EVALUATION OF STEM SUBSIDENCE OF DUAL-TAPERED AND TRIPLE-TAPERED POLISHED CEMENTED HIP STEMS

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Introduction
Polished, tapered hip stems have been used for decades clinically with success [1,2,3]. The philosophy behind the collarless polished stem is to retain the fixation of the hip stem within the cement mantle through controlled stem subsidence. Although surface polishing is employed to minimize the generation and form a seal to prevent particle migration to the surrounding bone, the stem geometry has a significant effect on the stem/cement stress transfer and fixation strength of the hip stem. While polished stems have enjoyed good long-term clinical results, excessive subsidence of the stem can lead to leg-length discrepancies and may ultimately require revision.

While many polished stems employ a dual-taper design (A/P and M/L tapers), the use of a trapezoidal stem cross-section creates a third taper which may distribute the stresses over a larger area and thus reduce the extent of stem subsidence. Using finite element analysis, photoelastic analysis, and mechanical testing, the cement mantle stress distribution and subsidence characteristics of a dual-tapered (Exeter, Howmedica Inc.) and triple-tapered (PCPS, Smith & Nephew, Inc.) design were examined.

Materials and Methods
Computer models of a dual-tapered and triple-tapered stems, shown in Figure 1, were analyzed using finite element (FE) methods. The FE method simulated the stems embedded within a cylinder of bone cement in order to examine the stress distribution and subsidence using both an axial and an anatomic (10° A/P 10° M/L) loading angle. The resultant stresses in the cement mantle were examined, as well as the predicted resistance to subsidence.

Three-dimensional photoelastic analysis (n=3 of each) was performed by molding a cylinder of photoelastic resin (PLM-9, Vishay Measurements, Raleigh, NC) around a dual-tapered and triple-tapered stem model. A 22 N (5 lbf) axial load was applied to the stems, and the photoelastic models were then put through a heating cycle to stress freeze the resulting fringe pattern. The stems were extracted and the photoelastic cylinders were sliced into 1 mm thick sections for evaluation of the stress distribution.

Mechanical testing (n=3 of each) was performed to evaluate the subsidence characteristics of the two stems under axial loading conditions. The stems were embedded in cylinders of Palacos R bone cement, and an axial load was applied to induce subsidence of the stems. The subsidence vs. load relationship was determined for each stem.

Results
The FE method and photoelastic analysis used to examine the stress distribution found similar peak stresses for both the dual and triple-tapered stems under both anatomic and axial loading conditions. However, the triple-tapered stem had a broader distribution of stresses with a lower stress gradient, both in the transverse plane as well as axially down the length of the stem. An example of two photoelastic slices taken approximately 4 mm below the calcar region is shown in Figure 2. The broader stress distribution should theoretically reduce the rate of subsidence of the stem, and possibly reduce the incidence of stress shielding in the calcar region. The decreased gradient seen with the triple-tapered stem reduces the sharp stress transitions that can cause shear forces within the cement, which may lead to cement fracture.

Under anatomic loading conditions, the FE method predicted a 20% lower displacement axially, and a 25% lower displacement in the medial/lateral direction. The analytical results were supported by mechanical testing of the stems within a cement mantle, which found a 25% higher subsidence for the dual tapered compared to the triple-tapered stem design under axial loading conditions, as shown in Figure 3. A statistical analysis performed to compare the slope of the load vs. displacement relationship for each stem found a difference to be statistically significant (p=0.003).

Conclusions
Based on analytical and experimental techniques, the addition of the third taper in the transverse plane improved the distribution of stresses while maintaining a similar peak stress. This resulted in a reduction in stem subsidence, which is the main mode of failure for polished cemented stems. The predicted decrease in subsidence was validated using laboratory testing, which showed a significant decrease in stem subsidence upon loading for the triple-tapered stem.

References

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