Femoral Component Positioning in Resurfacing Arthroplasty
Effects on Cortical Strains

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Abstract

Previous studies have suggested that femoral component positioning in resurfacing arthroplasty may affect strains in the femoral neck that could lead to decreased implant longevity. A strain gaged, Sawbones® model was used to determine the femoral neck strains for a variety of resurfacing head translations and angulations. We found that head positions affected strain distributions, most positions leading to increased neck strains, often over 100%, with the exception being a varus head position where the superior neck strains decreased over 50%. Although the clinical meaning of these findings is unclear, it could be of concern for stress-shielding or fatigue fracture of the femoral neck.

Surface replacement arthroplasty (SRA) has regained popularity as an alternative to total hip arthroplasty for the treatment of degenerative disease of the hip in younger patients, due to the use of modern metal-on-metal bearings and improved designs. Despite purported advantages of bone preservation, anatomic restoration, and physiological loading of the proximal femur, hip resurfacing can increase the risk for femoral neck fracture that has been reported as between 0.83% and 1.46%.1,12 A recent review of previous retrospective studies noted a relationship between femoral neck fracture and varus placement of the femoral component, intraoperative notching of the neck, older ages, and female gender.1 Additionally, fracture may be related to progressive osteonecrosis or stress shielding. Laboratory studies4-14 have used mathematical modeling and strain gage instrumented femurs to demonstrate changes in femoral neck strains after implantation of a femoral component but have generally been limited to one or two component positions.

To evaluate the effects of femoral component positioning, we measured the changes in strains in the femoral neck with nine component positions in relation to the anatomical neck axis: correct (coaxial with the femoral neck), 10° of varus, valgus, anteversion, and retroversion and 5 mm of translation superiorly, inferiorly, anteriorly, and posteriorly. Sawbones® third generation composite femurs (Pacific Research Laboratories, Inc., Vashon, Washington) were used to provide a reproducible model for testing.

Materials and Methods

The experiment was conducted in several steps: 1. determination of optimal strain gage placement; 2. comparison of femoral neck strains in intact Sawbones® and cadaver femurs; and 3. determination of femoral neck cortical strain changes for various femoral component placements in Sawbones® femurs.

Experimental Protocol

Strain Gaging

This experiment used strain gages to measure outer “cortex” strains in Sawbones® femurs for a variety of surface replacement head positions. We sought to mount the gages close to the surface replacement heads in a similar, reproducible position for all femurs. As gages could not be mounted exactly (same positions and orientations) and strain gradients in the neck are not known, each specimen served as its own control with measurements taken before
and after surface replacement head mounting.

Pre-wired simple and Rosette strain gauges (KFG-3-120-C1-11L1M2R and KFG-3-120-D17-11L1M2S, Omega, Stamford, Connecticut) were used. Rosette gages consist of three linear gages that are stacked at a fixed angle between the gages. A single rosette gauge was applied to the superior (lateral) femoral neck, such that it was placed 5 mm from the closest position to where the surface replacement femoral head would be located in the valgus position as measured from a radiograph template. The other three linear strain gauges were applied to the anterior, posterior, and inferior aspects of the femoral neck using similar templating to locate the closest respective, resultant replacement head positions. The axes of all gages were aligned with that of the femoral neck. They were all applied with cyanoacrylic adhesive after cleaning and degreasing of the neck with acetone and coated with a thin layer of silicone for protection. The gages were attached to a multiplexed data acquisition system (Microlink 770, Biodata Ltd., Manchester, United Kingdom), which allowed for simultaneous balancing of the strain gage bridges (precision resistors used for completion) and sample rates to 50 Hz. Data readings were started after each specimen was given two minutes to equilibrate and taken for a minute, which resulted in approximately 500 separate readings from each gage.

Specimen Preparation, Mounting, and Loading
The femurs were cut transversely 20 cm below the tip of the greater trochanter and potted with acrylic cement into 5x5x5 cm square aluminum tubes using a holding fixture to insure position and verticality. These specimens were held in an angle vise attached to a low friction X-Y table attached to the testing machine actuator. This support was chosen on the basis of a previous study of femoral strains produced by various support conditions. A trochanteric or ilio-tibial (IT) band force was not used.

Metal surface replacement acetabular cups were mounted with acrylic cement in a metal holder at 45° inclination and attached to the load cell of the testing machine at 15° anteversion to the necks of the femur specimens and used for loading of surface replacement heads. For loading of nonsurface replacement heads, a 3-mm thick sheet of silicone rubber was placed between the heads and an aluminum disc that was supported by a ball bearing slide mount.

An MTS (MTS Systems, Eden Prairie, Minnesota) was used to load the specimens to 1400N (load control feedback). Figure 1 shows this experimental set-up.

Comparison of Strains with Intact Sawbones® and Cadaver Femurs
Three proximal cadaveric femurs and three Sawbones® femurs were mounted and strain gauges applied as described above. The cadaver femurs were planed in the area of gage attachment with a knife blade to create a smooth surface and dehydrated and degreased with acetone and chloroform before application of the cyanoacrylate adhesive. They were then oriented at 15° of adduction (approximate coronal position of hip at normal heel strike) and loaded to 1400 N.

A great variability in strains between the human and Sawbones® femurs was observed. This was attributed to the variation in the neck-shaft angles of the human femurs. In order to eliminate this, the cadaver femurs were reoriented in the vise so that their necks replicated the same angle as the Sawbones® (approximately 140°) and re-tested.

Loading of Surface Replacement Heads
Twelve (including three spares) Sawbones® proximal femurs were mounted and strain gauges attached in the same manner as described above. Each intact femur was loaded to 1400N and the strains recorded for each specimen. Measurements were done with the femoral shafts vertical, at 15° abduction.
and at 15° abduction to determine initial strains as a control. Each femur was then prepared to accept femoral component heads (52 mm Cormet, Corin, Cirencester, United Kingdom) (Fig. 2) that were to be oriented in one of nine positions in relation to the anatomical neck axis: correct (coaxial with the femoral neck), 10° of varus, valgus, anteversion, retroversion, and 5 mm of translation superiorly, inferiorly, anteriorly, and posteriorly.

For the correctly positioned head, an initial guide wire was introduced along a neutral axis (longitudinal center of the femoral neck), using the caliper-like jig designed for this purpose. The position of the guide wire was confirmed on radiographs (Fig. 3). For the other specimens, attachments were added to the jig for control of angulation or translation of the guide wire. The positions of these guide-wires were checked on orthogonal radiographs (Fig. 3).

The Sawbones® femoral heads were then reamed with a cylindrical reamer, planed, and the chamfers cut, using the Cormet instruments. Care was taken not to notch the neck in any direction nor damage the already mounted strain gauges. This was avoided by using the sizing guide as a measurement template during reaming. Also, a rubber barrier was used to protect the strain gauges. The cylindrical reamer was cooled in a bucket of ice at regular intervals to prevent thermal damage to the strain gauges.

The femoral components were then cemented on the prepared femurs with low-viscosity acrylic bone cement. Additional orthogonal radiographs were taken to verify head position.

The specimens were loaded to 1400 N and strain measurements were recorded for each of the three femoral angulations. Each test was repeated three times. One specimen had problems with the strain gages and was redone; additional correct and varus head placement specimens were prepared and tested to evaluate test reproducibility.

**Data Analysis**

Strain measurements were recorded as microstrain and an average value for each gage determined. The three readings from the rosette gages were converted to the principle strain and direction using standard gage equations. The changes in strain were expressed as a percentage increase/decrease from the corresponding, non-implanted femoral neck strain values.

**Results**

Table 1 shows that the inferior and superior (maximum principle) femoral neck strains were, in general, similar for

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Maximum</th>
<th>Inferior Strain</th>
<th>Anterior Strain</th>
<th>Posterior Strain</th>
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<td>Cadaver</td>
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<td>Inferior Strain</td>
<td>Anterior Strain</td>
<td>Posterior Strain</td>
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<td>500</td>
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<td>1000</td>
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<td>-4000</td>
<td>450</td>
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<td></td>
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<td>-8000*</td>
<td>650*</td>
<td>1220*</td>
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<td>-50</td>
<td>-880</td>
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*Femur was osteoporotic on radiograph.
the cadaver and Sawbones® femurs, except for one cadaver femur that appeared osteoporotic on radiographs. However, the anterior and posterior strains were compressive for the Sawbones® and tensile for the cadaver femurs.

All of the surface replacement heads were within 20% of their intended experimental positions as determined by orthogonal radiograph measurements (Table 2).

The principle superior strains for the femoral neck (in 15° adduction) were 25% to 80% greater for all angulations of the surface replacement head except for varus positioning where it was approximately 50% less (Fig. 4). Although there were variations in the directions of the principle strains, their meaning is unclear and could be due to shifting of the specimen on the X-Y table.

The principle superior strains from the femoral neck (in 15° adduction) were 35% to 120% greater for all translations of the surface replacement head, except for the posterior gage reading with varus head positioning where it was approximately 300% greater (Fig. 5).

The remaining strain readings from the femoral neck (in 15° adduction) were affected by all translations of the surface replacement head. The posterior gage reading with varus head positioning increased approximately 100% in inferior and posterior translation and decreased approximately 225% in anterior translation (Fig. 7).

The angle of load application (femoral orientation) also affected the strain magnitudes. As seen in Figure 8, the principle superior strains for three surface replacement head positions changed when the femur was in adduction or abduction. The strains for the varus head position were

Table 2

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Axis of Orientation on AP Radiograph</th>
<th>Actual Value</th>
<th>Axis of Orientation on Lateral Radiograph</th>
<th>Actual Value</th>
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<tr>
<td>Correct-Neutral</td>
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<td>1 mm</td>
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<td>0 mm</td>
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<tr>
<td>Valgus</td>
<td>Valgus</td>
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<td>Neutral</td>
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<tr>
<td>Varus</td>
<td>Varus</td>
<td>11°</td>
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<td>6 mm</td>
<td>Neutral</td>
<td>0 mm</td>
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<tr>
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<td>Translated inferiorly (parallel to neutral)</td>
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<td>0 mm</td>
</tr>
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<td>Anteversion</td>
<td>Neutral</td>
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</tr>
<tr>
<td>Retroversion</td>
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<td>Retroverted</td>
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</tr>
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<td>1 mm</td>
</tr>
<tr>
<td>Posterior Transl.</td>
<td>Neutral</td>
<td>6 mm</td>
<td>Translated anteriorly (parallel to neutral)</td>
<td>0 mm</td>
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</table>

Figure 4 Principle superior strains and directions for angulations of the resurfacing head. Axis values are percent change from an intact Sawbones® femur at 15° adduction; angles are change from 0.0°. *Actual valgus value is -50%.

Figure 5 Principle superior strains and directions for translations of the resurfacing head. Axis values are percent change from an intact Sawbones® femur at 15° adduction; angles are change from 0.0°. *Actual inferior value is -50%.
The two repeated tests for the surface replacement heads in varus and the correct orientation had strains that were within 20% of the original tests.

Discussion

We found the varus positioning of the surface replacement head resulted in decreased superior strain in the femoral neck, as has been seen by several previous investigations.\textsuperscript{4,9} However, a recent study by Vail and colleagues demonstrated a slight increase.\textsuperscript{16} Although this head position results in lateral translation of the load and an decreased lever arm of the neck, this does not account for changes of such magnitude. What is probably occurring is that the longitudinal, tensile loads in the neck are being partially transformed to vertical shear stresses. This transformation seems to be supported by the observation that the compressive loads and resultant strains on the inferior neck do not appreciably vary with respect to head position, as would be expected if the neck was solely acting as a beam in bending. Other angular head positions generally resulted in an increased superior strain, as has been seen by other studies.\textsuperscript{5,10,13}

Anterior or posterior head translations resulted in expected changes in the anterior and posterior gages. Inferior head translation also affected these two gages; superior translation had little effect. It should be noted that these are linear gages and are only partially affected by shear strains. Furthermore, these two locations showed a major difference between the strains seen in Sawbones® and cadaver femurs.

There are several limitations to this experiment, one being that only single specimens were tested for each head position. We used Sawbones® femurs to provide specimen uniformity and tried to standardize gage positions. We did repeat fabrication and testing of two specimens (correct and varus) and found good agreement in strain data. We do not know the effect of gage position as only one location close to the implant was studied. Some studies\textsuperscript{7,9} suggest that there is a high strain gradient close to the implant; gage positions further down the neck might not have shown the same magnitude of changes. It is also important to know that only surface strains were measured; internal strains are unknown. We used simple loading and did not account for IT band effects and abductor loading.

Although Sawbones® composite femurs are designed to replicate the mechanical properties of actual femurs, we did find some major differences in strains between the two and also between actual femurs. The Sawbones do not duplicate the internal stress transfer found in actual bone, as they lack the internal load distribution trabecular architecture.

It is unclear what are the clinical implications of the increased or decreased strains in the femoral neck found in this study. The strains found in the cadaver femurs are within those shown to cause fatigue of cortical bone in the laboratory.\textsuperscript{11} and if the increased strains for certain head positions found with the Sawbones® femurs are effected

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**Figure 6** Anterior, posterior, and inferior strains for angulations of the resurfacing head. Values are percent change from an intact Sawbones® femur at 15° adduction.

**Figure 7** Anterior, posterior, and inferior strains for translations of the resurfacing head. Values are percent change from an intact Sawbones® femur at 15° adduction.

**Figure 8** Effect of Sawbones® femur test angle on the percent change in the maximum superior neck strain for three surface replacement head positions.
in the cadaver femurs, this could be of concern. However, bone remodeling could also modify this stress/strain state over time.

Disclosure Statement
This investigative report was supported by a grant from Stryker Orthopaedics, Mahwah, New Jersey.

References