Fixation Micromechanics of Cemented Glenoid Replacements

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INTRODUCTION:
Glenoid loosening is the most common complication in Total Shoulder Arthroplasty. Cemented glenoid replacements form a mechanically complex interlock with trabecular bone. 1 Glenohumeral joint forces can often reach full bodyweight, and these forces are repeatedly transmitted to the glenoid eccentrically in the superior-inferior and anterior-posterior directions. 2 A common challenge in glenoid replacement is that the native bone is worn posteriorly. In such cases the surgeon typically either implants a standard component malaligned relative to the scapula, or reams away healthy bone on the anterior side to achieve normal alignment, both of which can lead to complications. Previously in our laboratory we developed a posterior-augmented polyethylene implant to compensate for this bone loss. 3

In the present study we implanted standard and augmented components into cadaveric glenoids, subjected them to long-term cyclic loading, and measured implant toggle micromotions. We also assessed damage of the implant-cement-bone structure by micro-computed tomography (micro-CT) at six loading intervals. We hypothesized that micromotions would increase during cycling, and that this increase would correspond to internal construct damage.

METHODS:
Four glenoid bone specimens were isolated from fresh-frozen cadavers of elderly donors. Two specimens (S1, S2) were implanted by an experienced shoulder surgeon (A.A.) with a commercial three-pegged polyethylene glenoid implant (Zimmer, Warsaw IN), and two (PA1, PA2) were implanted with posterior-augmented prototype implants. These prototype implants were fabricated by attaching a conforming, CNC-fabricated polyethylene block to the posterior half of the commercial implants. A step was milled out of corresponding posterior halves of the glenoid bones. 4 The specimens were potted into blocks of acrylic bone cement (Lang Dental, Wheeling IL) (Fig. 1A).

![A] Glenoid implant cemented into potted cadaveric glenoid

Figure 1. (A) Glenoid implant cemented into potted cadaver bone and being loaded by humeral head; (B) Schematic of cyclic loading apparatus.

Eccentric loads were applied with a custom-built device consistent with the ASTM standard for assessing glenoid loosening (Fig. 1B). 5 A cyclic anterior-posterior displacement of +/- 2.5 mm was applied at 1 Hz. A constant compressive joint force of 750 N (approximately 1 bodyweight) was simultaneously applied. A total of 100,000 cycles were performed, representing 25 high-load shoulder movements per day for ten years. 4 At 0, 1000, 10000, 25000, 50000, and 100000 cumulative cycles, 6 toggle micromotions (indicative of implant loosening) were measured optically while static humeral head loading was applied centrally, anteriorly, or posteriorly. High magnification images (5 µm/pixel) were recorded of anterior and posterior implant rims (Fig. 1B). Distances between marks located on the implant and bone potting were determined using ImageJ, and micromotion was defined as the change in distance relative to the centrally loaded condition.

Micro-ct imaging was also performed at the above cycle intervals using a vivaCT 40 (Scanco Medical, Brütisellen Switzerland; energy 55kV/145µA). Images were reconstructed as 2k x 2k matrices of 19 µm isometric voxels. Images were filtered and resampled to 38 µm voxels in Matlab. Image volumes from each time point were three-dimensionally co-registered with the before-loading images so that damage evolution due to loading could be readily visualized. The registration used a least-squares landmark method in Avizo (VSG US, Burlington MA). Image volumes were then visually inspected using multiple slicing directions. The cement mantle around each peg was inspected for the presence of damage, and cracks were categorized as either through-mante (crossing from implant to bone space) or partial-mante.

RESULTS:
None of the implants exhibited gross loosening after the full 100,000 cycles. All toggle micromotions were less than 1 mm; most increased in magnitude due to the cycling (Fig. 2A). Minimal damage occurred in the standard implant specimens, whereas more cracking occurred in the augmented implants (Fig. 2B). All cement cracks occurred within areas surrounding the upper half of the pegs (nearer to the glenoid face); cement deeper in the vault appeared fully intact. Cracks first appeared small and then progressed to larger cracks. Some failure of trabecular occurred near the glenoid face and surrounding the cement. Small gaps became visible between the implant and cement near the glenoid face.

DISCUSSION:
Implant micromotions correlated with internal construct damage, but statistics were not performed due to small sample sizes. Number of specimens was limited by our use of cadaver specimens; in separate tests of porous synthetic bone specimens we observed earlier construct failure and differences in ‘trabecular’ architecture. Limitations include the lack of consideration of in vivo biological response such as bone remodeling. Although the trends in results show additional micromotion and construct damage for the augmented implant, the imaging data suggest locations where adjustments in implant design and cementing technique may improve loosening resistance.

SIGNIFICANCE:
To the best of our knowledge this study is the first to experimentally investigate the micromechanics, specifically damage evolution, of cemented glenoid fixation. This study may lead to improvements in glenoid design and cementing methods.

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REFERENCES: