The Importance of Off-Axis Loading and Articulation in Loosening of Cemented Glenoids

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Introduction: A common cause of failure in anatomic total shoulder arthroplasty is glenoid loosening, which may be precipitated or exacerbated by a “rocking horse” phenomenon associated with forces related to translation of the humeral head away from the center of the polymer bearing[1 2 3]. While many studies simulate this phenomenon through translation along the superior-inferior axis, clinically relevant translations may occur in any direction. The present study assesses loosening by cyclically displacing a humeral head component against a glenoid component under axial load along the superior-inferior axis (SI), anterior-posterior axis (AP), and at an intermediate angle, 45 degrees (45°). This was done along clinically relevant wear vectors that were derived from analysis of a library of shoulder retrievals[4]. The objective of the study is to track the motion of the glenoid component to estimate the rate of loosening that occurs in each orientation.

Methods: Nine five-peg symmetrical, all-polyethylene glenoid components from a single manufacturer were cemented into a polyurethane bone substitute by an experienced clinician: three in SI orientation, three in 45-degree orientation, and three in AP orientation. Each mounted glenoid was fixed within a shoulder simulator, in which a matched cobalt chrome humeral head articulates within a water bath. A transparent viewing window allowed a view of the submerged glenoid assembly with fiducial marks on the bone substitute and fixture, while red pins were inserted in the glenoid component for clear tracking of displacement (see Figures 1 and 2). 750 N of load was applied for 150,000 cycles at 80% of the subluxation translation distance. The subluxation translation distance was determined experimentally via the method described in ASTM F2028-17, section 4.2 and amounted to 3.4 mm for the AP orientation, 4.1 mm for the 45° orientation, and 5.1 mm for the SI orientation. Videos of this test were automatically taken at predetermined intervals. For each video the top and bottom pin along with the reference points were tracked for 5 seconds (8 cycles) using a Java-based supervised video tracking software, then adjusted to assess glenoid motion at the top and bottom of the glenoid relative to the bone substitute.

Results: On average over 150,000 cycles of articulation, the micromotion of SI samples increased by 159 microns (13.83%), 45° samples increased by 31 microns (4.63%), and AP samples increased by 46 microns (7.73%). Eight out of nine samples displayed linear loosening with time. One SI sample demonstrated a sharp increase after 140,000 cycles.

Discussion: Relative motion between a glenoid bearing and bone substitute may be attributed to elastic deformation of the system, crushing of the bone substitute over time, or fracture of the cement mantle. In a clinical setting, relative motion of an implant in the supporting bone often leads to pain and eventual mechanical dysfunction. The exact definition of “loose” varies by observer and clinical sequelae but might be as small as 100 microns of relative motion and can certainly be defined as greater than 1 mm of motion. Pilliar et al. identified that 150 microns of motion could cause fibrous tissue formation adjacent to the implant[5]. Thus, micromotion in the SI orientation could be clinically significant, as the average oscillation over 150,000 cycles exceeded this value. Loosening patterns varied by orientation, likely due to a constant load but a variable subluxation translation distance. The smaller translation distance of the AP and 45-degree orientations would result in smaller moments being transferred to the cement mantle and hence smaller generated forces. One SI device behaved differently than the other 8 devices with a significant increase in motion near the end of the test. While this may be indicative of catastrophic failure, other potential sources of variability should be considered: though the cementing was done by a single experienced shoulder surgeon, the intrinsic variability between glenoids may have led to differences in loosening patterns. In addition, though the setup was developed to ASTM specification and was similar to in vivo conditions, articulation did not occur in body-like fluids, nor was the glenoid implanted in bone. Despite these limitations, this work shows that glenoid edge micromotion differs across three physiologically relevant loading orientations, with the SI orientation representing the worst-case loading scenario both in terms of overall micromotion magnitude and increases in component motion. The increases in micromotion observed are clinically significant and aligned with the prominence of glenoid component loosening as a failure mode for anatomic total shoulder arthroplasty. Continued work will involve testing at 100% of the subluxation translation (ST) distance to challenge the glenoids beyond the ASTM recommended value of 90% ST distance.

Significance/ Clinical Relevance: While glenoid loosening in all orientations was demonstrated, articulation in the SI direction appears to provide the highest challenge to the cemented glenoid interface.

References: 1. Franklin et al. J. Arthroplasty 1988;3(1):39-46, 2. Papadonikolakis et al. J. Bone Jt. Surg 95(24) p. 2205-2212, 3. Solberg et al. Proc Int Soc of Arthro #7805, 2022 4. Solberg et al. Proc Int Soc of Arthro #7788, 2022. 5. Pilliar et al. Clin Orthop Relat Res. 1986 Jul;(208):108-13

Images:

Figure 1: 45° samples on the top row, SI samples in the middle row, and AP samples on the bottom row.

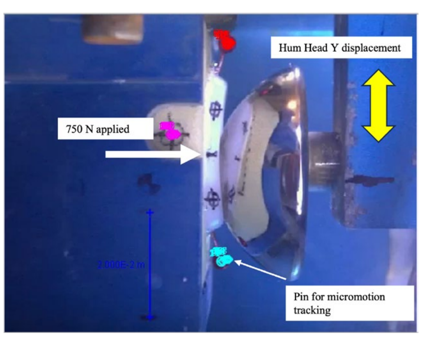

Figure 2: Video collection view.

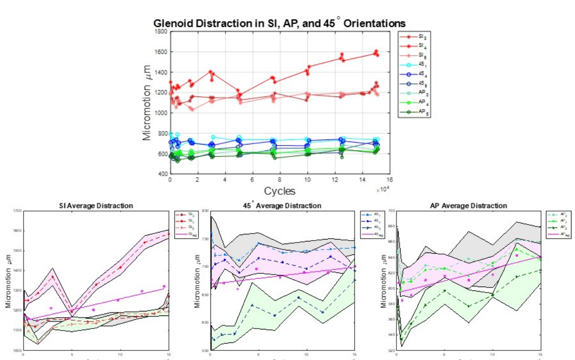

Figure 3: Results. The top graph depicts data of all orientations. The bottom three graphs depict the mean and standard deviation for each sample as well as the mean of all samples for each individual orientation.