Femoral neck fracture following hip resurfacing

THE EFFECT OF ALIGNMENT OF THE FEMORAL COMPONENT


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A total of 20 pairs of fresh-frozen cadaver femurs were assigned to four alignment groups consisting of relative varus (10° and 20°) and relative valgus (10° and 20°), 75 composite femurs of two neck geometries were also used. In both the cadaver and the composite femurs, placing the component in 20° of valgus resulted in a significant increase in load to failure. Placing the component in 10° of valgus had no appreciable effect on increasing the load to failure except in the composite femurs with varus native femoral necks. Specimens in 10° of varus were significantly weaker than the neutrally-aligned specimens.

The results suggest that retention of the intact proximal femoral strength occurs at an implant angulation of ≥142°. However, the benefit of extreme valgus alignment may be outweighed in clinical practice by the risk of superior femoral neck notching, which was avoided in this study.

Excellent short- and medium-term results have been reported with the new generation of hip resurfacing arthroplasties.1-7 The advantages of preserving proximal femoral bone stock, the low dislocation risk and the excellent wear characteristics make resurfacing an attractive alternative to total hip replacement. However, concerns about the risk of femoral neck fracture and the consequences of metal ions still remain.8 Alignment of the femoral component has been associated with an increased risk of femoral neck fracture in retrospective reviews9-13 and in finite element analysis.14,15 The purpose of this study was to establish the effect of orientation of the femoral component on the risk of fracture of the femoral neck.

Materials and Methods

The study was conducted in two phases. The first tested fresh-frozen cadaver femurs and the second used synthetic third-generation composite femurs with two different neck geometries. Cadaver specimen testing. We obtained 20 pairs of fresh-frozen cadaver femurs. Each pair was the left and right femurs from the same donor. Local ethics committee approval was obtained. The median age of the donors was 71 years (53 to 90); 12 were male and eight were female. The femurs were defrosted for 24 hours prior to testing.

Pairs of femurs were assigned randomly to four alignment groups, namely relative varus (10° and 20°) and relative valgus (10° and 20°). Each pair contained one control specimen in neutral alignment and the other at the experimental alignment value. Neutral alignment was taken as when the stem-shaft angle of the femoral component was at the same angle as the neck-shaft angle of the femur. All specimens underwent pre-preparation scaled digital radiographs and bone mineral density measurements using a DEXA scan (Hologic, Bedford, Massachusetts).

The femurs were prepared using imageless computer navigation (VectorVision SR, BrainLAB, Feldkirchen, Germany) to position the initial guide wire during preparation of the femoral head. Specimens were individually registered and digitally mapped using an infrared camera and array system. Planning was performed using the VectorVision SR (BrainLAB) console for the position of the implant and the alignment angle. An infrared handheld drill guide, providing real-time location relative to the planned location and angle, was used to insert the guide wire. This wire was the basis for the remainder of the standard preparation of the femoral head, including central canal drilling, reaming and chamfering. Once prepared, the appropriate Birmingham Hip Resurfacing (BHR) component (Smith & Nephew Inc., Memphis, Tennessee) was cemented on to the prepared femoral head using polymethylmethacrylate (PMMA) bone cement (Stryker Howmedica Osteonics, Allendale, New Jersey). Implant size was determined...
from the width of the femoral neck using the standard BHR measurement tool (Smith & Nephew). All implants were positioned in neutral version. The femoral neck was closely inspected to ensure that no notching had occurred. Implants were impacted in place and the stem-shaft angle was verified to confirm that no fracture had occurred, using scaled digital radiographs.

The prepared femurs were then sectioned 17 cm below the tip of the greater trochanter and potted using cement in 7 cm-high chambers. There were 10 cm of proximal femur left exposed. The potted femurs were placed in a position of single-leg stance and tested in axial loading to failure using an Instron mechanical testing machine (Model 8874, Instron, Canton, Massachusetts).

**Synthetic specimen testing.** The use of third-generation composite femurs (Pacific Research Laboratories Inc., Vashon, Washington) has been well validated as replicating cadaver bone. The availability of cadaver tissue often limits sample size. We therefore used the reproducible properties of synthetic bone to examine the effect of alignment in further detail. We examined two composite femur models, a medium left femur with a native neck-shaft angle of 135° and a large left femur with a neck-shaft angle of 120° (composite femur models 3303 and 3306,respectively; Pacific Research Laboratories Inc.). The 135° neck-shaft angle femurs were initially chosen to attempt to validate the synthetic model against cadaver results. We then used the 120° model to examine the effect of alignment of the femoral component in more detail in a model reproducing a varus native femoral neck.

A total of 30 femurs with a neck-shaft angle of 135° were divided into six groups of five specimens each. One group was assigned to be the intact group tested without an implant, a second control group was tested with the implant in neutral alignment at the native neck-shaft angle of 135°, and the remaining four groups were prepared in relative varus (5°, 10° and 15°) and relative valgus (5°, 10°, 15° and 20°). As in the specimen testing, all the femoral neck implants were positioned in neutral version and were closely inspected to ensure that no notching had occurred.

The synthetic femurs were prepared in the same way as the cadaver femurs, using imageless navigation to position the initial guide wire followed by standard preparation of the femoral head. The femurs were sized for the appropriate BHR component (42 mm for composite femur model 3303 and 46 mm for composite femur model 3306, Smith & Nephew Inc.), and cemented on to the prepared femoral head using PMMA cement. Implants were impacted in place and the stem-shaft angle was verified by scaled digital radiographs. All components were verified to be within ± 2° of the intended alignment angle.

Following resurfacing, each specimen was orientated in approximately 7° of adduction in the coronal plane and aligned vertically in the sagittal plane to simulate anatomical loading in single-leg stance. Distally, both femoral condyles were secured with threaded pins and mounted in a stainless steel jig. Proximally, the femoral head was inserted into an obliquely sectioned stainless steel cup which was orientated with no ante- or retroversion with respect to the femoral neck. The femoral head was not fixed, but was free to rotate inside the cup. Specimens were loaded in axial compression using a mechanical testing machine (Instron). The load to failure for each resurfaced femur was determined by applying a vertical force (displacement control, 10 mm/min, preload = 100 N) to generate axial compression until failure. Fracture patterns of the bone and implant at failure were recorded.

**Statistical analysis.** The statistical software package SPSS 13 (SPSS Inc., Chicago, Illinois) was used to analyse differences between alignment groups. A paired *t*-test was used to compare bone mineral density, femoral geometry and pre- and post-implant specimen stiffness. One-way ANOVA with Tukey post hoc analysis was performed, comparing the differences in post-implant stiffness and ultimate load to failure between the individual resurfaced alignment groups for both native neck-shaft angle femur geometries. A p-value of 0.05 was used to determine statistical significance.
Results

**Cadaver specimens.** The paired specimens were well matched for bone mineral density (BMD) and proximal femoral geometry (Table I). The load to failure results for the four different stem angles are shown in Figure 1. Placing the component in a relative valgus alignment of 20° resulted in a significant increase in mean load to failure of 22% between experimental and control specimens (6808 N; SD 3296 vs 5570 N; SD 3229, p = 0.03). The other three groups of alignment did not reach significance (p > 0.29); however, a trend was observed with 10° of varus alignment reducing the mean ultimate load to failure by 16% between experimental and control specimens (6008 N; SD 1304 vs 7146; SD 2253, p = 0.29). Placing the component in 10° of valgus did not appear to have a significant effect on proximal femoral strength (p = 0.836).

**Synthetic specimens.** The mean axial load to failure for the 135° neck-shaft angle intact specimen group was 6491.5 N; SD 441.8, which was not significantly different from the mean axial load to failure for the 120° intact group of 6855.8 N; SD 450.2 (p = 0.232).

The 135° intact specimens had a significantly greater mean load to failure than specimens prepared in 10° of relative varus alignment (p = 0.006), but were not significantly stronger than any other alignment group tested (p > 0.062). Ultimate load to failure values can be seen in Figure 2, where specimens prepared in 20° of relative valgus were significantly stronger than all other resurfaced groups (p < 0.024). Placing the component in 10° of relative varus significantly weakened the resurfaced femur compared with the neutrally-aligned component (p = 0.035), whereas placing the component in 10° of valgus had no appreciable effect on increasing the load to failure compared with neutral alignment (p = 0.999).

The 120° intact specimens had a significantly greater mean load to failure than neutral and varus aligned resurfaced specimens (p < 0.005), but were not significantly stronger than specimens prepared in any degree of valgus orientation (p > 0.207). Ultimate load to failure values can be seen in Figure 3, where specimens prepared in 20° of relative valgus were significantly stronger than those prepared in neutral or any degree of varus alignment (p < 0.002).
Specimens prepared in 10° of relative valgus were significantly stronger than specimens with a neutral component \((p = 0.017)\), but those in 10° or less of relative varus had no significant effect on reducing the load to failure compared with neutral alignment \((p > 0.135)\).

The load to failure for both synthetic geometries was standardised against the load to failure values for the intact femur (Fig. 4). Regression analysis demonstrated that the mechanical strength of the resurfaced specimens would approximate that of the unresurfaced, intact femur if a minimum femoral component angulation of 142° was achieved with respect to the two neck geometries studied.

Failure patterns were consistent within each alignment group and between the synthetic and cadaver specimens. Failure in the resurfaced specimens originated at the superior bone-implant interface and propagated toward the medial calcar, exiting proximal to the lesser trochanter. Fracture of the intact synthetic femoral neck started at the superolateral piriform fossa and propagated vertically toward the inferior neck at the superior margin of the lesser trochanter.

**Discussion**

The optimal alignment of the femoral component during resurfacing arthroplasty has remained an area of controversy since the initial designs in the 1970s. Freeman\(^\text{19}\) believed that it should be aligned with the medial trabecular system within the femoral neck. He showed that this system lies at approximately 20° to the vertical.\(^\text{19}\) This implies alignment of the component with a stem-shaft angle of 160°. This extreme angulation is technically difficult to obtain in the majority of hips and increases the risk of notching of the femoral neck,\(^\text{20}\) and of there being exposed cancellous bone at the rim of the component,\(^\text{9}\) which may predispose to femoral neck fracture.\(^\text{9,12,13,21}\) This angulation may also lead to the absence of superior bone supporting the implant, and to an increased risk of ‘internal notching’ of the medial calcar, both of which have also been speculated to weaken the proximal femur and predispose to fracture. Internal notching occurs in current hip resurfacing techniques which require a central drill to be used to prepare the femur for the stem of the component.

The inherent difficulty of placing the component at 160° leads others to advocate placing it in a less extreme position, and an absolute stem-shaft angle of 140° has been suggested as a compromise.\(^\text{7}\) Beaulé at al\(^\text{11}\) reviewed 94 hips in patients < 40-years of age who had undergone hip resurfacing and found that a stem-shaft angle ≤ 130° was associated with adverse radiological changes or early failure. This rate of adverse outcome was 6.1 times greater than in the group in which the stem-shaft angle was > 130°. A basic mathematical model was also constructed to predict the biomechanical consequences of alterations in alignment of the femoral component. This demonstrated an almost linear relationship between total stress within the superior femoral neck and stem-shaft angulation, with an increased angle (valgus placement) reducing the stress. Beaulé at al\(^\text{11}\) therefore suggested a valgus orientation of the femoral component. They also demonstrated that an increasing valgus position of the femoral component during resurfacing was negatively correlated with femoral offset, and that the two variables were closely interrelated. We therefore accept that the apparent increased strength of the valgus positioning within our study will in part relate to the reduced offset and resulting bending moment; however, this is also directly comparable to clinical practice. Others have used finite element analysis to observe the changes in bone stresses, concluding that a valgus placement will reduce bone stress in the superior neck and hence potentially reduce the risk of fracture of the femoral neck.\(^\text{14,15}\) A recent investigation into the effect of implant alignment on load transfer and strain distribution in the resurfaced femur showed that a component which is aligned in 10° of valgus reduced the strain in the superior neck, whereas a varus aligned component had the opposite effect.\(^\text{22}\) Although the study showed that orientation of the component had an impact on load patterns in the proximal femur, the others were unable to show that coronal alignment had an influence on the risk of fracture.

The new generation of hip resurfacing has excellent early to mid-term results,\(^\text{2,4}\) but the risk of early femoral neck fracture remains a concern. The 2007 Australian National Joint Replacement Registry data from 8945 hip resurfacings revealed that 47% of revision procedures were performed for femoral neck fracture.\(^\text{23}\) The overall rate of fracture has been found to be 1% to 3%.\(^\text{9,12,13,24,25}\) A retrospective review of 50 femoral neck fractures following resurfacing showed that more than 5° of varus alignment was observed in 71% of cases that fractured.\(^\text{13}\) This early failure due to femoral neck fracture is of great concern and therefore this amount of alignment was used as the baseline in the current study. We do, however, acknowledge that femoral component alignment may also contribute to the medium- and long-term risk of fatigue failure as alluded to by Beaulé et al.\(^\text{11}\)

The cadaver testing in this study appears to show that an increased resistance to femoral neck fracture is only achieved once a stem-shaft angle of 20° of relative valgus is obtained. Interestingly, it did not show a significant difference in proximal femoral strength when placing the component in 10° of relative valgus compared with placing it in a neutral alignment. These data would appear to contradict those of others, in which a slight valgus position was felt to protect against neck fracture.\(^\text{11}\) Although significance was not obtained, there did appear to be a trend toward reduced proximal femoral strength when the component was placed in 10° of varus alignment compared with the neutrally-aligned controls.

For both synthetic femoral geometries, 20° of relative valgus alignment appeared to have the most dramatic effect on increasing proximal femoral strength, agreeing with the results in the cadaver tests. For smaller increments of alignment, however, the two femoral geometries had
contradictory results. It appeared that 10° of relative valgus alignment significantly strengthened the varus neck resurfaced femurs (120° neck-shaft angle) but had little effect on the more valgus necks (135° neck-shaft angle). Conversely, 10° of relative varus alignment significantly weakened the more valgus resurfaced femurs but had little effect on the varus femurs. Regression analysis of the synthetic femurs showed that an absolute implant alignment of 142° preserved femoral strength, compared with the intact, unresurfaced specimens.

These results suggest that a minimum of 10° of relative valgus alignment increases the proximal femoral strength of the resurfaced femur with varus native geometry. In femurs with more valgus native geometry, the benefit of increased proximal femoral strength is not achieved until an alignment of 20° of relative valgus is obtained. The results also indicate that the proximal femoral strength of the intact femur is achieved in a resurfaced femur with an absolute implant alignment of 142°, with respect to the two neck geometries studied. Positioning the component in 20° of relative valgus does increase the risks of femoral neck notching, exposed cancellous bone, lack of superior medial support and internal femoral notching as discussed earlier; therefore, there may be little benefit in such a large amount of relative valgus orientation once absolute valgus alignment of 142° is exceeded.

The difficulties of studying cadaver bone are well demonstrated in this study. Despite the use of 40 femurs, and verifying that BMD and proximal femoral geometry were not significantly different between controls and experimental specimens, there was still wide variability between paired femurs. Avoiding the difficulties inherent in cadaver testing by using third-generation composite femurs has been well validated in previous studies. A graph showing the mean percentage difference in load to failure from a neutrally-aligned component for the cadaver and synthetic specimens (synthetic specimens with 135° neck-shaft angle).
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References


