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Posterior tibial slope changes after opening- and closing-wedge high tibial osteotomy: A comparative prospective multicenter study

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KEYWORDS
High tibial osteotomy; Opening-wedge; Closing-wedge; Tibial slope; Knee osteoarthritis

Summary

\textit{Introduction:} Valgus high tibial osteotomy is considered to be an effective treatment for unicompartmental medial osteoarthritis. It is generally admitted that tibial slope increases after open-wedge high tibial osteotomy and decreases after closing-wedge high tibial osteotomy. However, the effects on posterior tibial slope of closing- or opening-wedge osteotomies remain controversial.

\textit{Hypothesis:} We analyzed the modifications of tibial slope after opening- and closing-wedge high tibial osteotomies and compared the results of these two procedures. We hypothesized that there was no difference in postoperative tibial slope between opening and closing-wedge osteotomies.

\textit{Patients and methods:} This prospective consecutive nonrandomized multicenter study was conducted between January 2008 and March 2009 and included 321 patients: 205 men and 116 women. A total of 224 patients underwent an opening-wedge high tibial osteotomy and 97 a closing-wedge osteotomy. The mean age was 52 years ± 9 and the mean body mass index was

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Introduction

Tibial osteotomy has been practiced since the nineteenth century for certain major deformities, particularly in children. Its application in knee osteoarthritis is more recent, dating from the second half of the twentieth century. In 1962, Jean Debieyre [1] published his experience with medial open-wedge osteotomies performed beginning in 1951. In 1965, in the *Journées de Garches* (an unreferenced book), René Lohéac and Robert Judet reported a number of lateral closed-wedge osteotomies performed between 1950 and 1960. Later, many articles demonstrated the good medium- and long-term results of valgus high tibial osteotomy, providing relief to patients and thus postponing total knee arthroplasty. Daniel Goutallier [2] and later Philippe Hernigou [3,4] published satisfactory results at 10 years and then 20 years of follow-up.

One of the side effects of this technique is the modification of tibial slope, which may cause early failure, notably in cases of associated ligament damage [5], or technical problems during later total knee arthroplasty [6,7].

According to most authors, open-wedge high tibial osteotomy increases tibial slope by 3–4° [8–16] and closed-wedge high tibial osteotomy decreases tibial slope by 3–5° [13,17]. However, some authors have shown the absence of tibial slope modification in both open-wedge [18–21] and closed-wedge [22] high tibial osteotomy. Lerat et al. [23] have even shown that tibial slope decreased by 0.6° in valgus open-wedge high tibial osteotomy.

These sometimes contradictory reports must therefore be interpreted with caution, because most often these studies have a low level of evidence or have investigated small numbers of patients and are very rarely comparative [10,13,22,24,25].

The objective of this study was therefore to analyze and compare tibial slope modifications after open-wedge and closed-wedge high tibial osteotomy. We hypothesized that there would be no difference between open-wedge and closed-wedge high tibial osteotomies in this regard. We also attempted to identify the factors possibly correlated with substantial modifications in tibial slope.

Material and methods

The French Society of Orthopaedic Surgery and Traumatology (Société française de chirurgie orthopédique et traumatologique; SOFCOT) instigated a multicenter study involving ten French investigator centers’ with observational follow-up of the cohort and prospective data collection. This was a consecutive, comparative, but nonrandomized study because the surgical techniques employed by each unit were retained: only two centers performed closed-wedge high tibial osteotomies, four centers open-wedge high tibial osteotomies, and four centers both techniques with a preference for open-wedge procedures in cases of deformity beyond 8° varus.

The inclusion criteria were an indication for isolated valgus high tibial osteotomy. Complex cases of malunion of the upper extremity of the tibia requiring intra-articular intervention, repeated osteotomies, associated ligament procedures, as well as associated femoral osteotomies were excluded.

The inclusion period extended from January 2008 to March 2009, with a minimum follow-up of 6 months, sufficient to analyze the anatomical results; this study did not aim to analyze the clinical results. The data were collected anonymously and prospectively by each center using a

28 kg/m² ± 5. The main etiology was primary arthritis. Posterior tibial slope was measured preoperatively and at the last follow-up on a lateral radiograph in relation to the posterior tibial cortex.

Results: In the opening-wedge group, a definite 0.6° increase in tibial slope (P=0.016) was observed. In the closing-wedge group, a definite 0.7° decrease in tibial slope (P=0.02) was found. Fourteen percent of the opening-wedge osteotomies increased tibial slope by 5° or more versus only 2% of the closed-wedge osteotomies (P<0.001). Twelve percent of the closing-wedge high tibial osteotomies led to a decrease of 5° or more of the tibial slope versus 7% of the opening-wedge osteotomies (P<0.02).

Discussion and conclusion: These results confirm what is generally reported in the literature, i.e., an increase in tibial slope in opening-wedge high tibial osteotomy and a decrease in the slope in closing-wedge osteotomies. These tibial slope changes appear to be very limited in this series, less than 1° on average. However, there was a bias since the open-wedge technique was preferred in cases with substantial varus deformity. We emphasize the importance of surgical technique to avoid alteration of the tibial slope, particularly in opening-wedge high tibial osteotomy for which we recommend a release of posterior soft tissue and a complete osteotomy of the posterior cortex of the tibia.
standardized data form, then were centralized, merged, and verified for relevance.

Description of the cohort

The series grouped 321 osteotomies, 205 males (63.9%) and 116 females (36.1%), for 224 open-wedge osteotomies (69.8%) and 97 closed-wedge osteotomies (30.2%). Nineteen files (5.9%) could not be used. The tibial slope analysis therefore was performed on 302 knees: 210 open-wedge (69.5%) and 92 closed-wedge (30.5%) osteotomies.

Table 1 displays the cohort’s main data. The distributions in terms of age and body mass index were comparable, with statistically significant higher values in the open-wedge group. In the overall series, 14.6% of the patients presented varus greater than or equal to 10° and in 12.3% the hip-knee-ankle (HKA) angles were higher than or equal to 178°. Finally, the distribution of preoperative HKA angles was comparable between the two groups, but the value was statistically higher for the closed-wedge procedures. In the four centers performing both techniques, the open-wedge procedure was preferred in cases of substantial deformity, most often greater than 8° varus.

The etiologies were also distributed similarly, primarily knee osteoarthritis (84% for open-wedge versus 86% for closing-wedge), ahead of osteoarthritis secondary to ligament instability (7% for each group), posttraumatic osteoarthritis (4% for the open-wedge group versus 5% for the closed-wedge group), and other causes such as osteonecrosis and osteochondritis (6% of the open-wedge procedures versus 2% of the closing-wedge osteotomies).

From the radiological point of view, the osteoarthritis stage was assessed using the Ahlbäck classification [26]: 75.2% of the knees were classified stage II or III with a homogenous distribution between the open-wedge and closed-wedge groups.

The radiographic measurements of tibial slope were taken on lateral X-rays of the knee before surgery and at the last follow-up. They were not centralized; each department was responsible for producing these images. Tibial slope was measured according to Brazier et al. [27], using as the sole reference the tibia’s posterior cortex. Tibial slope was measured as the angle formed by the tangent to the medial tibial plateau and the line perpendicular to the tangent at the posterior tibial cortex (Fig. 1).

For the quantitative parameters, the statistical analysis used the matched Student t-test to compare the pre- and postoperative values. Statistical significance was set at $P < 0.05$.

<table>
<thead>
<tr>
<th>Table 1 Epidemiological data of the cohort.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<tr>
<td>Age (years)</td>
</tr>
<tr>
<td>Open-wedge 52 ± 9</td>
</tr>
<tr>
<td>Closed-wedge 49.7 ± 10.3</td>
</tr>
<tr>
<td>$P &lt; 0.0002$</td>
</tr>
<tr>
<td>BMI (kg/m$^2$)</td>
</tr>
<tr>
<td>Open-wedge 28.6 ± 5.5</td>
</tr>
<tr>
<td>Closed-wedge 27 ± 4.4</td>
</tr>
<tr>
<td>$P &lt; 0.007$</td>
</tr>
<tr>
<td>HKA (°)</td>
</tr>
<tr>
<td>Open-wedge 173.2 ± 3.2</td>
</tr>
<tr>
<td>Closed-wedge 175 ± 3</td>
</tr>
<tr>
<td>$P &lt; 0.000006$</td>
</tr>
</tbody>
</table>

BMI: body mass index (kg/m$^2$); HKA: hip-knee-ankle angle.

Figure 1 Measurement of tibial slope according to the method developed by Brazier et al. [27]: measurement of the inclination angle between the tangent to the medial tibial plateau and the line perpendicular to the tangent of the posterior tibial cortex.

Figure 2 Distribution of preoperative tibial slope for open-wedge and closed-wedge groups. X-axis: preoperative tibial slope in degrees; y-axis: percentage of each group.

Results

The preoperative tibial slope was $5.6° ± 4.4$ for the open-wedge group and $5.2 ± 3.2$ for the closed-wedge group (Table 2). The distribution of preoperative tibial slope was comparable in the two groups (Fig. 2). In total, in 88.4% of the cases, the preoperative tibial slope was between 0 and 10° (Table 3).

In the open-wedge group, postoperative tibial slope was $6.2° ± 5$, for a statistically significant increase of $0.6° ± 4.2$ ($P = 0.016$). In the closed-wedge group, the final tibial slope was $4.5° ± 3.1$, for a statistically significant decrease of $0.7° ± 3.3$ ($P = 0.02$) (Table 2). Fig. 3 shows the distribution of postoperative tibial slope.
Table 2 Preoperative and postoperative tibial slope values, tibial slope modification, and P-value for the open-wedge group and the closed-wedge group.

<table>
<thead>
<tr>
<th></th>
<th>Nb of patients</th>
<th>Preoperative TS and SD</th>
<th>TS at last follow-up and SD</th>
<th>Modification of TS and SD</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open-wedge</td>
<td>210</td>
<td>5.6° ± 4.4</td>
<td>6.2° ± 5.0</td>
<td>0.6° ± 4.2</td>
<td>0.016</td>
</tr>
<tr>
<td>Closed-wedge</td>
<td>92</td>
<td>5.2° ± 3.2</td>
<td>4.5° ± 3.1</td>
<td>−0.7° ± 3.3</td>
<td>0.02</td>
</tr>
</tbody>
</table>

TS: tibial slope; SD: standard deviation

Table 3 Distribution of preoperative tibial slope.

<table>
<thead>
<tr>
<th></th>
<th>TS &lt; 0°</th>
<th>TS &gt; 0° and &lt; 5°</th>
<th>TS &gt; 5° and &lt; 10°</th>
<th>TS &gt; 10°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open-wedge (n = 210)</td>
<td>4 (1.3%)</td>
<td>83 (27.5%)</td>
<td>102 (33.8%)</td>
<td>21 (7%)</td>
</tr>
<tr>
<td>Closed-wedge (n = 92)</td>
<td>4 (1.3%)</td>
<td>37 (12.3%)</td>
<td>45 (14.9%)</td>
<td>6 (2%)</td>
</tr>
</tbody>
</table>

TS: tibial slope. Percentage compared to overall number (n = 302).

Figure 3 Distribution of postoperative tibial slope for open-wedge and closed-wedge groups. X-axis: postoperative tibial slope in degrees; y-axis: percentage of each group.

The results of each center are presented in Table 4. A center effect was found: for example, open-wedge centers 4 and 6 showed a statistically significant increase and decrease, respectively, in tibial slope. Tibial slope was not modified in centers 3 and 5, but this was not statistically significant.

The distribution of tibial slope modifications (Fig. 4) shows that the open-wedge group was relatively homogenous, with slope variations evolving in both directions. Indeed, 7% of the open-wedge procedures induced a reduction in tibial slope greater than or equal to 5° and 14% increased it by 5° or more. In the closed-wedge group, the distribution was more heterogeneous, with tibial slope clearly decreasing: 12% of the procedures decreased the slope 5° or more and only 2% increased it 5° or more.

Fourteen percent of the open-wedge procedures resulted in an increase in tibial slope greater than or equal to 5° versus only 2% of the closed-wedge procedures (P < 0.0001). In addition, 4% of the open-wedge procedures increased slope by more than 10° versus 1% of the closing-wedge procedures (P could not be calculated).

Twelve percent of the closing-wedge procedures decreased the tibial slope by 5° or more versus 7% of the open-wedge procedures (P < 0.02). Decreases greater than 10° were found in 2% of the open-wedge osteotomies and 1% of the closed-wedge procedures (P could not be calculated).

Table 4 Tibial slope results versus center.

<table>
<thead>
<tr>
<th>Center</th>
<th>Number and surgical technique</th>
<th>Preoperative TS and SD</th>
<th>TS at last follow-up and SD</th>
<th>Modification of TS and SD</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>31 closed-wedge</td>
<td>4.9° ± 1.5</td>
<td>5.4° ± 1.6</td>
<td>0.5° ± 1.2</td>
<td>0.018</td>
</tr>
<tr>
<td>2</td>
<td>22 closed-wedge</td>
<td>3.9° ± 2.5</td>
<td>3.1° ± 2.2</td>
<td>−0.8° ± 2.5</td>
<td>0.073</td>
</tr>
<tr>
<td>3</td>
<td>16 open-wedge</td>
<td>5.4° ± 2.8</td>
<td>5.4° ± 3.8</td>
<td>0.0° ± 3.4</td>
<td>0.497</td>
</tr>
<tr>
<td>4</td>
<td>16 open-wedge</td>
<td>3.1° ± 2.4</td>
<td>6.1° ± 6.8</td>
<td>3.0° ± 6.4</td>
<td>0.0397</td>
</tr>
<tr>
<td>5</td>
<td>23 open-wedge</td>
<td>7.7° ± 3.8</td>
<td>7.7° ± 3.9</td>
<td>0.0° ± 2.0</td>
<td>0.46</td>
</tr>
<tr>
<td>6</td>
<td>43 open-wedge</td>
<td>5.3° ± 5.8</td>
<td>4.1° ± 6.1</td>
<td>−1.2° ± 3.5</td>
<td>0.014</td>
</tr>
<tr>
<td>7</td>
<td>8 closed-wedge</td>
<td>7.0° ± 5.4</td>
<td>8.3° ± 3.7</td>
<td>1.3° ± 6.0</td>
<td>0.29</td>
</tr>
<tr>
<td>8</td>
<td>25 open-wedge</td>
<td>7.6° ± 3.5</td>
<td>8.1° ± 4.2</td>
<td>0.4° ± 4.1</td>
<td>0.30</td>
</tr>
<tr>
<td>9</td>
<td>9 closed-wedge</td>
<td>5.0° ± 4.4</td>
<td>5.2° ± 4.2</td>
<td>0.2° ± 2.6</td>
<td>0.4</td>
</tr>
<tr>
<td>10</td>
<td>48 open-wedge</td>
<td>5.8° ± 4.4</td>
<td>6.8° ± 3.8</td>
<td>1.1° ± 4.6</td>
<td>0.056</td>
</tr>
<tr>
<td>11</td>
<td>19 closed-wedge</td>
<td>6.2° ± 3.3</td>
<td>3.4° ± 3.5</td>
<td>−2.8° ± 3.3</td>
<td>0.0009</td>
</tr>
<tr>
<td>12</td>
<td>8 open-wedge</td>
<td>6.0° ± 5.6</td>
<td>6.9° ± 9.2</td>
<td>0.9° ± 6.1</td>
<td>0.35</td>
</tr>
<tr>
<td>13</td>
<td>3 closed-wedge</td>
<td>8.3° ± 6.1</td>
<td>1.0° ± 1.7</td>
<td>−7.3° ± 4.5</td>
<td>p not calculated</td>
</tr>
<tr>
<td>14</td>
<td>31 open-wedge</td>
<td>3.9° ± 3.1</td>
<td>6.0° ± 3.6</td>
<td>2.1° ± 3.0</td>
<td>0.0002</td>
</tr>
</tbody>
</table>

TS: tibial slope.
Overall, in 86% of the cases, tibial slope varied by an absolute value less than 5° and in 97.4% of the cases by less than 10°.

Two factors were identified as being correlated with tibial slope modification greater than or equal to 5°:

- HKA: preoperative varus was significantly higher in the group with slope modification greater than 5°: (6.9° ± 3.0 versus 6.0° ± 3.2°; P=0.01);
- body mass index: 30.0 kg/m² ± 7 in the group with a tibial slope modification greater than 5° and 27.7 kg/m² ± 4 in the group with a slope modification less than 5° (P=0.008).

Discussion

This study presents certain limits: it was a nonrandomized study since the surgical techniques used at each center were retained. It was neither single- nor double-blinded. There is also a bias in the choice of the technique since four centers performed both techniques and the open-wedge technique was chosen in cases of substantial deformity (more than 8°). The number of deformities greater than 10° was relatively low and these were preferentially treated with the open-wedge procedure. The very clear predominance of open-wedge osteotomies should also be noted: slightly more than twice the number of closed-wedge procedures. In addition, the measurements were not centralized and the files were not checked for quality control.

On the other hand, this study presents a number of strong points: it is the largest series comparing open- and closed-wedge high tibial osteotomies. It is a consecutive and comparative series with prospective data collection. Moreover, the investigator centers all had substantial experience in clinical trials. Finally, retaining each team’s surgical practices, although inducing bias, does reflect actual practices and reveals the current preference for open-wedge tibial osteotomies in France.

This study invalidates our hypothesis postulating that there was no difference between open-wedge and closed-wedge high tibial osteotomies. However, the tibial slope modifications observed (+0.6° for open-wedge procedures and −0.7° for closed-wedge procedures) were very slight compared to those generally reported in the literature.

According to Hohmann et al. [17] and El-Azab et al. [10], the tibial slope reduction in closed-wedge osteotomies can be explained by the geometry of the proximal tibia, triangular at the anterior extremity. If the closed-wedge osteotomy is not strictly lateral and perpendicular to the anatomical axis, more bone is resected anteriorly, causing a reduction in tibial slope.

The slope increase after open-wedge osteotomy can also be explained by the bone anatomy: the anteromedial cortex of the tibia makes a 45° angle with the posterior cortex, whereas the lateral cortex is nearly perpendicular to the posterior plane of the tibia. Thus, a medial open-wedge osteotomy with anterior and posteromedial spaces of the same height results in an increase in tibial slope [12].

For open-wedge procedures, two factors seem essential so as not to modify the tibial slope, as demonstrated by Sariali et al. [21]:

- release of the posterior soft tissues: in the study reported by Marti et al. [11], the group with anterior cruciate ligament rupture had undergone complete osteotomy of the posterior tibial cortex as well as release of the posterior soft tissues. In this group, the increase in tibial slope was only 1° versus 3.2° in the group in which these precautions had not been taken;
- the position of the wedge during the open-wedge procedure and then the position of the plate: the more the wedge is positioned anteriorly, the more the slope increases. Rodner et al. [5] and Rubino et al. [28] demonstrated that a plate placed too anteriorly induces an increase in tibial slope. Laprade et al. [15] showed that the anteromedial position of the plate increases tibial slope by 4.3° versus only 1.0° when it is posteromedial.

Hernigou et al. [3] recommend positioning the plate as close as possible to the posteromedial corner and performing a complete posterior osteotomy (Fig. 5). It should be remembered that in the present study, one of the open-wedge centers respecting these principles obtained a statistically significant decrease in tibial slope of 1.2° (P=0.014). Does the recent and increasingly widespread use of locking plates make it possible to position them differently with no loss of correction? No published studies have compared the locking plates with the standard plates so conclusions cannot be drawn on this technical aspect.
This procedure is easy to implement and obtains the frontal correction required with no undesirable modification of tibial slope. Other techniques have been proposed to prevent tibial slope changes: Gunes et al. [19] and Jung et al. [20] suggest using an intraoperative external fixator, Golser et al. [29] rely on navigation. Papp et al. [30] performed a combined osteotomy with lateral closing then medial opening utilizing the removed lateral bone wedge. However, these more invasive and more complicated methods make them difficult to use in daily clinical practice and show no real gain in precision.

The effects of high tibial osteotomy on tibial slope have been widely debated. Modification of tibial slope is a source of instability and excessive anteroposterior tibial translation that may encourage the progression of osteoarthritis [3,9,31]. The biomechanical studies conducted by Agneskirchner et al. [9] and Giffin et al. [32] have shown the linear relation between tibial slope and tibial translation during monopodal stance: the more tibial slope increases, the more anterior tibial translation increases. This was already shown clinically by Dejour and Bonnin [33], who found a very strong correlation between anterior tibial translation and tibial slope, in both the healthy knee and when the anterior cruciate ligament is ruptured. On the other hand, closed-wedge osteotomy produces a decrease in tibial slope, which distributes the stresses on the posterior compartment. Consequently, in cases of associated rupture of the anterior cruciate ligament, it is often recommended to perform a lateral closed-wedge osteotomy and in cases of posterior cruciate ligament rupture a medial open-wedge osteotomy.

According to Giffin et al. [32], a slight modification in the tibial slope does not alter the anteroposterior stability of the knee or the stresses in the cruciate ligaments. In view of the results found in the present study, given the very slight variation in tibial slope whatever the method used, a mean of less than 1°, it can be assumed that there will be no biomechanical or clinical repercussion on the knee after high tibial osteotomy if the surgical technique is closely followed. In addition, if there is not considerable modification in the tibial slope, a future total knee replacement should not be compromised, as long as the modifications of the superior tibial epiphysis in the frontal plane can be disregarded.

Conclusion

This study on a very high number of patients is concordant with the majority of the data reported in the literature. Open-wedge osteotomy increases tibial slope slightly, a notion that should be nuanced since certain centers performing medial open-wedge procedures have observed no changes in tibial slope and one team even observed a statistically significant 1.2° reduction. As for closed-wedge osteotomy, it slightly decreases tibial slope. The variations in tibial slope are much smaller (all less than 1°) in this study than what is usually described in the literature. High tibial osteotomy is therefore an intervention that results in very few side effects in terms of tibial slope, provided that the surgical technique is respected. This study has shown that there is currently a clear preference for open-wedge procedures in most centers in France, particularly for patients with substantial deformities.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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