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The Effect of Surface Finish and of Vertical Ribs on the Stability of a Cemented Femoral Stem

An In Vitro Stair Climbing Test

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Abstract: The search for improved femoral fixation in cemented total hip arthroplasty is ongoing. Two design variables, surface finish and stem contour, were evaluated. Sixteen titanium femoral stems of one design were cemented into fiberglass femora. One half of the components had a polished surface and the rest had a roughened finish. Within each group, 4 stems had vertically oriented ribs on the proximal portion and 4 did not. Micromotion was measured in a stair climbing simulator with loading to a joint reaction force of 200 kg for 6 million cycles. Micromotion increased throughout the course of the experiment. Stems with a polished surface had significantly higher micromotion. Although stems with ribs had less micromotion compared with those without ribs, this difference was not statistically significant. **Key words:** femoral, total hip arthroplasty, cemented, stair climbing, CLS, micromotion.

Many cemented femoral components in total hip arthroplasty have achieved excellent longevity [1], whereas others have had early failures from aseptic loosening [2-4]. The factors responsible for these failures of fixation include both patient issues (eg, weight, age, sex, activity, bone quality, etc) and implant factors (material, surface finish, geometry, offset, neck length, etc). Multiple efforts have been made to reduce the rate of aseptic loosening by modification of implant design, surgical technique, and material composition [5-7].

Two design variables of particular interest are the surface finish and the contour of the proximal portion of the femoral stem. Rougher-finished femoral stems were developed in an effort to improve cement prosthesis adhesion [6]. However, some authors suggest that the rough surface can lead to abrasion of cement with the risk of periprosthetic osteolysis, were the implant to become loose [8-10].

Torsional stability plays a critical role in longevity of cemented stems. High torsional loads have been found on the femoral stem during stair climbing and rising from a chair [11-15]. In one series of 24 painful total hip arthroplasties, all 10 femoral components that were loose were found to have rotational instability, even in the absence of axial instability [16]. Burke et al [17] showed significantly higher micromotion in cemented femoral stems with simulated stair climbing compared with single leg stance.

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To assess the effect of 2 critical design variables, namely, a polished vs a roughened surface finish and the presence or absence of vertical ribs on the anterior and posterior surface of the proximal portion of the stem, we sought to test the stability of a widely used titanium cemented femoral stem in an in vitro stair climbing experiment using a previously described dynamic stair climbing simulator [18]. Our hypothesis was that both the contour of ribs on the anterior and posterior surface of the proximal portion of the stem, as well as the roughened surface finish, would provide superior rotational stability.

Methods

Sixteen CLS (size 5, 135 mm long, 145° neck angle) collarless titanium femoral components (Zimmer, Warsaw, Ind) were implanted into fiberglass femora (Pacific Research Laboratories, Vashon, Wash). These fiberglass femoral models have previously been shown in our laboratory to tolerate fatigue studies over many millions of cycles [19]. Fresh or embalmed human femurs were not used because of decay of the human material undergoing similar testing conditions. Fiberglass femurs were prepared using a neck cut 15 mm proximal to the lesser trochanter. The canal was then sequentially broached to accept the component plus a 2-mm to 3-mm mantle. All components were cemented in an identical manner using third generation cement technique [7] to obtain grade A cement mantles, as described originally by Barrack et al [20]. Simplex P bone cement (Stryker, Mahwah, NJ) was prepared at room temperature. The cement was hand-mixed until fully liquefied and then poured into a cement cartridge that was centrifuged for 30 seconds at 2400 rpm in an HNS-11 centrifuge (International Equipment Co, Needham, Mass). The cement was introduced in a retrograde fashion into the previously plugged femora using a cement gun (Johnson & Johnson, New Brunswick, NJ). After the cement was pressurized, the femoral component was inserted at 6 minutes from the start of mixing and was held in place until the cement hardened. Distal centralization was achieved with previously placed distal centralizers made from cement. Anteroposterior, lateral, and 2 oblique radiographs were examined after implantation to confirm an excellent cement mantle with centralization of the stem proximally and distally.

The CLS stem is composed of a titanium alloy (TiAlNb, Protasul 100, Zimmer, Warsaw, Ind) that is roughened by the manufacturer through the blasting of small corundum particles onto the metal surface. Polished stems were made by applying a polishing compound and using a fine buffing wheel to remove the rough manufactured surface. Stem roughness was then quantified using a Surftest 501 profilometer (Mitutoyo Institute of Metrology, Aurora, Ill). A straight-line trace with a 2.4-mm evaluation length was measured in the proximal and distal regions and repeated 4 times to obtain an average roughness (R_a). Of the 16 components, 8 had a polished surface with an R_a value of 0.125 μm (range, 0.10-0.17 μm). The other 8 components, with the roughened-finished surface, had a mean R_a value of 3.75 μm (range, 2.93-4.55 μm) (Fig. 1A and B). Within each group of either smooth or roughened-finished components, 4 stems had a proximal geometry with vertically oriented ribs. The ribs were located on the anterior and posterior surfaces of the stems. Three ribs with a width of 3 mm and a length of 54 mm were present on each surface. The distance between the ribs was 2 mm. The remaining 4 stems in each subset of surface finish had no ribs.

The femora were then potted in polymethylmethacrylate blocks (Fig. 2A) and loaded in the stair climbing jig with the proximal portion of the cement mantle and prosthesis placed in a saline bath at 37°C. They were mounted in a position of 30° flexion, 20° abduction, and neutral rotation. The design of this loading fixture reproduced the strains in the proximal femur and the proximal cement mantle as they occur during stair climbing (Fig. 2B). The stems were then loaded to a joint reaction force of 200 kg, corresponding to a body weight of approximately 50 kg with an MTS servohydraulic testing machine (MTS System Corporation, Eden Prairie, Minn). The femoral head used was a 28-mm-diameter with a neck length of 8 mm. The load was cycled at a frequency of 2 Hz. At each 1 million cycles, from zero to 6 million cycles, loading was discontinued and the specimens were examined radiographically and visually.

To quantify the micromotion at each million-cycle interval, the potted femurs were stabilized on a table. A dial indicator (Model 201434, Compaq, Houston, Tex) was mounted on the femoral neck of the prosthesis with its displacement rod resting on the lesser trochanter (Fig. 3). The dial indicator measured the relative rotational displacement of the femoral neck of the prosthesis relative to a fixed point on the femur (the lesser trochanter). The stems were then initially maximally externally rotated (anteverted) within the cement mantle with a torque wrench up to 30 nm. This external

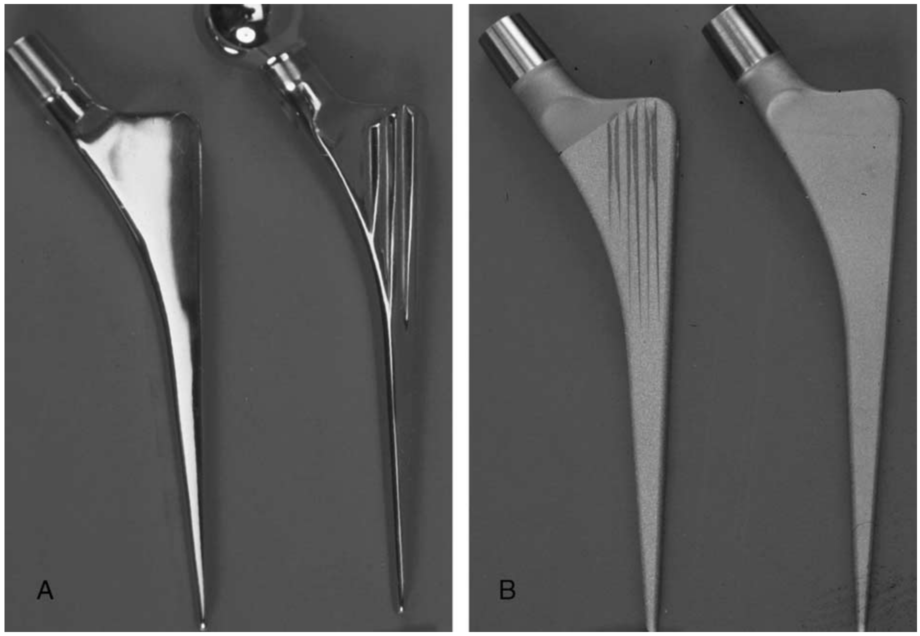

Fig. 1. A and B, Polished and matte-finished CLS implants with and without vertically oriented ribs.

rotation stress was performed before internal rotation to determine the full range of motion of the stems within the cement mantle. After the dial indicator had been zeroed, the micromotion was quantified as each stem was internally rotated (retroverted) within the mantle with a torque of 30 nm. Baseline measurements were taken before any loading to reflect the specimen-specific degree of micromotion present because of the compliance of the potting, the femur, the cement mantle, and the metal stem.

The effect of surface finish and the presence or absence of ribs on the mean micromotion was analyzed using a repeated measures analysis of variance (ANOVA) model. Post hoc testing was performed using the Bonferroni/Dunn test. Linear regression was performed to determine the progression rate of micromotion for each treatment over the course of the experiment. The slopes were reflective of the rate of progression of micromotion. The effect of surface finish and the presence of ribs on the slopes of the regression lines were analyzed using 2-way ANOVA model. All analyses were performed using statistical software (StatView, Abacus Concepts, Berkeley, Calif).

Results

Baseline micromotion values before the application of stair climbing cycles were not significantly different under all 4 testing conditions. Over the

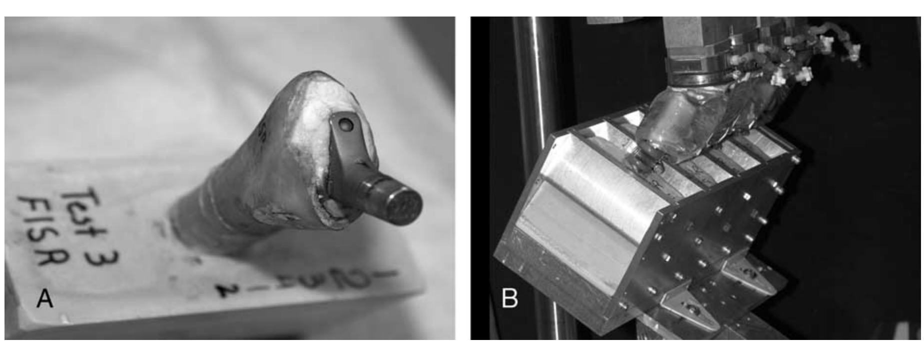

Fig. 2. A, Fiberglass femur with implanted cement stem, potted in polymethylmethacrylate block. B, Biomechanical testing apparatus consisting of MTS servohydraulic testing machine with 4 implanted prostheses exposed to a cyclic internal rotational torque at 30° flexion, 20° abduction, and neutral rotation.

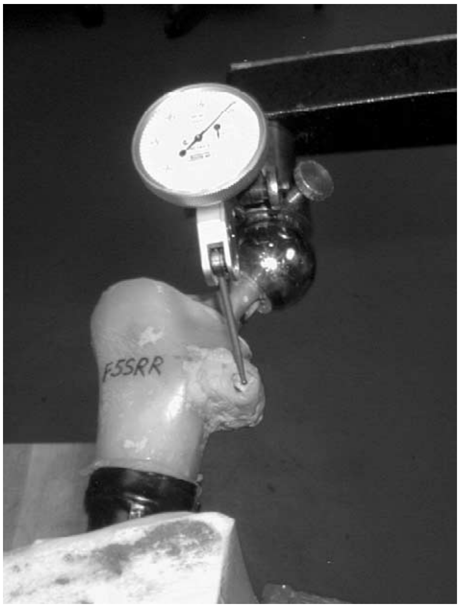

Fig. 3. Micromotion measurement apparatus consisting of a dial indicator mounted on the femoral neck of the prosthesis, with its displacement rod resting on the lesser trochanter.

course of the testing from zero to 6 million cycles, all stems demonstrated progressively increased micromotion ($P < .0001$) (Fig. 4).

Over 6 million cycles, for the polished nonribbed stems, the mean micromotion measurement was 419 ± 195 μm, whereas for the polished ribbed stems, it was 295 ± 110 μm. Over the course of 6 million cycles of simulated stair climbing, within the roughened-finish subgroup, the nonribbed stems had 209 ± 48 μm of micromotion compared with 205 ± 84 μm in the roughened-finished, ribbed stems. These values were derived from repeated measures of the same stem over the course of the experiment.

A polished surface was associated with a significantly greater micromotion than a roughened surface using the repeated measures ANOVA independent of other factors ($P < .0001$). The effect of a polished surface was significant as confirmed in post hoc analysis using the Bonferroni/Dunn test ($P = .0025$). Stems with vertically oriented ribs had lower mean micromotion than those without ribs, although this difference was not statistically significant ($P = .096$).

Linear regression analysis of the rate of progression of micromotion revealed an increase in micromotion for polished implants (56 ± 27 μm per million cycles) relative to roughened-finish implants (12 ± 18 μm per million cycles). This difference was statistically significant ($P = .0004$). The increased rate of progression in nonribbed implants (41 ± 39 μm per million cycles) compared with ribbed implants (27 ± 22 μm per million cycles) was not statistically significant($P = .15$).

Discussion

In this study, there was a greater increase in rotational micromotion in cemented femoral stems of identical design, which had a smooth surface finish, compared with those with a roughened-finished surface in a testing mode of 6 million cycles using a stair climbing simulator. However,

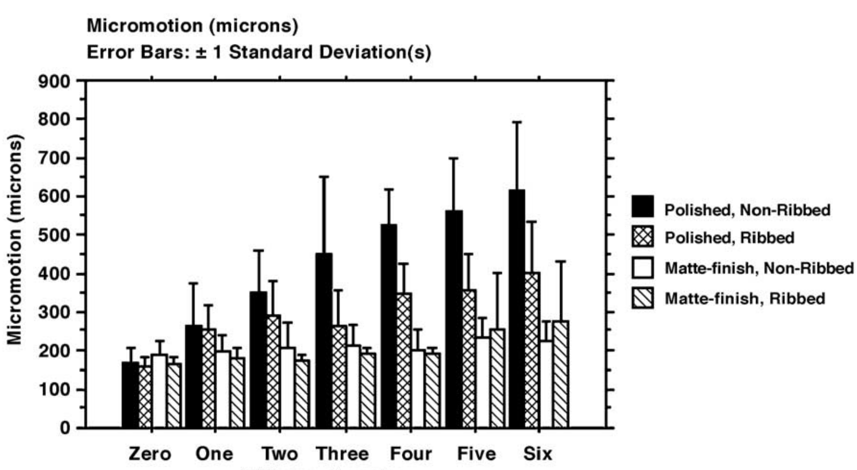

Fig. 4. Micromotion of ribbed and nonribbed prostheses with polished and matte-finished surface over the course of 6 million stair climbing cycles.

although stems with vertically oriented ribs had decreased micromotion compared with those without ribs, this difference was not statistically significant. As a secondary test of this effect, we calculated regression lines for the increase of micromotion over the course of the experiment. Surprisingly, the progression of micromotion followed a relatively linear path for all conditions. Roughened stems did not lead to an accelerated rate of loosening in the presence of early micromotion.

Crowninshield et al [21] studied the mechanical bonding strength at the implant-cement interface with a range of surface roughness and further evaluated the abrasive properties of such surfaces on the cement. They found increased bonding strength and increased abrasive particulate debris in implants with a higher surface roughness. The findings of their study highlight one possible adverse effect of an improved cement implant interface strength at the expense of increased debris generation, which, they felt, may ultimately lead to osteolysis and loosening. We did not study particle generation but our in vitro study did not demonstrate an accelerating rate of micromotion with rough stems.

Collis and Mohler [22] published clinical results on the effect of surface finish by comparing 122 cemented Iowa stems with a polished surface (R_a, 0.1 μm) to 122 essentially identical stems with a grit-blasted surface (R_a, 2.1 μm). The estimated survival at 7 years was 92% for the grit-blasted stems vs 100% for the polished stems (P = .05). The patient populations were similar in age, sex distribution, diagnosis, follow-up interval, and improvement in pain scores. Although the results were superior in the polished group of these Iowa stems with respect to revisions, this finding may be characteristic of the specific geometry of the Iowa stem.

The complex issue of surface roughness and its impact on stem performance is illustrated by the reports in the literature demonstrating good results with several stems that are intermediate in roughness relative to the stems evaluated in our study. Sporer et al [23] compared 36-bead blasted (matte-finished) Iowa stems (R_a, 0.8 μm) to 45 precoated, grit-blasted roughened Iowa stems (R_a, 2.1 μm). At 11 years, the revision rates were 6% for the matte-finished components vs 18% at a mean of 8 years for the grit-blasted stems. Bead-blasted femoral stems have demonstrated promising results in other reports. Smith et al [24] reported on such a series of femoral components at an average follow-up of 18 years. The overall loosening rate of all femoral components over this period was 6%. In addition, the aseptic failures of these cemented bead-blasted stems were not associated with osteolysis [25]. Bourne et al [26] confirmed the results of the Harris-Design 2 matte-finished femoral component (Howmedica, East Rutherford, NJ) in 195 patients at a mean of 12 years, with an aseptic loosening rate of 3%.

Using the Charnley design with a matte finish, Wroblewski and Siney [27] reported on a series of patients below 50 years of age at a mean of 10 years. From this group, the overall femoral revision rate was less than 1%. Rasquinha et al [28] have also supported the use of cemented matte-finished stems with a 15-year survivorship of 100% in a series of hips using the Omnifit femoral components. (Stryker, Mahwah, NJ). Experience from the Swedish Hip Register delivers further justification for the use of stems with a matte surface finish. In fact, the 2 stems with the best long-term clinical results in the Register, the Lubinus SP II (Waldermar Link, Hamburg, Germany) and the Spectron EF (Smith & Nephew, Memphis, TN), have a matte surface finish [29]. The Lubinus has a roughness of 1.5 μm throughout, and the Spectron stem has a proximal roughness of 2.8 μm proximally and 0.7 μm distally. The Spectron EF had a 100% stem survivorship with revision due to aseptic loosening as the end point in a study of 204 total hip arthroplasties at 11 years [30]. The superior results with the Lubinus stem have been confirmed using radiostereometric analysis [31]. A matte-finished Lubinus stem (R_a, 1.5 μm) had only one third the subsidence of a polished Lubinus stem (R_a, < 0.5 μm) with identical geometry at one-year follow-up. In summary, the issue of surface finish in cemented total hip arthroplasty continues to be a source of controversy. Excellent clinical results have been achieved with stems with a variety of surface finishes pointing out the multiple issues involved in long-term success.

Limitations of our study include those of many in vitro studies of total hip arthroplasty. We attempted to approximate some of the conditions of the human joint space by maintaining the hip joints in saline at 37°C during cycling. However, it is impossible to reproduce the exact joint milieu of the human hip joint in the laboratory. Furthermore, fiberglass femora are only an approximation of human femora, do not possess an identical complex matrix of cancellous bone, and do not undergo remodeling in the same fashion as the human femur. This study was performed using titanium cemented femoral stems, which, although not commonly used in North America, have achieved wide acceptance and good results in Europe [32].

In summary, femoral component loosening is a multifactorial process, which depends on the complex interplay between stem geometry, surface finish, torsional resistance, cementation technique, stem offset, patient weight and activity, age, sex, and other factors [8,33]. To our knowledge, this is the first study examining the effect of surface finish and vertically oriented ribs in a stair climbing model. We postulated that a rougher finish would result in greater rotational stability, and this was confirmed by our results. We also hypothesized that ribs would allow for improved interlock of the stems with the cement mantle. This hypothesis was not supported.

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