The Effect of Surface Finish on Micro Rotation and Frictional Torque of Taper-Locked Femoral Stems in Cemented Hip Joint Replacements

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Introduction: A number of designs of femoral stems have used taper locking to achieve long-term stability in clinical use (1-3). Several studies have reported excellent clinical performance for tapered stems with a polished surface, but a higher rate of failure for those with a matte-finished surface **(**1,2**)**, a difference that has been attributed, in part, to wear caused by micromotion at the stem-cement interface (4). In a previous study, we used a finite element model (FEA) to show that, even for a well taper-locked stem, some axial micromotion occurs under cyclic load, and the magnitude of the micromotion of a matte-finished stem may be comparable to that for a polished stem (5). In the present study, we addressed the question of whether, for a well taper-locked femoral stem, there is sufficient friction between the stem and the cement to prevent *rotational* micromotion, and, if not, how the magnitudes of the rotational micromotion and frictional torque are affected by the surface finish of the stem. These questions were assessed using an FEA model based on the Exeter stem, which features a straight, collarless, double-tapered shape.

Methods: The FEA model of the femoral bone was generated by digitizing a cadaver femur with a QCT scanner, and the model of the stem was developed from the manufacturer's blueprints. The femur, stem and cement were represented by a total of 28,404 eight-node brick elements, and the stem-cement interface was modeled with 2560 Coulomb friction interface elements. In order to take into account the effect of varying surface roughness, the coefficient of friction assigned to the stem-cement interface was varied from 0.1 to 0.8 in increments of 0.1, with 0.2 for a polished stem and 0.8 for a matte-finished stem (6). The elastic moduli of the bone elements were assigned individually, based on the local density of the bone as determined by the QCT scan. The cement mantle was assigned viscoelastic properties that had been measured experimentally (7).

Cyclic loads of 3200N and 2150N were applied to the femoral head and the greater trochanter, respectively, which produced an external rotational torque of 42.6 Nm about the central axis of the stem. The total reaction torque generated about stem by friction at the stem-cement interface was calculated as the vector sum of the frictional torques at each interface element, i.e., taking into account their directions, distance to the axis of the stem, and magnitude of the local frictional force. A user-compiled program was used for the calculation in the following steps: 1) the projection of the frictional force of the interface element on the plane perpendicular to the axis of the stem and passing through the center of the interface element; 2) the distance between the axis of the stem and the line of the projection; 3) the product of the distance and the magnitude of the projection.

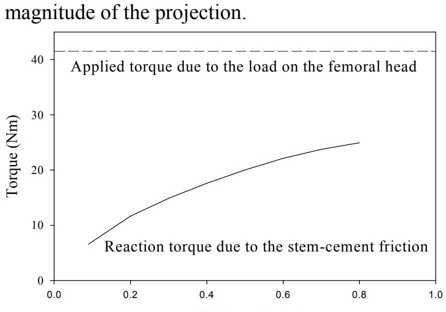

Fig. 1 The resultant frictional torque at the stem-cement interface with varying coefficient of friction

Results: As shown in Fig.1, the frictional reaction torque about the axis of the stem increased monotonically with an increasing coefficient of friction. For example, the frictional torques were 11.7, 17.6, and 23.7 Nm with coefficients of friction of 0.2, 0.4, and 0.7, respectively, with more than half of the torque produced in the broad proximal region. However, even the highest frictional reaction torque of 24.9 Nm, at a coefficient of friction of 0.8, was only 58% of the externally applied torque of 42.6 Nm. Consequently, under cyclic load, the external torque induced a rotational micromotion of the stem relative to the cement mantle, which decreased with increasing coefficient of friction. For example, the rotations at the mid-region of the stem were 0.195, 0.175, and 0.15 degrees for coefficients of friction of 0.2, 0.4, and 0.7, respectively. This micro-rotation was reflected in the stress distribution in the cement mantle (Fig. 2). That is, high compressive stresses occurred near the four corners of the mantle, i.e., on the anterior side of the lateral-anterior corner, the medial side of the anterior-medial corner, the posterior side of the medial-posterior corner and the lateral side of the posterior-lateral corner, and tensile stress occurred on the opposite sides.

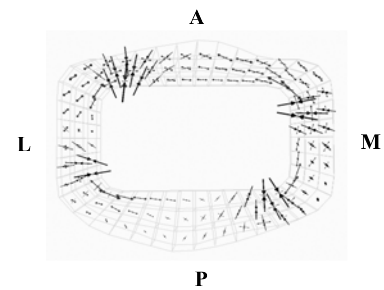

Fig. 2 Stress distributions in the cement at the mid-stem region with coefficient of frictional of 0.2. A = anterior, L = lateral, etc. Convergent arrows represent compressive stress, and divergent arrows represent tensile stress, with arrow length indicating the magnitude of stress.

Discussion: The results of this model indicated that, for the Exeter stem, which is similar to a number of designs of taper-locking cemented stems (3), the frictional torque produced at the stem-cement interface was not sufficient, in itself, to prevent rotational stem-cement micromotion caused by the externally applied torque, regardless of whether the stem was matte-finished or polished. Consequently, the resistance to rotation was a combination of frictional torque and a torque due to contact stresses between the stem and cement, the location and magnitude of the latter being determined by the rectangular cross section of the stem. Because of this, some rotational micromotion of the stem within the cement, and stress concentrations at the corners of the rectangular cross-section, are inevitable.

The results of the present model were consistent with Howell et al., (4) who observed more wear on the posterior-medial and anterior-lateral faces of clinically retrieved Exeter stems for both matte and polished surfaces. If, as indicated by the present and previous models (5), the rotational and axial micromotions with a matte-finished stem are comparable in magnitude to those of a polished stem, it is likely that a greater amount of stem-cement wear occurs with a matte finished stem. This could, in turn, partly explain the higher rate of clinical failure that occurred with the matte-finished Exeter stem (1,2).

The results indicated a unique feature of a taper locked stem. That is, even if the stem-cement interface has debonded, friction at the stem-cement interface can provide partial resistance to rotational micromotion that, in turn, may reduce the stress concentrations in the cement mantle. Although suitable modifications in the shape of the stem might increase the frictional torque and decrease the micro-rotation, such changes would need to take into account the overall mechanical performance of the stem. For example, while a wider proximal portion of the stem could provide greater resisting frictional torque, it also might increase the magnitude of the axial micromotion of the stem in the cement mantle(5).

References: 1) Fowler JL. Orthop Clin N Am. 1988;19:477-489; 2) Middleton RG. CORR. 1998;355:47-56; 3) Glyn-Jones S. JBJS [Br]. 2005;87B:921-927; 4) Howell JR. J Arthroplasty. 2004;9:88-101; 5) Lu Z. Trans ORS 2005;269; 6) Huiskes R. CORR. 1998;355:103-112; 7) McKellop H. Ph.D. Dissertation, USC, 1988.
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