THE EFFECT OF CROSS-SECTIONAL SHAPE ON TORSIONAL STABILITY OF CEMENTED IMPLANT COMPONENTS UNDER CYCLIC LOADING

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INTRODUCTION: Revision surgery following a joint replacement is most commonly required due to implant loosening. Torsional loading on an implant stem is one potential cause of such failure, particularly in the hip, elbow and shoulder. In the case of cemented stems, it has been shown that polymethylmethacrylate cement itself is not an adhesive, and the strength of the stem-cement interface is poor. Thus, stability of the implant, especially after the stem-cement interface has de-bonded, is reliant upon stem geometry. Although it has been shown that cement stresses are significantly affected by stem cross-sectional shape, relatively few studies have addressed the effect of stem shape on cemented implant fixation.

The purpose of this study was to compare the abilities of five different stem geometries to resist torsion under cyclic loading conditions.

METHODS: Cemented stems with five different cross-sectional shapes – circular, oval, triangular, rectangular with rounded edges (round rectangular), and rectangular with sharp edges (sharp rectangular) (Figure 1) – were tested to compare torsional resistance under cyclic loading. Stems were custom machined from stainless steel (E = 190 GPa), with dimensions to fit within the humeral canal and shapes based on commercially available designs. Seven specimens of each stem shape were tested.

The stems were potted to a depth of 16mm in square aluminum tubes using Surgical Simplex® P (Stryker Howmedica Osteonics, Allendale, NJ) bone cement. The cement was allowed to cure for 24 hours prior to testing at 21.5 ± 0.5°C. A materials testing machine and a custom designed loading fixture were used to apply torsion to the stems. A sine wave loading pattern was applied until 5° of stem rotation occurred. The loading pattern had a lower bound of 0.9Nm and an upper bound which started at 4.5Nm and was increased in increments of 2.25Nm every 1500 cycles. The load was cyclic at 2Hz and sampled at 16Hz.

Statistical analyses were performed using one-way Analyses of Variance (ANOVAs) followed by post-hoc Student-Newman-Keuls multiple comparisons with significance defined as p < 0.05.

RESULTS: Overall, ANOVAs showed an effect of stem shape on the number of cycles (p < 0.001) and torque to failure (p < 0.001) (Figure 2). Multiple comparison tests showed that the sharp rectangular stem provided the greatest resistance to torque (p<0.01; pTorque < 0.001) compared to all other stems. Other significant differences are noted in Figure 2, resulting in the following ranking of the stem shapes: sharp rectangular, round rectangular, triangular, and circular = oval.

DISCUSSION AND CONCLUSIONS: The results of this study agree with the findings of other studies in the literature in that the circular cross-section had less resistance to torsional loads. The current results also agree with static testing previously conducted on the same set of stem shapes. Although the sizes of the stems were chosen based on upper limb implant designs, these results may be extrapolated to larger stems used for other joints where torsional loading is also a concern, such as the hip.

It has been suggested that improving the stem-cement interface may raise the loads experienced by, and hence the failure of, the cement-bone interface, but that this may be less deleterious to fixation. In the current model, the cement-bone interface was not considered as the stems were potted in tubes as opposed to cadaveric bone. A thick cement mantle was used to avoid failure at the cement-tube interface and focus on the stem-cement interface. Although thinner cement mantles would be used clinically, the thickness remained consistent throughout testing, thereby permitting a relative comparison of the stems’ resistances to torque.

One possible explanation for the rankings of the stem shapes in torsional resistance is the “push perimeter” – section of the perimeter that pushes against the surrounding material as a torque is applied – of each stem. The circular (and, to a lesser extent, oval) stems can spin in the cement once the cement-stem bond is broken, while the round rectangular and sharp rectangular stems cannot move following debonding without either the cement or the stem material yielding. Interestingly, the corners of the sharp rectangular stem did not appear to create stress concentrations in the cement mantle under torsion. As the load was applied, the stems rotated and pushed cement out of the way, creating a small gap between the stem and cement at the corner. It is hypothesized that the absence of cement in this area meant that stress concentrations of the sharp rectangular stem had no effect. The effect of these sharp corners in other loading modes requires further study.

As joint replacements are performed on increasingly younger and more active patients, it is important that the best fixation possible be obtained through all available avenues, including improved implant designs. An alteration in implant stem shape may assist in achieving this goal.