

## Quantifying Degree of Difficulty in Hip Resurfacing of Pistol-Grip Deformity

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### Abstract

*This study used computer simulation to endeavor to quantify the relative degree of difficulty of resurfacing femora with pistol-grip deformities compared to relatively normal femora. Computer models of five pistol-grip femora and one relatively normal femur were computed from computed tomography (CT) scans of patients who had undergone computer-assisted hip resurfacing. A computer simulation of positioning the femoral resurfacing component on the femur was performed to count the number of acceptable configurations of the component on the femur. A high number of acceptable configurations implies that the surgeon has greater freedom, or greater margin for error, in implanting the component compared to a femur with a smaller number of acceptable configurations. We found that pistol-grip deformities dramatically reduce the number of acceptable configurations for valgus alignment, and that such configurations result in decreased femoral offset and increased depth of reaming.*

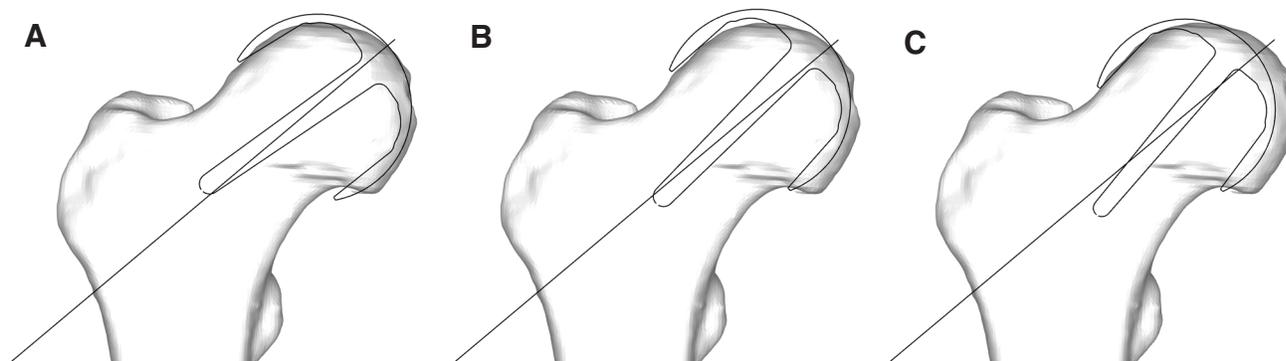
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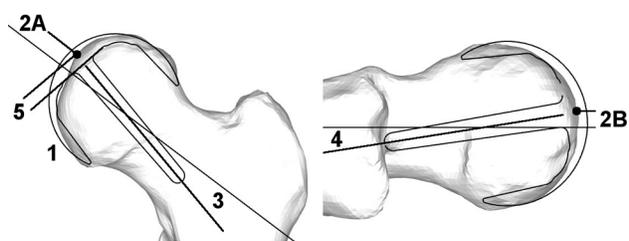
**M**etal-on-metal total hip resurfacing has become a promising alternative to total hip arthroplasty for a younger, more active population with osteoarthritis. Studies have shown good short to midterm results and low failure rates,<sup>1-4</sup> but there is general agreement that resurfacing is more difficult than total hip arthroplasty, and that the technique has a steep learning curve.<sup>5,6</sup> Varus alignment of the component and notching of the femoral neck have been implicated in early failure.<sup>1,7-9</sup> Achieving optimal implant alignment is further complicated by the presence of deformities around the femoral head and neck.

Patients commonly present with early osteoarthritis prior to resurfacing from a CAM-type impingement as a result of a pistol-grip deformity. As many as 40% of patients with primary osteoarthritis are found to have a pistol-grip deformity, typically characterized by asphericity of the femoral head and an abnormal contour of the head-neck junction due to flattening of the superolateral neck.<sup>10-14</sup> The posteroinferior angulation of the head and flattening of the transition between the head and neck presents challenges for positioning of the resurfacing head component. Notching might be avoided by choosing varus alignment of the component (Fig. 1A). Alternatively, valgus alignment can be achieved by excessive translation of the component superiorly, which results in an incomplete cylindrical cut and possibly compromised fixation (Fig. 1B). Valgus alignment with good fixation and without notching is possible by reducing femoral offset (Fig. 1C), but the margin for error appears to be quite small.

The goal of this computer simulation study was to quantify the relative difficulty of resurfacing a pistol-grip femur compared to a relatively normal proximal femur with valgus alignment of the component. In addition, we estimated the changes in femoral offset and limb length after the resurfacing procedure.



**Figure 1** A, Component placed in 5° varus alignment to avoid notching of the neck. B, Component in 5° valgus alignment shifted superiorly to avoid notching of the neck, resulting in a cylindrical cut that removes no bone from the superior-lateral head. C, Component in 10° valgus alignment with a complete cylindrical cut and no notching; however, femoral offset has been decreased.



**Figure 2** Configuration parameters: (1) component size, (2A and 2B) translation of stem insertion point perpendicular to neck axis, (3) valgus alignment angle, (4) version alignment angle, (5) depth of reaming measured along the axis of the stem.

## Materials and Methods

Computer simulation was used to model the placement of the femoral component on a proximal femur. The basic idea underlying the simulation was that a model of the component can be placed on a model of the proximal femur and can be checked as to whether or not the configuration of the component meets certain acceptability criteria. By varying the position and angular alignment of the component over a range of values, all acceptable configurations of the component on the femur can be enumerated. Moreover, computations of biomechanical measurements, such as the change in femoral offset, for each configuration can be made.

The position and angular alignment of the component was determined by configuration parameters, which were defined to be those parameters that the surgeon can control intraoperatively to affect the final placement of the

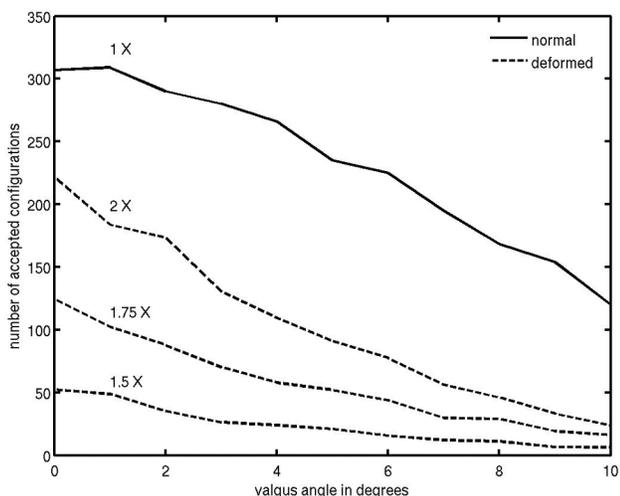
femoral component. These parameters are 1. component size, 2. stem entry-point location, 3. valgus alignment angle, 4. version alignment angle, and 5. depth of reaming. The entry-point location for the stem was measured relative to the point where the neck axis emerges from the femoral head. The varus and version alignment angles were measured relative to the neck axis. The depth of reaming was defined as the depth of bone reamed from the femoral head measured along the axis of the component. The configuration parameters are illustrated in Figure 2.

Four criteria were applied to evaluate whether the component was acceptably aligned relative to the femur. The first criterion was that the component stem remained completely within the femoral neck and did not pierce the cortex. The second criterion was that the rim of the component did not notch the femoral cortex. The third criterion was that the cylindrical cut removed some bone all around the circumference of the cylinder; failure to do so would mean that some part of the component would either be completely unsupported or only supported by the cement mantle. The final criterion was that any gap between component and head was less than 3 mm in depth.

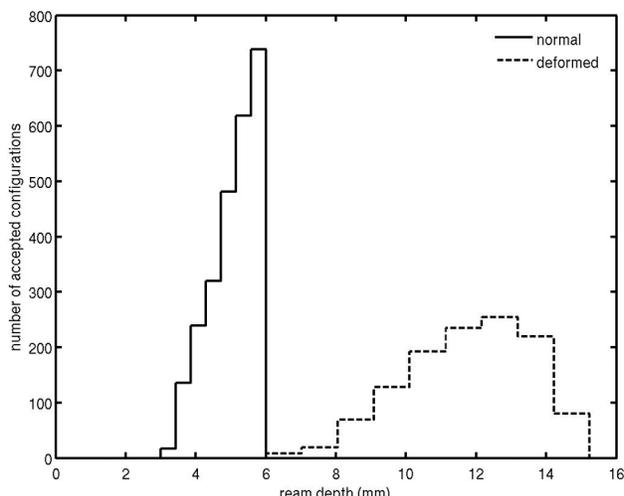
Computer models of the ASR™ femoral components were provided by the manufacturer (DePuy Orthopaedics, Inc., Warsaw, IN). Computed tomography (CT) scans of six patients who had undergone computer-aided hip resurfacing were processed to produce computer models of the proximal femora. All patients gave informed consent,

**Table 1** Range of Configuration Parameters Used in Our Experiment

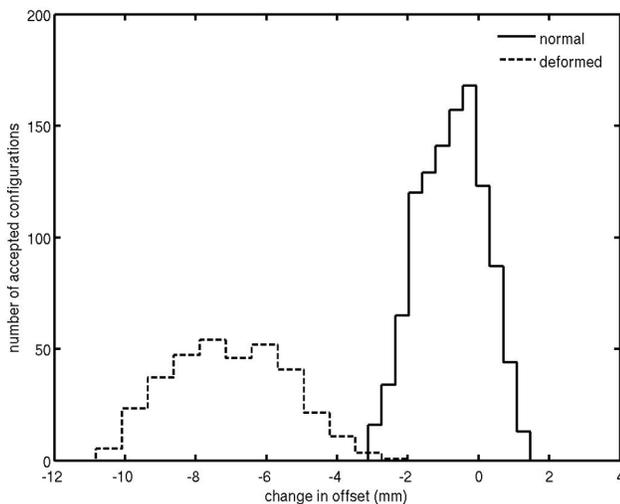
Configuration Parameter	Minimum Value	Maximum Value	Increment Size
Size	Smallest possible	+1 Upsizing	1 Size
Varus/Valgus	0°	10° Valgus	1°
Version	-10°	10°	1°
Entry point: anterior	-8 mm	8 mm	1 mm
Entry point: superolateral	-8 mm	8 mm	1 mm
Ream depth	0 mm	Two-times component thickness	1 mm



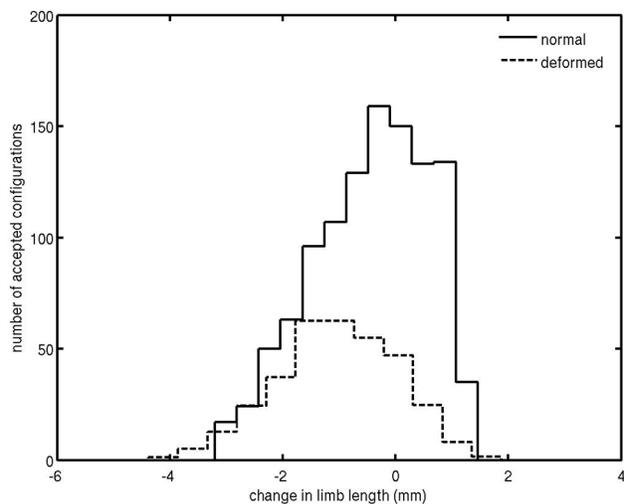
**Figure 3** Number of accepted configurations versus valgus alignment angle. Results for the normal femur are restricted to reaming depths less than the shell thickness of the component. Results for the deformed femora are for maximum reaming depths of 1.5, 1.75, and two-times the shell thickness.



**Figure 4** Number of accepted configurations versus reaming depth for 5°-10° valgus alignment. Results for the normal femur are restricted to reaming depths less than the shell thickness of the component.



**Figure 5** Number of accepted configurations versus change in offset for 5°-10° valgus alignment. Results for the normal femur are restricted to reaming depths less than the shell thickness of the component.



**Figure 6** Number of accepted configurations versus change in limb length for 5°-10° valgus alignment. Results for the normal femur are restricted to reaming depths less than the shell thickness of the component.

and we received institutional ethics approval for use of the medical images. One femur was relatively normal in appearance in that there was a clear concave transition between the femoral head and neck. The remaining five femora exhibited aspects of pistol-grip deformities, in particular varus tilt of the head and loss of the concavity at the superior aspect of the transition between head and neck. We identified the diameter and center of the femoral head in the coronal plane using a best-fit circle. The diameter of the head was used to set the smallest component size. We simulated resurfacing applying the same range of configuration parameters for each femur; details are provided in Table 1. For each acceptable

component configuration, we computed the changes in femoral offset and limb length as the horizontal and vertical distances, respectively, between the centers of the femoral head and the component.

Because the same set of configuration parameters were used to test every femur, all femora were compared by counting the number of accepted configurations. A femur with a large number of acceptable configurations implies that the surgeon has greater flexibility (or greater margin of error) in implanting the component. Conversely, a femur with a small number of acceptable configurations implies that the surgeon has less flexibility (or less margin of error) in implanting the component. Of particular interest was the

number of acceptable configurations as a function of valgus alignment, as the amount of valgus alignment has been associated with the risk of early failure.

## Results

When analyzing the results, we found that the normal femur had a large number of acceptable configurations, even if the maximum reaming depth was restricted to the thickness of the shell of the component. However, there were almost “zero” accepted configurations for the deformed femora under these conditions. Results for the deformed femora are shown at various maximum reaming depths in Figure 3. The influence of deformity on reaming depth is shown in Figure 4, where the maximum reaming depth for the normal and deformed femora was set to the shell thickness and twice the shell thickness, respectively, and the valgus alignment was between 5° and 10°.

The change in horizontal femoral offset for valgus alignment between 5° and 10° is shown in Figure 5. The mean change in offset for the normal femur was -0.8 mm, with a standard deviation (SD) of 0.9 mm. The mean change in offset for the deformed femurs was -7 mm (SD, 1.6 mm).

The change in limb length for valgus alignment between 5° and 10° is shown in Figure 6. The mean change in limb length for the normal femur was -0.5 mm (SD, 1.0 mm). The mean change in limb length for the deformed femurs was -1 mm (SD, 1.1 mm).

## Discussion

Using our simulation method, we attempted to count the total number of acceptable configurations of a resurfacing component on a proximal femur. The number of acceptable configurations for a desired outcome measure is related to the amount of freedom, or margin of error, that the surgeon has to achieve said outcome; alternatively, the number of acceptable configurations is inversely related to the risk of failing to achieve a desired outcome measure. The simulation results suggest that hip resurfacing of a femur with pistol-grip deformity is a high-risk procedure compared to resurfacing of a more normal appearing femur, especially if valgus alignment of the component is desired.

Two consequences of achieving valgus alignment on a pistol-grip femur were observed. The first consequence was an increase in the amount of bone that must be reamed compared to a normal femur. With a normal femur, limiting the reaming depth to the thickness of the shell of the component still allowed for a large number of configurations producing 10° valgus alignment. With a deformed femur, an increase in the maximum reaming depth to twice the shell thickness only produced one-fifth of the number of accepted configurations compared to the normal femur. Resurfacing with valgus alignment of a pistol-grip femur sacrifices some bone conservation due to the increase in reaming depth.

The second consequence of valgus alignment on a pistol-grip femur is a decrease in femoral offset. The clinical

disadvantages of failing to restore normal femoral offset in total hip arthroplasty are well known<sup>15</sup>; these disadvantages include compromised stability, range of motion, and abductor strength. An average decrease in offset of 7 mm was observed in the deformed femora. Upsizing of the femoral component may offset some of the decrease, but we have not yet attempted to verify this hypothesis. Studies comparing surface arthroplasty to total hip replacement have shown that the femoral offset is reduced by valgus alignment of the implant during resurfacing.<sup>7,16,17</sup> Our simulation result with the normal femur supports the observation of reduced offset; an average offset decrease of 0.8 mm for the normal femur with 5° to 10° valgus alignment was calculated.

These results suggest that restoration to valgus correction compromises bone conservation and femoral offset in pistol-grip deformities. Cobb and colleagues<sup>18</sup> have commented on the difficulty of correction and the possible need for compromise when using resurfacing in the presence of cam-type deformities. In a laboratory study, they observed that both conventional and image-free computer navigation failed to provide adequate information to inexperienced surgeons attempting to treat femora with cam-type deformities. We only examined deformed femora where the deformity was limited to posteroinferior angulation of the head and flattening of the superolateral aspect of the head-neck junction. We expect that there is a continuum between normal and pistol-grip deformity, and that the margin for error decreases as femora become progressively more deformed. The combination of a possibly high incidence of various deformities and the limitations of current instrumentation may help to explain why hip resurfacing has been characterized as having a steep learning curve.<sup>5,6</sup>

Deformities of the anterior part of the head and neck have also been reported. Flattening of the anterior aspect can be measured using the head-neck offset ratio from a cross-table lateral radiograph.<sup>19</sup> Beaulé and colleagues reported that small values of this ratio, less than 0.13, were associated with risk for femoroacetabular impingement after resurfacing.<sup>20</sup>

One criticism of our simulation method is that it is susceptible to errors in interpretation of the CT scan when constructing the model of the femur. Any actions that a surgeon might ordinarily take to address deformities, such as removal of osteophytes or other defects, must also be performed on the model of the femur. A second criticism is that we evaluated acceptability in a binary fashion; a configuration was either acceptable or it was not. For example, if a component configuration resulted in impingement of the rim on the cortex by even a miniscule amount, then the configuration was considered to cause notching and classified as unacceptable. Our estimates of the absolute number of acceptable configurations should be considered a lower bound (that is to say, there are probably additional configurations that would be clinically acceptable); however, because each femur was evaluated in an identical fashion, we believe that the difference in the number of acceptable

configurations between the normal and deformed femora is likely accurate.

We have described a method of computer simulation that can be used to predict risk and biomechanical outcome measures for resurfacing; however, our methods could also be used for planning of CT-based computer-navigated resurfacing. For example, the surgeon could simply ask to see all configurations with valgus alignment producing minimal changes to offset and limb length. Further analyses, similar to those proposed for total hip arthroplasty,<sup>21</sup> could also be performed.

## Conclusions

We have demonstrated through computer simulations that valgus alignment in resurfacing of a pistol-grip femur is possible, but considerably more difficult than resurfacing of a normal femur, and that it leads to compromises in bone preservation and femoral offset. The question remains of how much offset should be compromised to achieve an optimal valgus alignment of the component.

## Disclosure Statement

None of the authors have a financial or proprietary interest in the subject matter or materials discussed, including, but not limited to, employment, consultancies, stock ownership, honoraria, and paid expert testimony.

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