Original article

Tibial tubercle torsion, a new factor of patellar instability

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A B S T R A C T

Introduction: External torsion of the anterior tibial tubercle (TT), defined as external rotation around a craniocaudal axis with respect to the posterior femoral condylar plane, may induce patellar instability. To our knowledge no studies have focused on this parameter. The present study aimed to perform an MRI analysis of TT torsion. The study hypothesis was that TT torsion correlates with patellar instability and with 3 of its components: tibial tubercle-trochlear groove (TT-TG) distance, axial engagement index of the patella (AEI), and patellar tilt.

Material and methods: Four observers performed MRI measurements for 2 groups: 37 patellar instability patients (PI group) with history of at least 2 patellar dislocations, and 50 control patients with meniscal lesion but free from patellofemoral pathology. All measurements were taken from 2 axial slices with the posterior condylar plane as reference.

Results: The intra-class correlation coefficient (ICC) was 0.88. TT torsion correlated with patellar instability, with a mean 5.8° in controls and 17.9° in the PI group (P < 0.001). There were also excellent correlations between TT torsion and TT-TG distance, patellar tilt and patellar lateralization (measured by AEI), with correlation coefficients greater than 0.85.

Discussion: TT torsion is a reproducible measurement, with excellent ICC. It is significantly correlated with patellar instability, with a discrimination threshold of 11.5°, and correlations with all 3 components of instability. These statistical correlations enable TT torsion to be added to the list of patellar instability factors. Further studies should determine its biomechanical role and assess the contribution of associating TT derotation to medialization or distalization procedures.

Level of evidence: III; case-control study.

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1. Introduction

Screening for patellar instability factors is essential for assessment and surgical treatment of recurrent patellar dislocation. Some are authentic risk factors [1]: such is the case of excessive lateralization of the anterior tibial tubercle (TT), measured as tibial tubercle-trochlear groove (TT-TG) distance [2]. TT positioning is characterized not only by this transverse lateralization but also by tilt due to external torsion around a craniocaudal axis. Such torsion is observed intraoperatively, and merits dedicated study. We measured TT torsion angle with respect to the posterior femoral condylar plane. Although the literature on the TT is abundant, we found no references for TT torsion measurement. The main objective of the present study were therefore to describe a reproducible measurement and assess its correlation with patellar instability. The secondary objective was to assess correlation with 3 parameters of patellar instability: TT-TG distance, which is a factor of instability, and the axial engagement index (AEI) of the patella and patellar tilt, which are consequences of rather than factors for instability [1]. The study hypothesis was that TT torsion correlates with patellar instability and with the 3 above-mentioned parameters.

2. Material and methods

2.1. Materials

A retrospective case-control analytic study of MRIs taken between 2011 and 2016 comprised 2 groups of patients:
Table 1
Description of the 2 groups.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Control group (n = 55)</th>
<th>PI group (n = 37)</th>
<th>Total (n = 92)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>19 (34.5%)</td>
<td>23 (62.2%)</td>
<td>42 (45.7%)</td>
</tr>
<tr>
<td>Male</td>
<td>36 (65.5%)</td>
<td>14 (37.8%)</td>
<td>50 (54.3%)</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>46.0 (14.0)</td>
<td>28.6 (10.7)</td>
<td>39.0 (15.4)</td>
</tr>
<tr>
<td>Median [IQR]</td>
<td>46.0 [35.0; 54.0]</td>
<td>26.0 [20.0; 36.0]</td>
<td>37.5 [26.0; 48.2]</td>
</tr>
<tr>
<td>Range</td>
<td>17.0–77.0</td>
<td>15.0–56.0</td>
<td>15.0–77.0</td>
</tr>
</tbody>
</table>

SD: standard deviation; IQR: interquartile range; PI: patellar instability.

• thirty-seven with patellar instability (PI group), the inclusion criterion being history of at least 2 proven patellar dislocations, and the exclusion criterion being history of patellofemoral surgery;

• fifty-five control patients, seen in consultation, the inclusion criterion being meniscal lesion on MRI, and the exclusion criterion being history of patellar or ligament lesion or osteoarthritis.

The 2 groups differed in age and gender, mean age being 29 years in the PI group and 46 years for controls, with respectively 62% and 35% of females (Table 1).

Radiographs were not available.

MRIs were performed in different centers. Knee position was not specified. Imaging comprised proton-density fat-sat axial sequences, with slice thickness varying between 3 and 4 mm.

2.2. Measurements

Four measurements were made, on 2 different axial slices.

The first was TT external torsion (Fig. 1). On the first slice, femoral, chosen where the posterior cortex of the femoral condyles was clearest, the tangent through the posterior condyles was drawn. The second slice was tibial, at the complete insertion of the patellar tendon onto the TT. The TT landmarks were tendinous: the 2 lateral edges of the patellar tendon. TT torsion angle was measured between the posterior condylar line (copied onto the tibial slice) and the line through the TT landmarks.

Three other measurements were taken (Fig. 2):

• TT-TG distance, using the same tibial axial slice as for TT torsion, with the same patellar tendon edge landmarks. The tip of the TT was placed equidistantly between the two landmarks. The trochlear groove was taken on the most proximal slice on which it was identifiable;

• AEI [3] used the patellar slice on which the patella was widest and the trochlear slice on which the trochlear cartilage extended transversally outward the most. The index was the ratio between the length of the patellar cartilage projecting into the trochlea (TL) and the total patellar cartilage length (PL), and ranged between 0 (dislocated patella with no projection into the trochlea) and 1 (patella entirely within the trochlea). Using 2 slices, this measurement was always feasible, even in complete extension;

• patellar tilt [4] was defined as the angle between the long transverse patellar axis and the posterior condylar line.

Fig. 1. TT torsion measurement technique: (a) Femoral axial slice, enabling (b) drawing of posterior condylar line; c and d: axial slice through TT.

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2.3. Inter-observer study

Four observers performed measurements independently and secretly, but not blindly. The 3 orthopedic surgeons used Osirix® software, and the radiologist used her radiology department software (PhilipsPortal system).

2.4. Statistics

Statistical analysis used SAS® and R (CRAN) software. First-order alpha risk was set at 5%.

Quantitative variables were described by number (N), mean, standard deviation (SD), median and range, and qualitative variables by absolute (n) and relative frequency (%) for each class.

Inter-observer concordance was assessed by intra-class correlation coefficient (ICC), using Cicchetti’s criteria [5]: poor, <0.40; moderate, 0.40–0.59; good, 0.60–0.74; and excellent, ≥0.75.

Association between TT torsion and the other anatomic parameters was assessed by linear correlation coefficients.

The predictive value of TT torsion for patellar instability was assessed by logistic regression [6], modeling the probability of being in the PI group according to the various parameters; the estimators thus took the form of odds ratios (OR), expressing the size of the effect of the parameter on the probability of being in the PI group, with significance assessed on Wald test.

The discrimination capacity of the parameters was assessed by ROC curve, describing sensitivity and specificity. Parameters were compared by areas under the curve (AUC): the more discriminating, the greater the AUC [7]. At the outcome of analysis, a classification threshold was determined for PI group patients, with positive and negative predictive values.

3. Results

3.1. Intra-class correlation coefficient (ICC)

TT torsion showed a very good ICC, at 0.88 (95% CI: [0.82–0.91]) (Table 2). TT torsion and patellar tilt (0.92; 95% CI: [0.87–0.94]) had the best ICCs, followed by TT-TG distance (0.77) and AEI (0.75).

Given this level of agreement, mean values between the 4 observers were used for analysis.

3.2. Measurement results

Results are shown in Table 3.

Mean TT torsion differed significantly between groups: 5.8° for controls, and 17.9° for the PI group (P<0.001).

The distribution of TT torsion differed between groups, with few overlapping values (Fig. 3).

TT torsion correlated with TT-TG distance and patellar tilt (respectively, r = 0.87 and 0.85). Correlation with AEI was weaker (r = 0.64) (Table 4).

On univariate analysis (Table 5), TT torsion was significantly associated with instability (OR, 1.49), and the other 3 parameters (TT-TG distance, patellar tilt and AEI).

On multivariate analysis (Table 6), only TT torsion and patellar tilt were significantly associated with instability, mainly because of strong collinearity between TT torsion and TT-TG distance. A 10°

Table 3

<table>
<thead>
<tr>
<th>Variable</th>
<th>Control group (n = 55)</th>
<th>PI group (n = 37)</th>
<th>Total (n=92)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TT torsion (°)</td>
<td>Mean (SD)</td>
<td>5.8 (3.6)</td>
<td>17.9 (7.0)</td>
</tr>
<tr>
<td></td>
<td>Median [IQR]</td>
<td>5.3 [3.4; 8.4]</td>
<td>17.5 [13.0; 23.9]</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>–1.5 to 13.8</td>
<td>5.0 to 28.9</td>
</tr>
<tr>
<td>TT-TG distance (mm)</td>
<td>Mean (SD)</td>
<td>8.3 (3.1)</td>
<td>16.1 (4.8)</td>
</tr>
<tr>
<td></td>
<td>Median [IQR]</td>
<td>8.4 [6.7; 9.8]</td>
<td>17.0 [12.2; 20.1]</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>1.7 to 16.1</td>
<td>5.3 to 25.0</td>
</tr>
<tr>
<td>Patellar tilt (°)</td>
<td>Mean (SD)</td>
<td>5.5 (4.0)</td>
<td>20.9 (10.3)</td>
</tr>
<tr>
<td></td>
<td>Median [IQR]</td>
<td>5.3 [2.5; 8.2]</td>
<td>19.8 [13.8; 27.6]</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>–2.0 to 15.8</td>
<td>2.8 to 52.0</td>
</tr>
<tr>
<td>AEI</td>
<td>Mean (SD)</td>
<td>1.0 (0.0)</td>
<td>0.8 (0.2)</td>
</tr>
<tr>
<td></td>
<td>Median [IQR]</td>
<td>1.0 [0.9; 1.0]</td>
<td>0.8 [0.7; 0.9]</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>0.8 to 1.0</td>
<td>0.0 to 1.0</td>
</tr>
</tbody>
</table>

SD: standard deviation; IQR: interquartile range; PI: patellar instability; TT: tibial tubercle; TT-TG: tibial tubercle-trochlear groove; AEI: axial engagement index of the patella.

Table 2

<table>
<thead>
<tr>
<th>Measurement</th>
<th>ICC</th>
<th>95% CI</th>
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</thead>
<tbody>
<tr>
<td>TT torsion</td>
<td>0.88</td>
<td>(0.82–0.91)</td>
</tr>
<tr>
<td>TT-TG distance</td>
<td>0.77</td>
<td>(0.59–0.89)</td>
</tr>
<tr>
<td>Patellar tilt</td>
<td>0.92</td>
<td>(0.87–0.94)</td>
</tr>
<tr>
<td>AEI</td>
<td>0.75</td>
<td>(0.49–0.90)</td>
</tr>
</tbody>
</table>

TT: tibial tubercle; TT-TG: tibial tubercle-trochlear groove; AEI: axial engagement index of the patella.

Table 4

<table>
<thead>
<tr>
<th>Correlation</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>TT-TG distance</td>
<td>0.87</td>
</tr>
<tr>
<td>Patellar tilt</td>
<td>0.86</td>
</tr>
<tr>
<td>AEI</td>
<td>–0.64</td>
</tr>
</tbody>
</table>

TT: tibial tubercle; TT-TG: tibial tubercle-trochlear groove; AEI: axial engagement index of the patella; CI: confidence interval.

Fig. 2. Three parameters of patellar instability: a: TT-TG distance; b: axial MRI index of engagement of the patella; c: patellar tilt.
Table 5
Univariate model.

<table>
<thead>
<tr>
<th></th>
<th>Odds ratio</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TT torsion</td>
<td>1.49</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>TT-TG distance</td>
<td>1.60</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Patellar tilt</td>
<td>1.44</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>AEI</td>
<td>0.00</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Table 6
Final model with selected factors.

<table>
<thead>
<tr>
<th></th>
<th>Odds ratio</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td></td>
<td></td>
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<tr>
<td>TT torsion</td>
<td>1.27</td>
<td>0.040</td>
</tr>
<tr>
<td>Patellar tilt</td>
<td>1.33</td>
<td>0.011</td>
</tr>
<tr>
<td>AEI</td>
<td>0.00</td>
<td>0.006</td>
</tr>
</tbody>
</table>

Table 7
AUCs of ROC curves associated with each measurement.

<table>
<thead>
<tr>
<th></th>
<th>AUC</th>
<th>P-value (vs. TT torsion)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TT torsion</td>
<td>0.931</td>
<td></td>
</tr>
<tr>
<td>AEI</td>
<td>0.864</td>
<td>0.110</td>
</tr>
<tr>
<td>TT-TG distance</td>
<td>0.916</td>
<td>0.540</td>
</tr>
<tr>
<td>Patellar tilt</td>
<td>0.927</td>
<td>0.895</td>
</tr>
</tbody>
</table>

Fig. 3. Boxplot of TT torsion. Bottom to top: minimum (bottom of lower vertical), 1st quartile (25% of population: lower horizontal line), median (50% of population: middle horizontal line in box), 3rd quartile (75% of population: upper horizontal line), and maximum (100%) (top of upper vertical).

Fig. 4. ROC curve. Joint progression of parameter sensitivity and specificity.

4. Discussion

MRI measurement of TT torsion was reproducible (ICC, 0.88). It was feasible not only for a radiologist well practiced in on-screen measurement but also for orthopedic surgeons with little such experience.

TT torsion was closely correlated with patellar instability, confirming the main study hypothesis. It discriminated instability at a threshold of 11.5°, with 95% specificity and a positive predictive value of 91%. The predictive capacity for patellar instability (OR = 1.27, P < 0.05) was actually better than the 3 parameters of instability that were measured, with which it also correlated, and particularly with TT-TG distance.

Although TT torsion and TT-TG distance are correlated (r = 0.87), they provide different information. TT torsion is an orientation (external rotation around a craniocaudal axis), measured in degrees as the angle with the posterior condylar plane, whereas TT-TG distance is a linear measurement (in millimeters) of TT lateral positioning with respect to the trochlear groove.

Some authors use a similar but different measurement, TT rotation, which likewise correlates with patellar instability [8–11]. It measures not TT inclination with respect to a posterior plane but TT rotation around a center, the location of which varies from author to author (Fig. 5).

The association of these 3 positioning defects (TT torsion, TT-TG distance and TT rotation), all correlating with patellar instability, suggests a common origin: tibial torsion, which has long been measured between the superior tip of the tibia and the ankle. Laboureau et al. implicated metaphyseal torsion between the tibial plateau and the patellar tendon insertion in the onset of painful patellar syndrome, for which they recommended tibial tubercle derotation osteotomy [12]. Fouilleron et al. considered tibial torsion to be located proximally, indicating superior metaphyseal tibial derotation osteotomy [13]. It is easy to see how tibial torsion above the TT could induce torsion, lateralization and rotation in the TT [14].

The present study had certain limitations:

- MRI measurements were not blinded. However, this bias should not affect the results, as the inter-observer assessment was

increase in TT torsion multiplied the probability of instability 11-fold.

3.3. Diagnostic capacity: Threshold/sensitivity

Fig. 4 shows the ROC curve for each of the main parameters. The most discriminating was TT torsion, with AUC = 0.931 (Table 7). A threshold of 11.5° TT torsion showed 95% specificity and 81% sensitivity (positive predictive value, 91%; negative predictive value, 88%).
blinded and the correlations were excellent. Moreover, the statistical differences between groups were large;

- the two groups were not homogeneous for age and gender. However, like Steensen et al. [15] and Balcarek et al. [16], we found no evidence that the anatomic factors for instability change after bone maturity, unlike during growth [17]. Gender likewise seems not to affect knee rotation and tibial torsion [18], TT-TG distance [19,20] or Q angle [21];
- in the absence of radiographs, TT torsion could not be correlated to patellar height or trochlear dysplasia; Dejour et al.’s 4 dysplasia grades are radiological [22], and are used to assess dysplasia severity [23,24];
- variable knee flexion on MRI may have been a confounding factor. However, mean flexion on 2 sagittal slices was moderate and comparable between groups: 7.1° (SD, 5.8) in the PI group and 11.3° (SD, 6.5) in controls. This parameter was not significantly associated with patellar instability in the models;
- TT torsion was based on a tibiofemoral measurement and could be affected by intra-articular rotation of the knee, which would not be the case if the posterior landmark was tibial. To have the same reference plane as in the other measurements, however, we assessed TT torsion with respect to the femur rather than the tibia. It also seemed more appropriate for the purposes of assessing correlation with patellar instability, which is defined with reference to the femur. Finally, the tibial plateaux seem less precise as posterior MRI landmarks than the condylar landmarks used here.

TT torsion correlates with patellar instability and TT-TG distance (which is a factor of instability) and with AEI and patellar tilt. It is thus a new factor for patellar instability.

The present measurements demonstrated that TT external torsion extends upward as patellar tilt, showing torsion of the extensor system. The entire extensor system can be compared to belt, with the trochlea acting as pulley [12]. The unstable and misaligned patella loses contact with the dysplastic pulley due to lateral deviation of the TT, pulling it outward, and to TT torsion, pulling back the lateral edge of the patellar tendon. A biomechanical study is needed to determine the role of this TT torsion, and to assess the further stabilization that might be provided by associating TT derotation to medialization or distalization osteotomy.

Disclosure of interests

Service Orthopédie).S.M.: Statistician, paid by Ramsay Générale de Santé for this article. M.D.C., M.C., and J.LB declare that they have no competing interest.

References