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Clinical Paper

Comparison of Fit and Fill Between Anatomic Stem and Straight Tapered Stem Using Virtual Implantation on the ORTHODOC Workstation

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ABSTRACT The objective of this article was to determine the influence of stem design on fit and fill using the preoperative planning workstation of the ROBODOC system. Anatomic ABG and straight Osteolock femoral components were virtually implanted into 50 femora (25 from patients with developmental dysplasia of the hip (DDH), 25 morphologically normal) on the workstation display. Fit and fill, and length of the proximal posterolateral femoral cortex removed by milling (LPFCR), were measured on the cross-sectional images. Lateral curvature (α angle) and anteversion of the femur were evaluated. The ABG components showed significantly better fit than the Osteolock components at the levels proximal to the lesser trochanter. The Osteolock components showed significantly greater LPFCR than the ABG components, especially in the patients with DDH. The patients with DDH showed significantly greater Y angle and femoral anteversion than those with morphologically normal femora. With the Osteolock components, the Y angle correlated significantly with femoral anteversion and LPFCR. Use of an anatomic proximal body of the stem helped to improve the proximal canal fit. Greater LPFCR was required when a straight stem was implanted in patients with a relatively high α angle. Comp Aid Surg 6:290-296 (2001). ©2002 Wiley-Liss, Inc.

Key words: ORTHODOC, ROBODOC, virtual operation, fit and fill, hip arthroplasty, femoral components

INTRODUCTION

Fit and fill of the femoral canal by cementless femoral components are important factors in component stability. 1–5 Although, ideally, surgeons would know which femoral component would result in a better fit and fill for each patient based on a preoperative plan, in practice, fit and fill cannot be predicted preoperatively because of the inaccuracy of surgical techniques and preoperative planning techniques based on the use of X-rays and a template. 6 Therefore, fit and fill are usually evaluated using postoperative X-rays of the patient.

ORTHODOC is the CT-based preoperative planning workstation associated with the ROBODOC system 7 (Integrated Surgical Systems, Davis, CA). Accurate three-dimensional (3D) preoperative planning (virtual implantation) of ce-
mentless femoral components can be performed on the ORTHODOC display, including determination of the size and level of insertion of femoral components and reconstruction of any cross-sectional images after implantation. ORTHODOC assists surgeons in preoperatively determining differences between femoral components in terms of fit and fill of the femoral canal of a patient, and the influence of femoral component designs on fit and fill. The purpose of the current study was to evaluate the difference in fit and fill between an anatomic-type femoral component and a straight-type femoral component, and to analyze the factors affecting fit and fill for these two design types.

MATERIALS AND METHODS

Preoperative CT scans of 50 femora (43 patients: 18 men and 25 women) were used for virtual implantation. The patient demographics are given in Table 1. Eighteen patients (25 hips) showed developmental dysplasia of the hip (DDH). The remaining 25 patients (25 hips) did not show DDH and were assigned to the control group. The diagnosis of each patient was made by the senior authors using an anteroposterior X-ray of the hip. All 25 hips showing DDH were classified as Group 1 (less than 50% subluxation) or Group 2 (50 to 75% subluxation), according to the classification of Crowe et al.; none of them had previously undergone femoral osteotomy. All the patients of the control group were confirmed to have morphologically normal proximal femora. There was no significant difference in age between the patients with DDH and those in the control group. However, there was a significant difference in sex ratio between the patients with DDH and the patients of the control group. This is because most patients with DDH are women, and because CT data for only three male patients with DDH were available.

The femoral components used for virtual implantation were the ABG Hip System (Stryker Howmedica Osteonics, Rutherford, NJ) and the Osteolock Hip System (Stryker Howmedica Osteonics, Rutherford, NJ). The ABG femoral components were anatomic stems with a posteriorly bowed proximal body and a cylindrical distal portion (Fig. 1A and B). The Osteolock femoral components were straight tapered stems (Fig. 1C and D).

Virtual implantation of femoral components was performed as follows. The center of the femoral head was marked by fitting a circle to the femoral head contour on the coronal, sagittal, and axial views of the workstation display. The femur was reoriented on the workstation to obtain the coronal plane that passed through the head center and the proximal femoral medullary axis. The sagittal plane through the medullary axis was then obtained. Stems of the maximum size that would not overream the endo-osteal cortical bone on the workstation display were selected and virtually im-

![Fig. 1. Configurations of the two femoral components used in this study. (A) An anteroposterior view of the ABG stem. (B) A lateral view of the ABG stem. (C) An anteroposterior view of the Osteolock stem. (D) A lateral view of the Osteolock stem.](image-url)
planted into the femoral canal to achieve maximum proximal medial fit7 by referring to the fit and fill of the stem in the coronal and sagittal planes. Each virtual implantation was discussed by two of the senior authors until a consensus was obtained.

After the femoral component was implanted, the canal fill ratio and the canal fit ratio were calculated from the cross-sectional images at the following five levels: the lower corner of the femoral neck cut (level 1); the center of the lesser trochanter (level 2); 1 cm distal from the lesser trochanter (level 3); the middle of the stem (level 4); and 1 cm proximal from the stem tip (level 5). The canal fill ratio was defined as the ratio of stem area to the total medullary cavity area at each cross-section level. The canal fit ratio was defined as the ratio of the length of stem-endo-osteal contact to the total endo-osteal length at each cross-section level. A distance of less than 1 mm between the stem surface and the endo-osteal line was defined as contact. The length of the proximal posterolateral femoral cortical bone removed by milling at the vertical midpoint of the neck cut level (LPFCR) was also measured to evaluate the fit of stems at a distance more proximal than level 1 (Fig. 2).

In our examination of the effects of proximal femoral canal geometry, the lateral curvature of the proximal femur and femoral anteversion were assessed on the workstation display. The lateral curvature of the proximal femur was assigned an α angle, according to the method of Noble et al. (Fig. 3)9 The α angle of the femur was defined as the angle of intersection of the anterior bow of the diaphysis and the posterior bow of the metaphysis. Femoral anteversion was measured using the single-slice CT method.10 Femoral anteversion was defined as the angle of intersection of the line passing through the midpoints of the neck at the medial and lateral edges of the central portion of the neck just below the femoral head and the tangent to the posterior condyles. All measurements were performed by one of the senior authors in a blind fashion.

The paired t-test, unpaired t-test, and single regression analysis were used for statistical analysis. Differences were considered significant when the p-value was less than .05.

**RESULTS**

**Canal Fill Ratios**

With the ABG components, the average canal fill ratios were highest at level 5 and lowest at level 1 (Fig. 4). With the Osteolock components, the av-
Fig. 5. Canal fit ratios for all 50 femora. Averages and error bars are shown for each level. * **Difference was statistically significant (paired t-test; *p < .05; **p < .0001). NS: Difference was not significant.

The average canal fill ratios were highest at level 4 and lowest at level 1.

The Osteolock components showed significantly greater canal fill ratios than the ABG components at levels 1, 3, and 4, while the ABG components showed significantly greater canal fill ratios than the Osteolock components at level 5. At levels 1, 3, 4, and 5, the differences were significant in the patients with DDH and in the patients of the control group.

**Canal Fit Ratios**

The canal fit ratios were relatively low (Fig. 5) in comparison to the canal fill ratios. However, for both ABG and Osteolock components, the levels with the highest and lowest average canal fit ratios were the same levels as those with the highest and lowest average canal fill ratios.

The Osteolock components showed significantly greater canal fit ratios than the ABG components at level 4, while the ABG components showed significantly greater canal fit ratios than the Osteolock components at levels 1, 2, and 5. At level 1, the differences were significant in the patients with DDH but not in the patients of the control group (Fig. 6). At levels 4 and 5, the differences were significant in the patients of both groups. At level 2, the differences were significant in neither group.

**Length of the Proximal Posterolateral Femoral Cortical Bone Removed by Milling at the Vertical Midpoint of the Neck Cut Level (LPFCR)**

The LPFCR was significantly greater for the Osteolock components than for the ABG components (Fig. 7). When ABG components were used, the LPFCR was similar for the patients with DDH and those of the control group. However, when the Osteolock components were used, the LPFCR was significantly greater in the patients with DDH than in the patients of the control group.

**The α Angle and Femoral Anteversion**

The α angle and femoral anteversion are shown in Table 2. The α angle and femoral anteversion were both significantly greater in the patients with DDH than in those of the control group. In the patients with DDH, the α angle and femoral anteversion were greater in women than in men, but the numbers were so small that statistical analysis was not performed. In the patients of the control group, differences in the α angle and femoral anteversion between men and women were not significant.

With the Osteolock components, the α angle significantly correlated with femoral anteversion (Fig. 8) and the LPFCR (Fig. 9).
Table 2. The \( \alpha \) Angle and Femoral Anteversion

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Sex</th>
<th>Number of femora</th>
<th>( \alpha ) angle (*)</th>
<th>Femoral anteversion (*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDH</td>
<td>Men</td>
<td>25</td>
<td>30.5 (18.0–48.2)†</td>
<td>38.1 (18.5–75.7)†</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>3</td>
<td>21.3 (18.3–23.5)</td>
<td>28.0 (19.9–33.3)</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>22</td>
<td>31.8 (18.0–48.2)</td>
<td>39.5 (18.0–75.7)</td>
</tr>
<tr>
<td>Control</td>
<td>Men</td>
<td>25</td>
<td>21.9 (−6.2–41.0)†</td>
<td>22.3 (2.6–43.7)†</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>15</td>
<td>21.1 (−6.2–41.0)</td>
<td>20.6 (11.0–43.7)</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>10</td>
<td>23.4 (7.8–38.7)</td>
<td>25.1 (2.8–35.3)</td>
</tr>
<tr>
<td>Total</td>
<td>Men</td>
<td>50</td>
<td>26.3 (−6.2–48.2)</td>
<td>30.4 (2.8–75.7)</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>18</td>
<td>21.1 (−6.2–41.0)</td>
<td>21.9 (11.0–43.7)</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>32</td>
<td>29.4 (7.8–48.2)</td>
<td>35.3 (2.8–75.7)</td>
</tr>
</tbody>
</table>

* Values are given as mean (range).
† Differences were statistically significant (unpaired t-test).

DISCUSSION

Fit and fill are determined by femoral component design, femoral canal geometry, and operative techniques. In virtual operations using ORTHODOC, factors related to operative technique are eliminated. Consequently, the effects of femoral component design and femoral canal geometry on fit and fill can be better defined. This is very helpful not only in selecting the right femoral component for optimal fit and fill, but also in developing new designs for cementless femoral components. Because this type of system can allow repeated implantation of various designs of implants in a single femur, the cost and time in developing a new design of implant can be greatly reduced compared with traditional cadaver-based methods.9,11

In our examination of femoral component designs, differences in proximal shape (ABG: posteriorly bowed anatomic; Osteolock: straight) and distal shape (ABG: cylindrical; Osteolock: tapered) were the focus of analysis. To assess the effects of differences in femoral canal geometry, results of virtual operations on patients with DDH (in which femoral canal geometry is different from that of normal femora12) and patients without DDH were compared.

The difference in distal stem design is the likely reason for the fact that the canal fill ratios and the canal fit ratios are both higher for the ABG components than for the Osteolock components at 1 cm proximal from the stem tip (level 5), and the

![Fig. 8. Significant positive correlation was found between the angle \( \alpha \) and femoral anteversion \((r = .69, p < .0001)\).](image)

![Fig. 9. Significant positive correlation was found between the length of the proximal posterolateral femoral cortex removed by milling at the vertical midpoint of the femoral neck osteotomy level (LPFCR) and the \( \alpha \) angle \((r = .33, p = .019)\).](image)
fact that they are lower for ABG components than for Osteolock components at the middle of the stem (level 4). In some patients in the current study, the distal cylindrical portion of the ABG components prevented optimal proximal fit and fill because of tight diaphyseal fit near the stem tip. Because the femoral canal is flared towards the femoral neck, tight diaphyseal fit near the stem tip results in poor fit and fill at the upper area of the cylindrical portion, i.e., at level 4. In contrast, the tapered design does not generally result in a tight diaphyseal fit near the stem tip, and thus it allows for better fit and fill at level 4.

At levels in the proximal femoral metaphysis (levels 1–3), where the proximal femur is bowed posteriorly in the sagittal plane, the lateral curvature of the stem and the femur is thought to affect the fit and fill. In the current study, both the lateral curvature of the femur and the femoral anteversion were measured. The results were consistent with those reported by Sugano et al., in which femora with DDH showed significantly greater anteversion than morphologically normal femora. Furthermore, in the current results for Osteolock components, the lateral curvature of the femur correlated with femoral anteversion and the LPFCR. These findings indicate that, to achieve good fit and fill, implantation of a straight-stem component requires removal of more cortical bone at the posterolateral femoral neck than implantation of an anatomic stem component, especially in patients with relatively extreme femoral anteversion (lateral curvature of the proximal femur).

ABG components have lateral curvature, while Osteolock components do not. This difference in the proximal body of the stems may be the reason for the significantly higher canal fit ratios of ABG components, relative to Osteolock components, at the levels proximal to the lesser trochanter (levels 1 and 2) in patients with DDH. The better fit is most likely due to the correspondence between the lateral curvature of the proximal portion of the anatomic stem in the sagittal direction and the lateral curvature of the proximal femoral canal in patients with DDH, and the resultant better endo-osteal contact at both the anterior aspect of the cavity and the posterior aspect (Fig. 10A and B). In patients with relatively small lateral curvature of the proximal femur, a straight-stem component may achieve a degree of canal fit that is similar to that of an anatomic stem component, and this may be the reason that the above-mentioned differences in fit were not detected in the patients of the control group.

In contrast, the canal fill ratios for the Osteolock components were higher at the lower corner of the femoral neck cut (level 1). This is most likely because the canal fill ratio is affected not only by
the curvature of the stem, but also by the cross-sectional area of the stem in the proximal portion.

The influence of fit and fill on component stability has been investigated biomechanically. Dujardin et al.\(^4\) showed that the metaphyseal fill was significantly linked with the vertical and rotational components of instability. Naidu et al.\(^5\) indicated that increasing the proximal fit reduces implant rotation about its longitudinal axis in flexion loading. In the current results, proximal fit was better in an anatomic stem, and proximal fill was better in a straight stem. It is unknown which type of implant can achieve greater stability.

The differences between ABG and Osteolock that may affect the clinical results were supposed to be the greater distal canal fit and fill in ABG, and the greater LPFCR in Osteolock. Distal fixation resulting from the greater distal canal fit and fill may lead to proximal stress-shielding by stress concentration in the diaphysis.\(^14\) The greater LPFCR may result in loss of bone stock and fracture of the proximal femur. When selecting or developing a cementless femoral stem, the influence of fit and fill of the stem on these possible biomechanical and clinical consequences should be considered.

The current study has one limitation. There was a significant difference in sex ratio between the patients with DDH and those of the control group. Although, with the numbers available in the current study, no differences were found in the \(\alpha\) angle or femoral anteversion (indicators of femoral geometry) between men and women in the control group, a greater number of male patients with DDH would be required for a precise comparison of male and female DDH patients.

In conclusion, a distal cylindrical design tends to have relatively poor proximal fill because of high distal fit and fill, although a stem with an anatomic proximal body tends to have relatively good proximal canal fit. Implantation of a straightstem femoral component in patients with extreme femoral anteversion requires removal of a relatively large amount of the proximal posterolateral femoral cortical bone, leading to loss of bone stock and fracture of the greater trochanter. However, a tapered design results in an increase in fit and fill at the middle of the stem and a decrease in fit and fill near the stem tip. This may result in less stress-shielding by avoiding the distal fit. Virtual implantation on the ORTHODOC workstation could clearly define the influence of the proximal and distal stem designs on fit and fill.

REFERENCES