Enlarged post-operative posterior condyle tightens extension gap in total knee arthroplasty

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We investigated whether the extension gap in total knee replacement (TKR) would be changed when the femoral component was inserted. The extension gap was measured with and without the femoral component in place in 80 patients with varus osteoarthritis undergoing posterior-stabilised TKR. The effect of a post-operative increase in the size of the femoral posterior condyles was also evaluated. The results showed that placement of the femoral component significantly reduced the medial and lateral extension gaps by means of 1.0 mm and 0.9 mm, respectively (p < 0.0001). The extension gap was reduced when a larger femoral component was selected relative to the thickness of the resected posterior condyle. When the post-operative posterior lateral condyle was larger than that pre-operatively, 17 of 41 knees (41%) showed a decrease in the extension gap of > 2.0 mm. When a specially made femoral trial component with a posterior condyle enlarged by 4 mm was tested, the medial and lateral extension gaps decreased further by means of 2.1 mm and 2.8 mm, respectively.

If the thickness of the posterior condyle is expected to be larger than that pre-operatively, it should be recognised that the extension gap is likely to be altered. This should be taken into consideration when preparing the extension gap.

Optimising the extension gap is one of the goals in total knee replacement (TKR) and the gap is often evaluated using laminar spreaders, spacer blocks or a tensing device without the femoral component in place.1-7 However, the effect of the posterior condyle of the femoral component on the extension gap should also be taken into account. Prominent posterior condyles will tighten the posterior capsule, resulting in a smaller extension gap. Therefore, it is possible that in the absence of the femoral component the extension gap might be overestimated. In particular, when using the gap technique with a posterior cruciate ligament (PCL)-sacrificing TKR, a larger femoral component is sometimes selected to compensate for the enlarged flexion gap created by resecting the PCL.8-10 This produces post-operative posterior condyles which are larger than the bone they replace, and can affect the extension gap after the femoral component is inserted. These relationships have not previously been evaluated.

Another important consideration is the extent to which the extension gap is changed by the removal of posterior condylar osteophytes and the release of the posterior soft tissues. The effects of these ligamentous releases have been investigated mainly in normal cadaver knees,2,5,11-14 and much less in osteo-arthritic knees.6

The aims of this study were: (1) to investigate how much the extension gap would enlarge at each step of the surgical procedure; (2) to assess the effect on the extension gap of insertion of the femoral component; and (3) to examine the effect of a change in the thickness of the posterior condyles on the extension gap in varus osteo-arthritic knees undergoing TKR. We also evaluated how much the extension gap would be changed when the femoral component was increased by one size.

Our hypothesis was that when a femoral component was implanted having posterior condyles larger than the bone it replaced, the extension gap would be tightened on its insertion.

Patients and Methods
Between April 2007 and March 2009, 80 knees in 64 patients (56 women and 8 men) underwent TKR using the NexGen Legacy Posterior-Stabilised prosthesis (Zimmer, Warsaw, Indiana), for varus osteoarthritis. The mean age of the patients was 74.5 years (51 to 89) at the time of surgery. Their mean pre-operative American Knee Society score15 was 54.4 (4 to 70). This study had ethical approval and all patients gave informed consent for participation in the study. All knees were exposed using a standard medial parapatellar approach or a midvastus approach. A measured resection...
For soft-tissue balancing, we performed a stepwise medial soft-tissue release. The first step included removal of any residual osteophytes at the posterior part of the medial femoral condyle and at the medial to posterior part of the tibia. This was coupled with the release of the deep medial collateral ligament (MCL) and release of the posteromedial capsule (PMC) from the proximal tibia. The second step included the release of the superficial MCL, which was performed with a 10 mm osteotome by elevating its

Fig. 1a

Photographs showing a) the tensor used to measure the extension gap and b) the tensor in situ.

Fig. 1b

insertion subperiosteally along the upper medial tibial surface for a distance of about 6 cm below the joint line. This was performed when the ligament imbalance was more than approximately 5° in extension with a tension device inserted between the femur and tibia at a distraction force of 176.4 N. We selected this distraction force because it creates a gap in the joint in full extension with the trial femoral component in place which corresponds to the thickness of the insert derived from our preliminary clinical studies. The tension device consists of three parts, which was customized by Zimmer (Warsaw, Indiana): an upper seesaw plate which rests on the cut femoral surface or the implanted femoral component, a lower platform plate which rests on the resected surface of the tibia, and an extra-articular main body. The tension device provides two measurements: the central gap between the cut femur and the tibia, and the angle between the seesaw plate and the platform plate (Fig. 1a). The extension gap and the ligament balance were measured after the completion of bony resection (Gap 0 and Angle 0), osteophyte removal, and the release of the deep MCL and PMC (Gap 1 and Angle 1) and the release of the superficial MCL (Gap 2 and Angle 2). After soft-tissue balancing, the extension gap was measured again with the femoral trial component positioned on the prepared femurs (Component gap and Component Angle) (Fig. 1b). The extension gap without the femoral component was defined as the Bone gap to distinguish it from the Component gap. The extension gaps at the centre of the medial and lateral condyles of the femoral component were calculated from the centre gap, the angle and the mediolateral length of the tibial component. The angle between the seesaw and platform plates was displayed on the tension device in degrees, with positive values representing varus imbalance.

The change in the extension gap was calculated as the value that was subtracted from the total of the Component gap and the thickness of the distal part of the femoral component (9 mm) by the Bone gap (Fig. 2). Negative values indicated that the extension gap had been reduced by implanting the femoral component. The thickness of the resected bone, including the thickness of the bone cut of 1.3 mm, was measured with a caliper, and the change in posterior condyle thickness was defined as the difference between the resected bone and the thickness of the posterior part of the femoral component (Fig. 3). Positive values indicated that the resected bone was thicker than that part of the femoral component.

In 16 knees of 13 patients who gave informed consent, a custom-made femoral component was used with identical internal geometry but with posterior condyles that were 4 mm thicker than the standard component to represent a one-size increase in the component (Fig. 4). The extension gap was then measured with this larger femoral component (Larger-sized component gap) and compared with the standard component (Standard-sized component gap) in these patients.
Statistical analysis. A paired t-test was performed to compare the differences in the extension gaps before and after medial and lateral soft-tissue releases. A simple linear regression analysis was used to evaluate the relationship between the change in the posterior condyle and the change in the extension gap medially and laterally. In order to verify our hypothesis, we divided the patients into two groups according to the change in the thickness of the lateral posterior condyle. The first group showed a decrease or no change in posterior condylar thickness (Undersized group); the second group showed an increase in posterior condylar thickness (Oversized group). An unpaired t-test was performed to compare the change in extension gap between groups. In addition, Pearson's chi-squared test was used to compare the likelihood of a change of > 2 mm in the extension gap medially and laterally. The results were analysed using the statistical software package Statview 5.0 (Abacus Concepts Inc., Berkeley, California). The level of significance was determined at p < 0.05.

Results
The mean pre-operative hip-knee-ankle angle was -14.7° (SD 4.7°) on full-length weight-bearing anteroposterior radiographs.

Assessment of soft-tissue release. Correct ligament balance was achieved with Step 1 in 63 knees. However, 17 knees required release of the superficial MCL (Step 2). With each release, the mean extension gap increased significantly (medially, 2.8 mm (-0.7 to 10.9) by Step 1 and 3.3 mm (0.0 to 6.8) by Step 2; laterally, 1.5 mm (-1.5 to 5.6) by Step 1 and 1.9 mm (-0.8 to 3.6) by Step 2) (p < 0.0001, paired t-test) and the ligament balances were significantly corrected by 2.3° (-2° to 8°) by Step 1 and 2.4° (-2° to 6°) by Step 2 (p < 0.0001 and p = 0.0002, respectively, paired t-test). The change in the medial gap was greater than that of the lateral gap (Table I). The mean flexion gaps were 26.4 mm (SD 4.1) on the medial side and a mean of 27.9 mm (SD 4.0) on the lateral side after soft-tissue balancing without the femoral component in position. There were no cases with medial instability due to excessive release of the deep MCL.

Assessment of the effect of inserting the femoral component on the extension gap. With the femoral component in place the extension gap decreased approximately 1 mm in addition to the thickness of the femoral component. These differences were statistically significant on both the medial and the lateral side (p < 0.0001, paired t-test) (Table II). The angle did not change significantly with insertion of the femoral component (p = 0.0723, paired t-test).

Assessment of the effect of the presence of the posterior condyles on the extension gap. The mean changes in posterior condyle thickness were -2.0 mm (SD 2.4) medially and -0.2 mm (SD 2.5) laterally. The medial posterior condyle tended to decrease in thickness after surgery. Regarding the correlation between the posterior condylar change and the extension gap, an increase in the thickness of the posterior condyle resulted in a reduced extension gap (Figs 5 and 6). The correlation coefficient of the lateral aspect of the extension gap (r = 0.52, p < 0.0001) was higher than that of the medial aspect of the extension gap (r = 0.27, p = 0.0154). Comparing the Undersized and the Oversized groups, classified according to the thickness of the lateral posterior condyles, the change in the extension gap was significantly larger in the Undersized group than in the Oversized group (p = 0.0107 on the medial side and p < 0.0001 on the lateral side, unpaired t-test) (Table III). On the medial side, the extension gap decreased more than 2.0 mm in 17 of 41 (41%) knees of the Oversized group and in 9 of 39 (23%) knees of the Undersized group. However, this difference was not statistically significant between the groups (p = 0.0793, Pearson's chi-squared test). On the lateral side, a change > 2.0 mm was significantly associated with the Oversized group (41%, 17 of 41) over the Undersized group (12%, 5 of 39) (p = 0.0041, Pearson's chi-squared test).

Comparison between the Standard-sized component gap and Larger-sized component gap. Using the larger femoral component, the extension gap decreased more than when the standard-sized component was used (p < 0.0001, paired t-test) (Table IV). The angle did not change significantly with the use of the larger component (p = 0.1299, paired t-test).

Discussion
Achieving a proper extension gap is one of the most important issues in TKR. We explored how the extension gap in varus osteoarthritic knees changed after soft tissue balancing, which consisted of two main steps. We tried to avoid release of the superficial MCL when possible, as this can produce instability, especially in flexion.14,16-17

The initial step of osteophyte removal and release of the deep MCL and the posteromedial capsule was undertaken.
in all cases and resulted in an increase in the medial and lateral extension gaps by a mean of 2.8 mm and 1.5 mm, respectively. Secondly, the superficial MCL was released, resulting respectively in a mean 3.3 mm and 1.9 mm increase in the extension gap both medially and laterally. Our findings contradict the results of a previous cadaveric study, which showed that the deep MCL and the posteromedial capsule release had a negligible effect on the extension gap in normal knees. However, another intra-operative evaluation in varus arthritic knees by Yagishita et al. found that these procedures increased the medial and lateral extension gap by 3.1 mm and 1.9 mm, respectively, which is consistent with our findings.

Intra-operatively, the effect on the extension gap of inserting the femoral component after securing the tibial component, in what appears to be an adequate space prepared by correct bone resection, osteophyte removal and soft tissue balancing, may lead to difficulty in achieving full extension. This may require the surgeon to re-cut the femur or to release the soft tissues excessively. We found that femoral component placement affected the ligament balance and reduced the extension gap by approximately 1 mm in total. This result is consistent with those of Muratsu et al., who showed that the femoral component placement changed the extension gap and the decrease in the extension gap was 5.3 mm. This difference in values of the extension gap might be due to the tensor they used, and also the fact that they did not evaluate the influence of posterior condylar thickness. In our study, when the post-operative posterior condyle was larger than the pre-operative...
bone contour (Oversized group), the placement of the femoral component had a greater effect on the extension gap than in the Undersized group and the extension gap decreased by approximately 1.5 mm. Without a detailed description regarding the change in posterior condylar thickness, it is difficult to make a direct comparison between our results and those of Muratsu et al.\textsuperscript{18}

Bellemans et al.\textsuperscript{19} showed that the size of the posterior condyles of the femoral component correlated with the final range of flexion. Regarding the influence of the posterior condyle on ligament balance, Sugama et al.\textsuperscript{20} and Minoda et al.\textsuperscript{21} reported that the extension gap was altered by the posterior bone resection, but did not evaluate the effect of changing the thickness of the posterior condyle on the extension gap. When the posterior condyle was enlarged by the femoral component approximately 40\% of our patients had a decrease in the extension gap by > 2.0 mm. When the 4 mm-enlarged component was used the extension gap decreased further by 2 mm to 3 mm. In the PCL-sacrificing TKR, a larger femoral component can be selected to compensate for an enlarged flexion gap. In addition, when using the tensioned gap technique, excessive external rotation of the femoral component in order to achieve a rectangular flexion gap would result in a larger post-operative posterior condyle laterally. In these situations the surgeon should recognise how this will compromise the extension gap.

Our study has some limitations. First, most of our patients were female, as in Japan more women than men are affected with osteoarthritis. However, we are unaware of any studies describing differences in balancing techniques between the genders. Secondly, only Japanese patients were studied, and there may be variability in ligamentous laxity among races. Thirdly, we determined the

![Change of posterior condyle thickness in the medial side (mm)](image)

\textbf{Fig. 5} Scatter plot showing the correlation between the change in the extension gap and the change in posterior condylar thickness on the medial side.

![Change of posterior condyle thickness in the lateral side (mm)](image)

\textbf{Fig. 6} Scatter plot showing the correlation between the change in the extension gap and the change in posterior condylar thickness on the lateral side.

\textbf{Table I.} Mean extension gap and angle measured at each step

<table>
<thead>
<tr>
<th>Bone gap</th>
<th>Medial side</th>
<th>Lateral side</th>
<th>Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gap 0</td>
<td>Step 1 (n = 63)</td>
<td>19.0 (SD 2.5) (13.4 to 26.1)</td>
<td>22.9 (SD 2.6) (16.7 to 29.9)</td>
</tr>
<tr>
<td></td>
<td>Gap 1 (after step 1)</td>
<td>22.0 (SD 2.6) (18.0 to 29.3)</td>
<td>20.3 (SD 1.9) (17.3 to 23.4)</td>
</tr>
<tr>
<td></td>
<td>Gap 2 (after step 2)</td>
<td>23.8 (SD 2.4) (19.1 to 27.8)</td>
<td>27.0 (SD 2.4) (23.9 to 31.6)</td>
</tr>
</tbody>
</table>

* \( p < 0.0001 \) (statistically significant difference before and after the releases, paired \( t \)-test)

† \( p = 0.0034 \) (statistically significant difference before and after the releases, paired \( t \)-test)

‡ \( p = 0.0002 \) (statistically significant difference before and after the releases, paired \( t \)-test)
rotational alignment of the femoral component using a measured resection technique only. Therefore, the thickness of the medial posterior condyles tended to decrease after surgery. However, the best method of obtaining rotational alignment remains controversial. Finally, we measured the extension gap with a seesaw plate. It is possible that equal forces were not applied at both the medial and the lateral compartments, because the tensor applied the distraction force at the centre of the joint.

Regardless of these limitations, we have shown: (a) that in medial osteoarthritis the extension gap increased by 2 mm to 3 mm with osteophyte removal and release of the deep MCL and the posteromedial capsule; and (b) that inserting the femoral component reduced the extension gap, and the reduction was greater when the posterior femoral component was thicker than in the pre-operative state.

Table II. Difference between the extension gaps with and without the femoral component

<table>
<thead>
<tr>
<th>Gap</th>
<th>Extension gap (mm; mean, SD, range)</th>
<th>Angle (*; mean, SD, range)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Medial side</td>
<td>Lateral side</td>
</tr>
<tr>
<td>Bone gap (after soft-tissue release)</td>
<td>22.3 (SD 2.6)</td>
<td>25.1 (SD 2.9)</td>
</tr>
<tr>
<td></td>
<td>(18.0 to 29.3)</td>
<td>(17.6 to 33.0)</td>
</tr>
<tr>
<td></td>
<td>Bone angle</td>
<td>4.7 (SD 2.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-1.5 to 10.0)</td>
</tr>
<tr>
<td>Subtracting the thickness of the distal part of the femoral component (9 mm)</td>
<td>13.3 (SD 2.6)</td>
<td>16.1 (SD 2.9)</td>
</tr>
<tr>
<td></td>
<td>(9.0 to 20.3)</td>
<td>(8.6 to 24.0)</td>
</tr>
<tr>
<td>Component gap</td>
<td>12.3 (SD 2.3)</td>
<td>15.2 (SD 2.7)</td>
</tr>
<tr>
<td></td>
<td>(8.7 to 17.8)</td>
<td>(10.0 to 24.2)</td>
</tr>
<tr>
<td>Change of extension gap</td>
<td>-1.0 (SD 1.6)*</td>
<td>-0.9 (SD 1.7)*</td>
</tr>
<tr>
<td></td>
<td>(-5.5 to 2.5)</td>
<td>(-5.0 to 3.5)</td>
</tr>
</tbody>
</table>

* p < 0.0001 (statistically significant difference before and after inserting the femoral component, paired t-test)

Table III. Comparison of the change in extension gap between groups according to the change in posterior condylar thickness

<table>
<thead>
<tr>
<th>Group</th>
<th>Change of extension gap (mm; mean, SD, range)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Medial side</td>
</tr>
<tr>
<td>Undersized group (n = 39)</td>
<td>-0.6 (SD 1.4)</td>
</tr>
<tr>
<td></td>
<td>(-2.8 to 2.5)</td>
</tr>
<tr>
<td>Oversized group (n = 41)</td>
<td>-1.5 (SD 1.7)*</td>
</tr>
<tr>
<td></td>
<td>(-5.5 to 1.0)</td>
</tr>
</tbody>
</table>

* p = 0.0107 (statistically significant difference between the Undersized group and the Oversized group, unpaired t-test)
† p < 0.0001 (statistically significant difference between the Undersized group and the Oversized group, unpaired t-test)

Table IV. Change in the extension gap when a large component with a 4 mm increase in the anteroposterior dimension was used

<table>
<thead>
<tr>
<th>Component gap (n = 16)</th>
<th>Extension gap (mm; mean, SD, range)</th>
<th>Component angle (*; mean, SD, range)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Medial side</td>
<td>Lateral side</td>
</tr>
<tr>
<td>Standard component gap</td>
<td>12.6 (SD 2.5)(9.1 to 17.8)</td>
<td>15.6 (SD 3.0)(11.6 to 24.2)</td>
</tr>
<tr>
<td>Large component gap</td>
<td>10.5 (SD 3.1)(75 to 19.2)</td>
<td>12.9 (SD 4.1)(9.3 to 24.8)</td>
</tr>
<tr>
<td>Change in extension gap</td>
<td>-2.1 (SD 1.6)*(-5.6 to 1.4)</td>
<td>-2.8 (SD 2.1)*(-8.4 to 0.6)</td>
</tr>
</tbody>
</table>

* p < 0.0001 (statistically significant difference between the standard and large component gaps, paired t-test)

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References