Distal femur rotational alignment and patellar subluxation: A CT scan in vivo assessment

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Summary
Background: Patellofemoral instability following total knee arthroplasty is a very common complication which may result from a defective rotational positioning of the femoral component. However, rotational landmarks for optimal orientation are not unequivocal. Moreover, no proven correlation has yet been established between preexisting rotational malposition and patellofemoral instability occurrence.

Hypothesis: Any preexisting distal femoral rotational misalignment is associated with a preop patellofemoral instability in arthritic knees prior to undergoing arthroplasty. A prospective diagnostic study was conducted to test this hypothesis on the basis of morphometric data.

Material and methods: One hundred and eighteen patients were prospectively enrolled in this study. Patellar lateralization was measured on 30° flexion patellofemoral views. Three positionings were arbitrarily defined (less than 3 mm of lateralization, between 3 and 5 mm, over 5 mm). Three angles were preoperatively measured using CT scans: (1) the posterior condylar angle between posterior bicondylar axis and transepiphyseal axis, (2) the anterior trochlear angle between transepicondylar axis and trochlear opening plane, (3) the sum of anterior trochlear and posterior condylar angles finally formed the global trochlear opening angle.

Results: The patella was centered in 86 cases and lateralized in 32 cases (less than 5 mm in 25 cases and over 5 mm in seven cases). Independently from the degree of patellar lateralization, the global trochlear opening angle was constant \( p = 0.41 \). The value of the posterior condylar angle was statistically inferior when patella was centered \( p = 0.01; r = 0.44 \). The value of the anterior trochlear angle varied opposite to the posterior condylar angle. Femoral anteversion, position of the anterior tibial tuberosity and tibiofemoral index could not be correlated with patellar positioning. No relationship could be established between patellar lateralization and overall torsional deformities of the lower extremity.
Conclusion: The centering of the patella in arthritic knees depends on distal femoral osseous factors which determines the posterior condylar angle and anterior trochlear angle on either side of the transepicondylar axis. Since the trochlear opening angle is constant, the obliquity of the transepicondylar axis appears crucial in patellar lateralization. A better understanding of the influence of distal femoral morphology on patellar positioning will ensure improved positioning of femoral components in total knee arthroplasties or in isolated femoropatellar joint replacements.

Level of Evidence III: Prospective diagnostic study.

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Introduction

Many studies have demonstrated that enhanced patellofemoral kinematics depends on proper positioning of the femoral implant [1–5], more specifically in rotation. When an independent cutting technique is performed, rotation of the total knee prosthesis femoral component should be properly adapted to the torsion of the distal femur [4]. Torsion of the distal femur should be preoperatively determined by computed tomography (CT) scanning to accurately reproduce rotational positioning of the femoral component during surgery [4,5], since it may vary according to each patient’s specific anatomy [6]. Actually, when the patella is well centered before surgery, the aim of total knee arthroplasty is to maintain this centering whereas when the patella is initially lateralized, the aim of arthroplasty is therefore to restore its centering. The femoral rotation is one the main factors of this correction.

Our hypothesis is that distal femoral torsion increases in case of patellar subluxation. Within a population of arthritic knees, the purposes of this prospective study were:

- to assess the correlation between distal femoral torsion and preoperative patellar positioning for proper adaptation of the femoral implant rotation to the distal femoral torsion;
- to look for a relationship between the patellar positioning and the femoral anteversion, the distance between the anterior tibial tubercle and the trochlear groove (TTTG), the torsion of the lower limb.

Material and methods

Patients

This prospective study was conducted from November 2004 to June 2006. One hundred and eighteen patients, with osteoarthritic tibiofemoral joint, and ready for arthroplasty were enrolled (unicompartmental or total knee prosthesis). Thirty males and 88 females were included that is 61 right knees and 57 left knees. Mean patient age was 74 years (ranged 57 to 85 years).

Methods

Preoperative evaluation included AP radiographs of both knees in extension and weight bearing at 30° of flexion, lateral radiographs, and 30° flexion patellofemoral views. Analysis of patellar lateralization was performed using 30° flexion patellofemoral views. It corresponded to the distance (d) between two parallel lines, respectively passing through the trochlear groove and the patellar crest and running perpendicular to the trochlear opening plane. Three positionings were thus arbitrary defined according to the “d” value (less than 3 mm considered as centered patella, between 3 to 5 mm, over 5 mm). Patellar tilt and patellofemoral joint space narrowing were not taken into account (Fig. 1).

A spiral CT scan was systematically performed. Knees were positioned in neutral rotation and at 10° of knee flexion. The posterior condylar angle (PCA) was formed by the angle between the posterior bicondylar line tangent to the most posterior part of the condyles and the
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Figure 2  CT scan measurements. A: Posterior condylar angle (PCA) and anterior trochlear angle (ATA) measured by CT scan, which sum corresponds to the angle of the global trochlear angle (GTA). GTA = ATA + PCA. B: The diagram shows the different studied angles and their description. The anterior trochlear angle is formed by the angle between the tangent to the trochlear opening and the transepicondylar line. The PCA is formed by the transepicondylar axis and the tangent line to the posterior condyles. The PCA was positive by definition. The angle of trochlear opening corresponded to the sum of the PCA and the anterior trochlear angle.

Moreover, the femoral neck anteversion, the TTTG distance, the overall torsion of the lower limb (angle formed by the tangent to the posterior superior tibial metaphyseal cortical and the line drawn through both malleolar centers), and the femorotibial torsional index were measured. Measurement of femoral neck anteversion was performed in two different manners: one conventional manner corresponded to the angle between the posterior bicondylar line and the femoral neck axis (usually positive); the second one was no longer based on the posterior bicondylar line but on the transepicondylar line.

Statistical analysis

Student t-tests were used. The chosen level of significativity was set at 5%. Statview 5.0 software (Berkeley, CA, USA) was used for statistical analysis.

Results

Measurements made on standard radiographs and preoperative CT scan are shown in Table 1.

Values measured on standard radiographs

Eighty-six centered patellas and 32 lateralized patellas were noted. Lateralization was less than 5 mm in 25 cases and greater than 5 mm in seven cases.

Distal epiphyseal femoral torsion and patellar subluxation

Whatever the degree of patellar lateralization, the global trochlear angle was constant: $-1.15^\circ$ when the patella was centered; and $-2.28^\circ$ and $-0.57^\circ$ respectively depending on whether patellar lateralization was less or greater than 5 mm. These differences were not statistically significant ($p=0.41$). The PCA averaged $6.5^\circ$ when patella was centered, $8^\circ$ when patellar lateralization was 3 mm. The PCA was statistically smaller when patella was centered ($p=0.01$; $r=0.44$). PCA is related to patellar lateralization (Fig. 3).

The anterior trochlear angle evolved inversely to the PCA: $-7.74^\circ$ when patella was centered, $-10.32^\circ$ when patellar lateralization was less than 5 mm and $-8.57^\circ$ when patellar lateralization was greater than 5 mm. Such difference was significant ($p=0.05$). Patellar positioning was thus correlated with anterior trochlear angle.

Femoral anteversion and position of the patella

Measurements of femoral anteversion using the posterior bicondylar line were $9.1^\circ$; $12^\circ$ and $1.11^\circ$ respectively depending on the degree of patellar centering or lateralization. Such differences were not significant ($p=0.81$).

Figure 3  Relationship between patellar lateralization and degree of trans-epicondylar line inclination. The value of ATA and PCA angles varies according to the centering of the patella.
Femoral anteversion, measured from the transepicondylar axis, was 2.6°; 0.9° and 3.1° respectively depending on the amount of patellar lateralization ($p=0.83$). Femoral anteversion and patellar lateralization were independent whatever the femoral anteversion measurement method (Table 1).

### TTTG, lower limb torsion, femorotibial index and patellar lateralization

Measurement of the TTTG distance and lower limb torsion according to the position of the patella were reported in Table 1. The TTTG distance increased with lateralization of the patella but the difference was not significant ($p=0.10$). The lower limb torsion was independent from the patellar lateralization.

According to the tibiofemoral index of torsion, two subgroups were determined (Table 2): A high femorotibial index was observed in 35 lower limbs (greater than 30°), by external tibial hyper torsion, and a low index (less than 30°) in 83 lower limbs, either by small femoral and tibial torsions, or by equilibrated compensation of high values. No relationship could be established between femorotibial index and patellar centering ($p=0.73$).

### Discussion

#### Methodology

**Validity of studied measurements**

Radiographic evaluation was limited to the analysis of 30° flexion patellofemoral views. At 30°, the extensor apparatus was tensed and patellar centering, when present, was only dependent on the morphology of the distal femoral epiphysis, wear of the lateral patellar cartilage and position of the anterior tibial tubercle [8]. Only patellar shift was noted. Patellofemoral joint dysplasia was hardly differentiated in these arthritic knees. Therefore, the lateralized patella subgroup included patellofemoral joint dysplasia with decompensation but also initially well-centered patellas with lateral wear thus leading to a lateral patellar shift. Wear of the lateral patellar cartilage, thus increasing lateralization, was not taken into account in our study.

Our work was limited by the static aspect of measurements. Patellofemoral kinematics has been largely discussed in the literature. However, kinematic analysis of the patellofemoral joint might be carried out in three planes:

- in the horizontal plane, up to 30° of flexion, patellar positioning depends on soft tissues [9,10] and internal tibial rotation which appears in the first degrees of flexion [11,12]. Patellar movement combines internal rotation and medial translation. Beyond 30° of flexion, there is a contact between the patellar facet and the lateral trochlear facet. Patella is thus laterally translated to a minimum distance of 3 mm related to the groove of the trochlea [9–13];
- in the frontal plane, patella undergoes a slight continuous abduction during the whole flexion phase [14–18];
- in the sagittal plane, there is a continuous flexion of the patella, which, according to Jenny et al. [17] represents 60% of the knee flexion.

#### Results

According to our study, preoperative patellar lateralization was related to the PCA. To our knowledge, this work is the first one to correlate the PCA with the position of the patella. The posterior femoral condyles appear to participate in the centering of the patella (Fig. 3a). The PCA and anterior trochlear angle evolve inversely whatever the position of the patella: The anterior trochlear angle compensates for the internal distal femoral torsion. Therefore, the trochlea is always in the same direction whatever the position of the patella when taking the posterior bicondylar axis as a landmark. Orientation of the transepicondylar axis seems determining within this constant envelop constituted by the global trochlear angle. For a given overall angle, a high PCA, compensated by a high anterior trochlear

<table>
<thead>
<tr>
<th>Patellar positioning (d)</th>
<th>PCA</th>
<th>ATA</th>
<th>GTA</th>
<th>Femoral version (TEL)</th>
<th>Femoral version (PCL)</th>
<th>TTTG distance</th>
<th>Lower limb torsion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centered (d &lt; 3 mm)</td>
<td>6.5° (1 to 17)</td>
<td>-7.74° (-26 to 0)</td>
<td>-1.15° (-16 to 8)</td>
<td>2.66° (1 to 17)</td>
<td>9.28° (-21 to 36)</td>
<td>7 mm (0 to 25)</td>
<td>11.52° (0 to 31)</td>
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<td>(n = 86)</td>
<td></td>
<td></td>
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<tr>
<td>3 &lt; d &lt; 5 mm (n = 25)</td>
<td>8.04° (3 to 13)</td>
<td>-10.32° (-22 to -3)</td>
<td>-2.28° (-14 to 5)</td>
<td>3.96° (13 to 22)</td>
<td>12° (0 to 27)</td>
<td>9 mm (0 to 21)</td>
<td></td>
</tr>
<tr>
<td>(d = 5 mm)</td>
<td>8° (4 to 12)</td>
<td>-8.57° (-22 to -3)</td>
<td>-0.57° (-8 to 4)</td>
<td>3.14° (4 to 12)</td>
<td>11.14° (3 to 23)</td>
<td>10 mm (0 to 18)</td>
<td></td>
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<tr>
<td>(n = 7)</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>$p$</td>
<td>0.01</td>
<td>0.05</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

**PCA**: posterior condylar angle; **ATA**: anterior trochlear angle; **GTA**: global trochlear angle; **TEL**: transepicondylar line; **PCL**: posterior condylar line; **TTTG**: distance between the anterior tibial tubercle and the bottom of the trochlear groove; **NS**: non significant.
angle leads to a very oblique transepicondylar axis and a lateralized patella. Conversely, a small PCA, compensated by a small anterior trochlear angle leads to a slightly oblique transepicondylar axis and a centered patella.

In our study, femoral antetorsion based on the posterior bicondylar line or transepicondylar line was independent from the position of the patella. No anomaly of the femoral antetorsion could explain by itself patellar positioning. In his study of non-arthritic lower limb torsion defects, Lerat [16] identified a specific morphotype which induces femoropatellar instability and characterized by a high tibiofemoral index. Patellar lateralization in arthritic knees only seems dependent on intra-articular distal femoral osseous factors. Extrapolation of the results regarding the TTTG in our study thus confirms this idea. Knowing that lower limb deviation is constant whatever the patellar centering, and knowing otherwise that the TTTG distance tends to increase in the lateralized patella subgroup, this increase is only attributable to the distal femoral torsion.

A correlation was found between distal femoral torsion and patellar lateralization which confirms the idea that alignment of the extensor apparatus of the knee is restored with the trochlea under the patella more than with the patella on the trochlea. This is obtained by an adapted rotation of the femoral component which is greater in case of patellar lateralization than centered patella. Cloutier [19], Hungerford and Barry [20] had already proven the interest of lateral rotation of the femoral component to ensure a satisfactory ligament balance in flexion in varus knees. Any tightening in flexion causes overloading of the medial tibiofemoral compartment and induces polyethylene wear. Moreover there is a risk of dynamic instability of the patellofemoral joint related to internal rotation of the femoral component which might give rise to pain [21]. Lateralization of the femoral implant combined with its lateral rotation contributes to the patellar centering.

**Conclusion**

According to our study, patellar centering in arthritic knees depends on distal femur osseous factors which determine the posterior condylar and anterior trochlear angles on both sides of the transepicondylar axis. Since there is a constant angle of trochlear opening, the obliquity of the transepicondylar axis appears determining in patellar lateralization. Patellar lateralization seems dependent on distal femur osseous factors. No relationship could be established between patellar lateralization and overall deviation of the lower limb. A better understanding of the influence of the distal femoral morphology on patellar positioning will ensure improved positioning of the femoral implant in total knee arthroplasties or isolated femoropatellar joint replacements.

**Conflict of interest**

None.

**References**