnberg B, Wiener E, et al. Prevalence and patterns of anatomical risk factors in patients after patellar dislocation: a case control study using MRI. Eur Radiol 2013; 23:1067-1074.
4. Charles MD, Haloman S, Chen L, Ward SR, Fithian D, Afra R. Magnetic Resonance Imaging–Based Topographical Differences Between Control and Recurrent Patellofemoral Instability Patients. Am J Sports Med. 2013; 41: 374-384.
5. Stäubli HU, Dürrenmatt U, Porcellini B, Rauschning W. Anatomy and surface geometry of the patellofemoral joint in the axial plane. J Bone Joint Surg Br. 1999; 81: 452-458.
6. Chhabra A, Subhawong TK, Carrino JA. A systematised MRI approach to evaluating the patellofemoral joint. Skeletal Radiol. 2011; 40: 375-387.
7. Kujala UM, Osterman K, Kormano M, Nelimarkka O, Hurme M, Taimela S. Patellofemoral relationships in recurrent patellar dislocation. J Bone Joint Surg Br. 1989; 71: 788-792.
8. Muellner T, Funovics M, Nikolic A, Metz V, Schabus R, Vécsei V. Patellar alignment evaluated by MRI. Acta Orthop Scand. 1998; 69: 489-492.
9. Wittstein JR, Bartlett EC, Easterbrook J, Byrd JC. Magnetic resonance imaging evaluation of patellofemoral malalignment. Arthroscopy. 2006; 22: 643-649.
10. Shih YF, Bull AM, Amis AA. The cartilaginous and osseous geometry of the femoral trochlear groove. Knee Surg Sports Traumatol Arthrosc. 2004; 12: 300-306.
11. Van Huyssteen AL, Hendrix MR, Barnett AJ, Wakeley CJ, Eldridge JD. Cartilage-bone mismatch in the dysplastic trochlea. An MRI study. J Bone Joint Surg Br. 2006; 88: 688-691.
12. Diederichs G, Issever AS, Scheffler S. MR imaging of patellar instability: injury patterns and assessment of risk factors. Radiographics. 2010; 30: 961-981.
13. Bernageau J, Goutallier D, Larde D, Guerin L. L'obliquitè de la joue externe de la throclee femorale. Encyclop Med Chir 1981; 30: 39-42.
14. Carrillon Y, Abidi H, Dejour D, Fantino O, Moyen B, Tran-Minh VA. Patellar instability: assessment on MR images by measuring the lateral trochlear inclination-initial experience. Radiology. 2000; 216: 582-585.
15. Hasler RM, Gal I, Biedert RM. Landmarks of the normal adult human trochlea based on axial MRI measurements: a cross-sectional study. Knee Surg Sports Traumatol Arthrosc. 2014; 22: 2372-2376.
16. Insall J, Salvati E. Patella position in the normal knee joint. Radiology. 1971; 101: 101-104.
17. Miller TT, Staron RB, Feldman F. Patellar height on sagittal MR imaging of the knee. AJR Am J Roentgenol. 1996; 167: 339-341.
18. Pandit S, Frampton C, Stoddart J, Lynskey T. Magnetic resonance imaging assessment of tibial tuberosity-trochlear groove distance: normal values for males and females. Int Orthop 2011; 35:1799-1803.
19. Pfirrmann CW, Zanetti M, Romero J, Hodler J. Femoral trochlear dysplasia: MR findings. Radiology. 2000; 216: 858-864.
20. Schoettle PB, Zanetti M, Seifert B, Pfirrmann CW, Fucentese SF, Romero J. The tibial tuberosity-trochlear groove distance; a comparative study between CT and MRI scanning. Knee. 2006; 13: 26-31.
21. Shabshin N, Schweitzer ME, Morrison WB, Parker L. MRI criteria for patella alta and baja. Skeletal Radiol. 2004; 33: 445-450.
22. Brattstroem H. Shape of the Intercondylar Groove Normally and in Recurrent Dislocation of Patella. A Clinical and X-Ray-Anatomical Investigation. Acta Orthop Scand Suppl. 1964; 68: 1-148.
23. Merchant AC, Mercer RL, Jacobsen RH, Cool CR. Roentgenographic analysis of patellofemoral congruence. J Bone Joint Surg Am. 1974; 56: 1391-1396.
24. Colvin AC, West RV. Patellar instability. J Bone Joint Surg Am. 2008; 90: 2751-2762.
25. Koh JL, Stewart C. Patellar instability. Clin Sports Med. 2014; 33: 461-476.
26. Ogden JA. Radiology of postnatal skeletal development. X. Patella and

tibial tuberosity. Skeletal Radiol. 1984; 11: 246-257.

27. Dickens AJ, Morrell NT, Doering A, Tandberg 1, Treme G. Tibial tubercle-trochlear groove distance: defining normal in a pediatric population. J Bone Joint Surg Am. 2014; 96: 318-324.

28. Kim HK, Shiraj S, Anton C, Horn PS. The patellofemoral joint: do age and gender affect skeletal maturation of the osseous morphology in children? Pediatr Radiol. 2014; 44: 141-148.

29. Amis AA, Senavongse W, Bull AM. Patellofemoral kinematics during knee flexion-extension: an in vitro study. J Orthop Res. 2006; 24: 2201-2211.

30. Aglietti P, Insall JN, Cerulli G. Patellar pain and incongruence. I: Measurements of incongruence. Clin Orthop Relat Res. 1983; 176: 217-224.

31. Mundy A, Ravindra A, Yang J, Adler BH, Klingele KE. Standardization of patellofemoral morphology in the pediatric knee. Pediatr Radiol. 2016; 46: 255-262.

32. Dvorak J, George J, Junge A, Hodler J. Age determination by magnetic resonance imaging of the wrist in adolescent male football players. Br J Sports Med. 2007; 41: 45-52.

Cite this article

Mundy A, Ravindra A, Yang J, Adler B, Beran M, et al. (2016) Age-Based Patellofemoral Morphology in the Immature Knee. Ann Sports Med Res 3(5): 1079.