Are the Current Classifications and Radiographic Measurements for Trochlear Dysplasia Appropriate in the Skeletally Immature Patient?

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Background: The assessment and classification of trochlear dysplasia in pediatric patients has yet to be well documented or validated.

Purpose: To examine several different measurements/classifications of trochlear dysplasia in skeletally immature patients to assess inter- and intraobserver reliability and to determine which best correlates with patellar instability.

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

Methods: Radiographs and magnetic resonance imaging (MRI) scans of 36 skeletally immature patients undergoing surgery for patellar instability were compared with 27 age-matched cohort patients who had similar imaging for an acute knee injury but no clinical evidence of patellar instability. Trochlear dysplasia was measured/classified using the radiographic and MRI Dejour classifications, the trochlear depth index (TDI), the lateral trochlear inclination (LTI), and the medial condyle trochlear offset (MCTO). Additionally, the tibial tubercle–trochlear groove (TT-TG) distance was calculated for all patients. Inter- and intraobserver reliability of each measurement, as well as the ability to discriminate patients with patellar instability, were evaluated.

Results: Inadequate radiographs prevented the radiographic Dejour classification from being assessed in 78% of cases. The MRI Dejour classification had the lowest inter- and intraobserver reliabilities (κ = 0.687 and 0.596, respectively); all other measurements were greater than 0.80. The TDI, LTI, and MCTO all significantly differentiated patients with patellar instability compared with those with no instability, with critical cutoffs of 3 mm, 17°, and 1 mm, respectively. Patients with a TDI <3 mm or MCTO <1 mm were 33 and 38 times more likely to have patellar instability, respectively. The TT-TG was directly correlated with trochlear dysplasia severity.

Conclusion: Trochlear dysplasia is common in skeletally immature patients with patellar instability. The objective assessment of trochlear dysplasia with axial imaging MRI is reliable. The objective measurements of TDI, LTI, and MCTO are more reproducible than the more subjective Dejour classification. The TDI, LTI, and MCTO all significantly differentiated patients with patellar instability.

Keywords: trochlear dysplasia; patellar instability; reliability; validity

Trochlear morphology is recognized as one of the main factors responsible for patellar stability. While trochlear dysplasia is estimated to occur in less than 2% of the general population, studies have shown that 62% to 96% of patients with patellar instability have evidence of trochlear dysplasia. The presence and severity of trochlear dysplasia has commonly been evaluated and categorized based on the Dejour radiographic and magnetic resonance imaging (MRI) classifications, and more recently using more objective measurements, including the lateral trochlear inclination (LTI) and the trochlear depth index (TDI).

Although patellar dislocations are commonly encountered in the pediatric population, the frequently cited radiographic and MRI classifications for trochlear dysplasia...
have not been validated in the skeletally immature population. Additionally, there are inconsistencies in the adult literature regarding the inter- and intraobserver agreement of the Dejour classification as well as poor correlation between the objective measurements of trochlear dysplasia and the Dejour classification.

The purpose of the current investigation was to assess several measurements/classifications of trochlear dysplasia in skeletally immature patients to assess the inter- and intraobserver reliability in this population and determine which correlate best with patellar instability. Secondary aims were to identify a simplified threshold measurement that correlates with patellar instability and to evaluate the relationship between trochlear dysplasia measurements and tibial tuberosity–trochlear groove (TT-TG) distance in the skeletally immature patient. Finally, as we suspected multiple patients would have repeat MRI examinations, we sought to evaluate the effect of skeletal growth on trochlear morphology.

We hypothesized that the objective measurements assessed on axial MRI images would be more sensitive for correctly identifying patellar instability and more reproducible than the radiographic or MRI Dejour classifications. We also hypothesized that increased TT-TG distance would be strongly correlated with a history of patellar instability as well as more advanced trochlear dysplasia in the skeletally immature patient.

METHODS

This was an institutional review board–approved retrospective review of skeletally immature patients (open distal femoral physis) between August 2006 and February 2013 performed at a single institution. Patients undergoing surgical treatment for patellar instability were reviewed. Patients were included if they were skeletally immature (defined as open distal femoral physis on radiograph and MRI), had a history of an acute patellar dislocation, and had complete radiographs and MRI of the affected knee. Of the 92 eligible patients, 56 were excluded because they were skeletally mature (closed distal femoral physis on radiograph and/or MRI), had an underlying neurologic disorder, had previous knee surgery, or had a lack of appropriate imaging.

The control group consisted of age-matched patients who underwent knee radiographic and MRI examination for a condition other than patellar instability. Because of the limited number of patients with MRI for reasons other than instability, there were fewer patients in the cohort group, and they could not be matched for sex. Control patients were excluded if they had a history of patellar instability, had previous knee surgery, were skeletally mature (closed distal femoral physis on radiograph and/or MRI), or had a lack of appropriate imaging. Reasons for radiographic/MRI examination in the control group include knee pain (n = 12), meniscal injury (n = 6), cruciate ligament injury (n = 4), and osteochondritis dissecans (n = 5).

Radiographic examination included AP, 30° lateral, and Merchant views of the knee. MR axial imaging was performed using a 1.5-T Signa Scanner (GE Healthcare) or a 1.5-T Symphony System (Siemens Medical Solutions). An MRI protocol with axial, sagittal, and coronal proton density; proton density fat saturation; and T1-weighted sequences was employed. MR slice thickness was 4.0 mm in 62 subjects and 5.0 mm in 1 subject. Patients were evaluated with the knee in full extension. Two board-certified orthopaedic surgeons, blinded to the underlying reason for the radiographic studies, reviewed and measured/classified all available films.

Radiographic Analysis

All knee radiographs of the affected extremity for each patient were evaluated. The initial assessment was made to determine whether the lateral radiograph was adequate. An adequate lateral radiograph was defined as one in which both the posterior and distal aspects of the medial and lateral femoral condyles were superimposed or had less than 2 mm separation, as measured using the picture archiving and communication system (PACS).

The absence or presence and severity of trochlear dysplasia was classified according to the Dejour classification (Figure 1) using the first adequate lateral radiograph. If no adequate lateral radiograph was taken, that subject was not given a radiographic Dejour classification.

MRI Analysis

The MRIs were also examined in a blinded fashion. All classifications and measurements were made utilizing the first axial cut of the distal femur, beginning proximally, with complete cartilage coverage of the trochlea. This image was chosen over an arbitrary distance (3 cm) from the tibiofemoral joint because it was felt to be more reproducible in skeletally immature patients with a large variation in height and femur size. The following outlines the measurements/classifications obtained from the MRI examinations:

1. The absence or presence and severity of trochlear dysplasia was classified according to the Dejour classification types A to D.

2. Femoral width was measured on axial imaging recording maximum medial to lateral dimension, as previously described.

3. LTI was measured, modifying the technique previously described by Carrillon et al as the angle formed from a line drawn parallel to the posterior femoral condyles and a second line drawn parallel to the articular surface of the lateral trochlear facet (Figure 2).

4. Modification of the technique previously described by Pfirrmann et al was used to determine the TDI. A line parallel to the posterior femoral condyles was drawn and made to intersect the lowest point of the trochlea. Utilizing this line, the heights of the (a) medial and (b) lateral trochlear facets were then measured utilizing a line drawn perpendicular to the previous line drawn.
through the trochlea. In normal and mildly dysplastic knees the site of measurement for height (a) remains the highest aspect of the medial condylar cartilage. In severe trochlear dysplasia (Dejour D), the point at the medial aspect of the cliff where the cartilage ended was chosen as the reference point for the medial height. The TDI was then calculated with the equation \((a + b)/2\), as depicted in Figure 2.

5. The medial condyle trochlear offset (MCTO) was recorded using value \(a\) from the aforementioned equation for TDI. This is a measurement, positive or negative, of the medial trochlear facet height from the line drawn parallel to the posterior bony femoral condyles that directly intersects the floor of the trochlear groove. In cases of severe trochlear dysplasia with significant medial femoral condyle hypoplasia, this may represent a negative value. In these severe cases, the medial measurement point can be challenging to identify. We therefore draw a second line perpendicular to the posterior condyle line and parallel to and touching the medial wall of the posterior notch. The medial measurement point is where this line intersects the articular cartilage or bone if cartilage is not present (Figure 2).

6. TT-TG distance was measured on MRI as previously described by Schoettle et al. The deepest point of the trochlear groove was identified, and a line was drawn perpendicular to the posterior condylar line through this point. The distance between this line and a parallel line drawn through the central point of the tibial tubercle was recorded.

In cases with 2 MRIs, the first MRI was used for primary analysis. The radiographic and MRI results from the 2 blinded readers were evaluated for intra- and interobserver reliability. The intraobserver reliability measurements were conducted more than 1 month apart.
Basic descriptive statistics were reported. The intraclass correlation coefficient (ICC) was used for continuous data and kappa statistic for categorical data to evaluate intra- and interobserver reliability. In the radiographic Dejour classification, there was a single recorded instance of classification D among the 2 observers and the 2 time periods. This subject was dropped to perform the intra- and interobserver reliability for the radiographic Dejour classification system. The Shapiro-Wilk test of normality and Levene test of homogeneity of variances were performed for continuous data. Analysis of variance (ANOVA) or Kruskal-Wallis and Mann-Whitney tests were used to determine differences in continuous data. Pearson chi-square and Fisher exact tests were used to evaluate differences in proportions of stable/unstable knees among various groups of classifications. Pearson correlation and simple linear regression analysis were used to evaluate relationships among various classification systems. Repeated-measures ANOVA and the Wilcoxon signed-ranks test were used to evaluate changes over time in subjects who had more than 1 MRI. All statistics were calculated using SPSS (version 12; IBM Corp), with statistical significance defined as $P < .05$.

**RESULTS**

There were 36 subjects in the instability group and 27 subjects in the stable group. Descriptive demographic information on the entire cohort is listed in Table 1. The instability group had nearly equal numbers of males and females; the stable group had more males. The difference in proportion of males to females between the 2 groups approached statistical significance ($P = .067$). Six patients had bilateral involvement, and both knees were included in the study. The 63 patients meeting the inclusion criteria had a total of 161 knee radiographic examinations that were reviewed, of which only 35 (22%) were found to have an adequate lateral radiograph allowing them to be classified using the Dejour classification. Forty-two percent (15/36) of subjects in the unstable group and 37% of subjects in the stable group had at least 1 adequate lateral radiograph that could be used for the radiographic Dejour classification.

The inter- and intraobserver reliabilities for each classification system are listed in Table 2. The MRI Dejour classification was found to have the poorest inter- and intraobserver reliabilities of all classifications/measurements. Inter- and intraobserver reliabilities were greater than 0.85 for MCTO, TDI, and LTI.

![Figure 2. Sample measurements taken from a normal knee, a patient with mild dysplasia, and a patient with severe dysplasia. $a$, medial condyle trochlear offset; $c$, lateral trochlear inclination; trochlear depth index = $(a + b)/2$. In severe cases, a second line (blue), perpendicular to the posterior condyle and parallel to and touching the medial wall of the posterior notch, can be drawn to help with measurement. The medial measurement point is where this line intersects the articular cartilage or bone if cartilage is not present.](https://example.com/figure2.png)
Based on the radiographic Dejour classification, no patient in the control group had evidence of trochlear dysplasia. In the patellar instability group, 7% had no trochlear dysplasia, 20% had grade A dysplasia, 27% had grade B dysplasia, 20% had grade C dysplasia, and 27% had grade D dysplasia. Sixty percent of subjects in this study never had a lateral radiograph that could be used to assess the radiographic Dejour classification. By comparison, 100% of subjects could be classified using the MRI Dejour classification. Based on the MRI Dejour classification, 63% of patients with no patellar instability had normal knees, whereas the rest of the cohort (37%) had grade A dysplasia. In the patellar instability group, 6% of patients had no trochlear dysplasia, 19% had mild dysplasia (grade A), and 75% had more severe dysplasia (grades B-D) (Table 3).

When analyzed as normal or mild dysplasia (Dejour A) compared with severe dysplasia (Dejour B-D), we found the radiograph Dejour classification to correctly identify patellar instability with 100% specificity and 73% sensitivity for the entire cohort. Positive (PV+) and negative (PV-) predictive values of the radiograph Dejour classification for the entire cohort were 100% and 71%, respectively. When the cohort was divided into males and females, the radiograph Dejour classification correctly identified patellar instability with 63% sensitivity in males and 86% sensitivity in females. Similarly, the MRI Dejour classification correctly identified patellar instability with 100% specificity and 75% sensitivity for the entire cohort (PV+, 100%; PV−, 75%). When the cohort was divided into males and females, the MRI Dejour classification correctly identified patellar instability with 70% sensitivity in males and 81% sensitivity in females.

All MRI measurements, except femur width (P = .594), were significantly different between the patellar instability group and the control group (P < .001) for the entire cohort (Figure 3 and Table 4). Female patients, independent of a known history of patellar instability, were found to have significantly decreased femoral width (P < .001), TDI (P = .03), and LTI (P = .034) when compared with male patients. There was a significant direct correlation between MCTO, TDI, and LTI (P < .001), and all were significantly inversely correlated to TT-TG distance (P < .005). This correlation was maintained when subjects were divided by sex for all correlations except TT-TG and LTI in female subjects (Table 5).

Table 6 describes the sensitivities and specificities for the objective MRI measurements. LTI ≤11°, as described by Carillon et al, was the most specific at 96% but only 50% sensitive for patellar instability. Both TT-TG ≥13 mm and MCTO ≤1 mm were found to be highly specific and fairly sensitive for patellar instability, both with values of 93% and 75%, respectively. Patients with either TT-TG ≥13 mm

### Table 2

| Classification | Interobserver Reliability | Intraobserver Reliability |
|----------------|---------------------------|---------------------------|
|                | ICC/κ | Lower | Upper | P    | ICC/κ | Lower | Upper | P    |
| MCTO           | 0.857 | 0.706 | 0.932 | <.001 | 0.95  | 0.867 | 0.982 | <.001 |
| TDI            | 0.928 | 0.851 | 0.966 | <.001 | 0.976 | 0.934 | 0.992 | <.001 |
| LTI            | 0.944 | 0.882 | 0.974 | <.001 | 0.926 | 0.803 | 0.973 | <.001 |
| MRI Dejour     | 0.687 | 0.497 | 0.887 | <.001 | 0.596 | 0.3   | 0.892 | <.001 |
| Radiograph Dejour<sup>a</sup> | 0.839 | 0.678 | 1     | <.001 | 0.819 | 0.603 | 1     | <.001 |

<sup>a</sup>ICC, intraclass correlation coefficient; LTI, lateral trochlear inclination; MCTO, medial condyle trochlear offset; MRI, magnetic resonance imaging; TDI, trochlear depth index.

<sup>b</sup>One observer had a single instance of a “D” classification, which was dropped to perform analysis.

### Table 3

| Radiograph Dejour | MRI Dejour |
|-------------------|------------|
|                   | All (n = 25) | Male (n = 16) | Female (n = 9) | All (n = 63) | Male (n = 41) | Female (n = 22) |
|                   | Unstable (n = 15) | Stable (n = 10) | Unstable (n = 8) | Stable (n = 8) | Unstable (n = 36) | Stable (n = 27) |
| Normal            | 1 (7) | 10 (100) | 1 (13) | 8 (100) | 0 (0) | 2 (100) | 2 (6) | 17 (63) | 1 (5) | 12 (57) | 1 (6) | 5 (83) |
| A                 | 3 (20) | 0 (0) | 2 (25) | 0 (0) | 1 (14) | 0 (0) | 7 (19) | 10 (37) | 5 (25) | 9 (43) | 2 (13) | 1 (17) |
| B                 | 4 (27) | 0 (0) | 2 (25) | 0 (0) | 2 (29) | 0 (0) | 14 (39) | 0 (0) | 9 (45) | 0 (0) | 5 (31) | 0 (0) |
| C                 | 3 (20) | 0 (0) | 0 (0) | 0 (0) | 3 (43) | 0 (0) | 12 (33) | 0 (0) | 5 (25) | 0 (0) | 7 (44) | 0 (0) |
| D                 | 4 (27) | 0 (0) | 3 (38) | 0 (0) | 1 (14) | 0 (0) | 1 (3) | 0 (0) | 0 (0) | 0 (0) | 1 (6) | 0 (0) |

<sup>a</sup>Data are presented as n (%). MRI, magnetic resonance imaging.

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or MCTO ≤1 mm were 37.5 times more likely to have patellar instability than those with TT-TG <13 mm or MCTO >1 mm. When TT-TG ≥13 mm and MCTO ≤1 mm were both present, no cases of patellar instability were missed, but the sensitivity was noted to decrease to 64%. Utilizing a cutoff of ≤3, as described by Skelley et al, TDI was found to be the most sensitive indicator of patellar instability (81%). Skeletally immature patients having a TDI ≤3 were 33.1 times more likely to have patellar instability than those with a TDI >3.

Sixteen subjects had 2 MRIs (8 males, 8 females). The mean time between MRIs was 22.4 ± 15.8 months (range, 5.3-62.1 months). There were no significant differences in MCTO, TDI, or LTI from time 1 to time 2 (Table 7).

Figure 3. Box plots showing the medial condyle trochlear offset (MCTO), tibial tubercle–trochlear groove (TT-TG), trochlear depth index (TDI), and lateral trochlear inclination (LTI) measurements for control and patellar instability patients. Bottom of box = 25th percentile; circles outside of range, outliers; dashed line, cutoff value; top of the box, 75th percentile; thick black line, median; thin black line, range.
DISCUSSION

In the present study, trochlear dysplasia was identified in 93% of skeletally immature patients with patellar instability based on the radiographic Dejour classification. The current study, however, identified several limitations of applying this classification. First, relatively few “adequate” lateral radiographs, defined as near perfect overlap (within 2 mm) of the distal and posterior femoral condyles, were obtained. Using this criterion, only 22% of the 161 lateral radiographs reviewed were “adequate,” limiting the applicability of this classification. Obtaining additional radiographic views or using fluoroscopy to obtain an “adequate” radiograph, while possible, is often impractical in the clinical setting and exposes the patient to additional radiation. Another limitation of this classification is that it becomes less reliable in younger patients who have incomplete ossification of the trochlea and femoral condyles. In our experience, this is particularly true in patients under the age of 10 years (Figure 4).

Recent attention has focused on axial imaging for the assessment of trochlear dysplasia. The Dejour classification

| Table 4 | MRI Measurement for Stable Versus Unstable Knees<sup>a</sup> |
|---------|-----------------|
|         | All Male Female | All Male Female | All Male Female |
| **TT-TG, mm** | | | |
| Stable | 9.6 ± 3 3.4 to 16.6 | 9.5 ± 3.2 3.4 to 16.6 | 9.9 ± 2.1 6.5 to 11.8 |
| Unstable | 16.2 ± 6 3.3 to 29.3 | 17.4 ± 7.2 3.3 to 29.3 | 14.7 ± 3.6 6.9 to 21.4 |
| **Femur width, mm** | | | |
| Stable | 75.6 ± 8.4 54.4 to 88.6 | 78.7 ± 5.7 68.6 to 88.6 | 64.9 ± 7.7 54.4 to 77.2 |
| Unstable | 74.6 ± 6.7 63.2 to 90.2 | 78.5 ± 5.7 69.0 to 90.2 | 69.7 ± 4.2 63.2 to 80.1 |
| **TT-TG ratio** | | | |
| Stable | 0.13 ± 0.04 0.04 to 0.22 | 0.12 ± 0.04 0.04 to 0.22 | 0.15 ± 0.03 0.11 to 0.21 |
| Unstable | 0.22 ± 0.07 0.05 to 0.37 | 0.22 ± 0.09 0.05 to 0.37 | 0.21 ± 0.05 0.1 to 0.28 |
| **MCTO, mm** | | | |
| Stable | 2.9 ± 1.3 0.5 to 5.3 | 3.0 ± 1.3 0.5 to 5.3 | 2.7 ± 1.2 0.8 to 3.9 |
| Unstable | −0.1 ± 2.3 −7.6 to 6.4 | −0.1 ± 2.5 −7.6 to 3.6 | −0.1 ± 1.9 −2.9 to 4.6 |
| **TDI, mm** | | | |
| Stable | 4.5 ± 1.2 2.5 to 6.4 | 4.7 ± 1.2 2.7 to 6.4 | 3.8 ± 0.9 2.5 to 4.5 |
| Unstable | 1.5 ± 1.9 −3.8 to 6.1 | 1.7 ± 2.1 −3.8 to 6.1 | 1.3 ± 1.7 1.5 to 4.9 |
| **LTI, deg** | | | |
| Stable | 19.7 ± 3.9 11 to 29 | 19.9 ± 4.3 11.0 to 29.0 | 18.8 ± 2.0 16.0 to 22.0 |
| Unstable | 12.3 ± 6.7 0 to 25 | 13.5 ± 6.4 4.0 to 25.0 | 10.8 ± 7.0 0.0 to 23.0 |

<sup>a</sup>Boldfaced P values indicate statistical significance between stable and unstable knees. LTI, lateral trochlear inclination; MCTO, medial condyle trochlear offset; TDI, trochlear depth index; TT-TG, tibial tubercle–trochlear groove.

| Table 5 | Correlations Among Classification Systems<sup>a</sup> |
|---------|-----------------|
|         | TDI Male Female | LTI Male Female | TT-TG Male Female |
| **MCTO** | | | |
| r | 0.923 0.891 0.927 | 0.622 0.590 0.612 | −0.585 −0.626 −0.601 |
| P | <.001 <.001 <.001 | <.001 <.001 <.001 | <.001 <.001 <.001 |
| **TDI** | | | |
| r | — — — | 0.833 0.825 0.846 | −0.593 −0.662 −0.530 |
| P | — — — | <.001 <.001 <.001 | <.001 <.001 <.001 |
| **LTI** | | | |
| r | — — — | — — — | −0.374 −0.445 −0.284 |
| P | — — — | — — — | .003 .004 .2 |

<sup>a</sup>Boldfaced values indicate statistical significance. LTI, lateral trochlear inclination; MCTO, medial condyle trochlear offset; TDI, trochlear depth index; TT-TG, tibial tubercle–trochlear groove.
has been modified so that it can be applied to MRI. We found that the MRI modification of the Dejour classification had suboptimal reliability. Lippacher et al\textsuperscript{12} had similar findings. When the MRI Dejour classification is simplified from a 4-part to a 2-part classification system, in an attempt to differentiate mild and severe trochlear dysplasia, it has been shown to have better reproducibility.\textsuperscript{12} This was also found to be true in our population of skeletally immature patients where the simplified 2-part classification was 75\% sensitive and 100\% specific for identifying patients with patellar instability.

Because of the limitations of both the radiographic and MRI Dejour classifications, more objective measurements of trochlear dysplasia have been developed.\textsuperscript{2,16} These include the TDI as well as the LTI. Both of these tools provide objective measurements that have been shown by their describing authors to be highly sensitive and specific for detecting trochlear dysplasia. Carrillon et al\textsuperscript{2} demonstrated that an LTI $\leq$11$^\circ$ was 93\% sensitive and 87\% specific for identifying patellar instability, and in severe trochlear dysplasia, an LTI $<$0$^\circ$ can be visualized. In our skeletally immature population, this 11$^\circ$ threshold was also highly specific at 96\% but had poorer sensitivity at 50\%. This relatively low sensitivity may indicate that different thresholds are required in patients with continued growth potential. A better cutoff in the skeletally immature patient population is closer to 17$^\circ$, as shown by our data. As far as the TDI, Pfirrmann et al\textsuperscript{16} demonstrated that with a cutoff of $\leq$3 mm, TDI was highly sensitive (100\%) and specific (96\%) for the presence of trochlear dysplasia. Our study demonstrates that TDI can also be utilized with relatively high sensitivity (81\%) and specificity (89\%) in correctly identifying patellar instability in skeletally immature patients.

A hallmark feature of trochlear dysplasia is hypoplasia of the medial femoral condyle.\textsuperscript{1} We believe this occurs because the patella never fully engages the medial femoral condyle during embryologic or early skeletal development. Based on Wolff's law, without appropriate pressure, the trochlea fails to fully develop and ossify. A similar phenomenon is seen in acetabular dysplasia, where the femoral head is not fully

| TABLE 6 |
|-------------------------|
| **Sensitivity and Specificity for Each Classification System$^a$** |
|                         | All     | Male | Female |
|-------------------------|---------|------|--------|
| Specificity            | Sensitivity | PV+ | PV−  | Specificity | Sensitivity | PV+ | PV−  | Specificity | Sensitivity | PV+ | PV−  |
| LTI $\leq$11$^\circ$   | 96      | 50   | 95    | 59      | 95      | 50   | 91    | 67      | 100      | 50   | 100   | 43   |
| TT-TG $\geq$13 mm      | 93      | 75   | 93    | 74      | 90      | 75   | 88    | 79      | 100      | 75   | 100   | 60   |
| MCTO $\leq$1 mm        | 93      | 75   | 93    | 74      | 95      | 70   | 93    | 77      | 83       | 81   | 93    | 63   |
| TDI $\leq$3 mm         | 89      | 81   | 91    | 77      | 90      | 75   | 88    | 79      | 83       | 88   | 93    | 71   |
| TT-TG $\geq$13 mm and MCTO $\leq$1 mm | 100 | 64   | 100   | 68      | 100     | 60   | 100   | 72      | 100      | 69   | 100   | 55   |

$^a$Data are presented as percentages. LTI, lateral trochlear inclination; MCTO, medial condyle trochlear offset; PV, predictive value; TDI, trochlear depth index; TT-TG, tibial tubercle–trochlear groove.

| TABLE 7 |
|-------------------------|
| **Measurement Change From Time 1 to Time 2$^a$** |
|                          | Mean $\pm$ SD | Range     | $P$  |
|-------------------------|---------------|-----------|------|
| MCTO, mm                |               |           | .451 |
| Time 1                  | 1.2 $\pm$ 2.2 | $-2.9$ to $4.6$ |      |
| Time 2                  | 0.9 $\pm$ 2   | $-3$ to $4.6$ |      |
| TDI, mm                 |               |           | .071 |
| Time 1                  | 2.8 $\pm$ 2   | $-1.45$ to $5.85$ |      |
| Time 2                  | 2.5 $\pm$ 1.9 | $-1.5$ to $5.6$ |      |
| LTI, deg                |               |           | .718 |
| Time 1                  | 14.5 $\pm$ 7.5 | 0 to 25  |      |
| Time 2                  | 14.6 $\pm$ 7.3 | 0 to 24  |      |

$^a$Sixteen subjects had 2 magnetic resonance images; sex distribution was equal. LTI, lateral trochlear inclination; MCTO, medial condyle trochlear offset; TDI, trochlear depth index.

Figure 4. Lateral radiograph of a skeletally immature patient showing the challenges of accurately assessing the required features of the radiographic Dejour classification.
seated in the acetabulum leading to its lack of development. The hypoplasia of the medial femoral condyle (MFC) helps explain the key features that are seen both on the radiographic Dejour classification as well as the MRI Dejour classification. With increasing severity of trochlear dysplasia, there is progressive medial femoral condylar hypoplasia. Radiographically, this manifests as a crossover sign in milder forms of trochlear dysplasia where the floor of the trochlea crosses over the highest point of the MFC. In more advanced forms of trochlear dysplasia, a double contour is appreciated such that the trochlea lies significantly anterior to the hypoplastic MFC. Finally, with the most severe trochlear dysplasia, a “cliff-like drop-off” is present because there is no appreciable MFC. In reviewing many of our skeletally immature knees, we found that the height of the MFC relative to the floor of the trochlea is the most distinguishing feature between normal, mild, and severe trochlear dysplasia. That is why we are proposing a new measurement that focuses on the MFC–trochlear floor offset (MCTO). This simple measurement requires no formula, is reproducible, and adequately discriminates between patients with patellar instability and those with no instability.

Another key risk factor for patellar instability is an elevated TT-TG distance.\(^5,8,19\) In skeletally immature patients with no history of patellar instability, the mean TT-TG was 12 mm, compared with 16 mm for patients with a history of patellar instability.\(^15\) Based on these findings, some authors have suggested that a TT-TG of greater than 15 or 20 mm is an indication for a tubercle transfer.\(^5,9\) An association between trochlear dysplasia and an elevated TT-TG, while intuitive, has yet to be established. Our results show a direct correlation between TT-TG and the MRI Dejour classification. As TT-TG increases, the MRI Dejour grade also increases in severity. Additionally, MCTO was found to be inversely correlated with TT-TG. For every millimeter decrease in MCTO, the TT-TG increased by 4.2 mm. Whether this is purely a correlation or an etiologic relationship remains to be seen. It seems plausible though that significant elevations of the TT-TG will result in the lateral offset of the patella relative to the trochlea. If this is true, particularly in utero or early in skeletal development, the MFC may not receive appropriate pressure and signals to develop, which could predispose to trochlear dysplasia. Further studies will be necessary to clarify this potential link. While a reasonable estimate can be made at the TT-TG by assessing the MCTO, it is not clear whether the MCTO in isolation can be used as a tool for determining the need for any bony treatment such as a tibial tubercle osteotomy when managing patients with patellar instability.

Another important consideration in skeletally immature patients is whether these measurements of trochlear dysplasia change as a function of age and skeletal maturity. Recent studies have suggested that trochlear dysplasia occurs early in development, possibly in utero.\(^10,14\) This may suggest that trochlear dysplasia does not change significantly during the adolescent period when patients are reaching their peak growth rate. We therefore looked at all of our patients who had multiple MRIs (n = 16; 10 unstable, 6 stable) to see how these measurements are changing as a function of age and skeletal maturity. Across different time points, trochlear dysplasia measurements remained constant. We therefore think that these measurements can be used regardless of patient age or maturity since significant changes do not occur along the age spectrum when most cases of patellar instability develop. However, we recognize that the current study may not have sufficient power to answer this question.

There are several limitations to this study. First, our patellar instability cohort was identified from a series of patients who had undergone surgical stabilization, so this may have led to a selection bias as our chosen instability group likely represents a more severe form of patellar instability compared with those with milder forms of patellar instability. Additionally, a greater percentage of our instability patients were female compared with the control group. How these may affect the specificity and sensitivity calculations used in this study is unclear. A second limitation is that while our control patients did not have a history of any patellofemoral symptoms, they underwent an MRI to evaluate other knee pathology. It is unclear whether these other pathologies have an association with trochlear dysplasia and affect the measurements used in this study. Potentially, a better cohort would be asymptomatic knee subjects. For cost reasons, this was prohibitive for this study, but it could be considered in the future.

**CONCLUSION**

Trochlear dysplasia is a significant risk factor for patellar instability in skeletally immature patients and was present in nearly all of our patellar instability patients. The clinical utility of the 4-grade Dejour classification, given the difficulty in obtaining adequate films and the variable interpretation of these images, necessitates a simplified approach of grading trochlear dysplasia on MR axial imaging. The objective measurements of TDI, LTI, and MCTO are easy to measure, reproducible, and correlate well with patellar instability, making them a valuable assessment tool for trochlear dysplasia in the skeletally immature. While the focus of this study was not geared toward clinical outcomes, future studies will be necessary to see how these measurements should be optimally utilized in dictating treatment and surgical planning for patients with trochlear dysplasia and patellar instability.

**REFERENCES**

1. Biedert RM, Bachmann M. Anterior-posterior trochlear measurements of normal and dysplastic trochlea by axial magnetic resonance imaging. *Knee Surg Sports Traumatol Arthrosc.* 2009;17:1225-1230.
2. 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.

3. Dejour D, Le Coulter B. Osteotomies in patello-femoral instabilities. Sports Med Arthrosc. 2007;15:39-46.

4. Dejour D, Saggin P. The sulcus deepening trochleoplasty—the Lyon’s procedure. Int Orthop. 2010;34:311-316.

5. Dejour H, Walch G, Nove-Josserand L, Guiet C. Factors of patellar instability: an anatomic radiographic study. Knee Surg Sports Traumatol Arthrosc. 1994;2:19-26.

6. Düppe K, Gustavsson N, Edmonds EW. Developmental morphology in childhood patellar instability [published online June 5, 2015]. J Pediatr Orthop. doi:10.1097/BPO.0000000000000556.

7. Fithian DC, Paxton EW, Stone ML, et al. Epidemiology and natural history of acute patellar dislocation. Am J Sports Med. 2004;32:1114-1121.

8. Fulkerson JP. Anteromedialization of the tibial tuberosity for patellofemoral malalignment. Clin Orthop Relat Res. 1983;177:176-181.

9. Koëter S, Diks MJF, Anderson PG, Wymenga AB. A modified tubercle osteotomy for patellar maltracking: results at two years. J Bone Joint Surg Br. 2007;89:180-185.

10. Kohlhof H, Heidt C, Bähler A, et al. Can 3D ultrasound identify trochlea dysplasia in newborns? Evaluation and applicability of a technique. Eur J Radiol. 2015;84:1159-1164.

11. Lewallen LW, McIntosh AL, Dahm DL. Predictors of recurrent instability after acute patellofemoral dislocation in pediatric and adolescent patients. Am J Sports Med. 2013;41:575-581.

12. Lippacher S, Dejour D, Elsharkawi M, et al. Observer agreement on the Dejour trochlear dysplasia classification: a comparison of true lateral radiographs and axial magnetic resonance images. Am J Sports Med. 2012;40:837-843.

13. Nelitz M, Lippacher S, Reichel H, Dornacher D. Evaluation of trochlear dysplasia using MRI: correlation between the classification system of Dejour and objective parameters of trochlear dysplasia. Knee Surg Sports Traumatol Arthrosc. 2014;22:120-127.

14. Øye CR, Holen KJ, Foss OA. Mapping of the femoral trochlea in a newborn population: an ultrasonographic study. Acta Radiol. 2015;56:234-243.

15. Pennock AT, Alam M, Bastrom T. Variation in tibial tubercle–trochlea groove measurement as a function of age, sex, size, and patellar instability. Am J Sports Med. 2014;42:389-393.

16. Pfirrmann CW, Zanetti M, Romero J, Hodler J. Femoral trochlear dysplasia: MR findings. Radiology. 2000;216:858-864.

17. Rémy F, Chantelet C, Fontaine C, Demondion X, Migaud H, Gougeon F. Inter- and intraobserver reproducibility in radiographic diagnosis and classification of femoral trochlear dysplasia. Surg Radiol Anat. 1998;20:285-289.

18. 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.

19. Skelley N, Friedman M, McGinnis M, Smith C, Hillen T, Matava M. Inter- and intraobserver reliability in the MRI measurement of the tibial tubercle–trochlear groove distance and trochlea dysplasia. Am J Sports Med. 2015;43:873-878.

20. Steensen RN, Bentley JC, Trinh TQ, Backes JR, Wiltfong RE. The prevalence and combined prevalences of anatomic factors associated with recurrent patellar dislocation: a magnetic resonance imaging study. Am J Sports Med. 2015;43:921-927.