Rocking-Horse Loosening of Glenoid Components Cemented in Cadaver Bone and Bone Foam

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Introduction: Cyclic off-center loading of the humeral head on the glenoid (rocking-horse effect), is thought to be associated with glenoid component loosening in total shoulder arthroplasty. Several laboratory studies have assessed rocking-horse loosening of glenoid components implanted in polyurethane bone foam. However, to our knowledge, there are limited laboratory reports on rocking-horse loosening in cadaver bone. The goal of this study was to compare the rocking-horse loosening of glenoid components cemented into polyurethane bone foam and into human cadaver scapulae utilizing a standard biomechanical test protocol.

Methods: Following approval from the Institutional Review Board, 6 scapulae were harvested from human cadavers, prepared by removing all soft tissue, and then potted in polymethylmethacrylate (PMMA) such that the glenoid was protruding out of the block. In addition, 6 blocks of solid rigid polyurethane bone foam (20pcf foam, Sawbones, Vashon, WA) were machined to simulate a glenoid/scapula and then potted in the same manner as the cadaver bone. Subsequently, glenoid components (Bigliani/Flatow Pegged Glenoid, Zimmer, Warsaw, IN) were implanted using the manufactures recommended cementing technique. After glenoid placement, the constructs were mounted in the biomechanical testing apparatus (Fig 1) based upon ASTM F 2028-08. The glenoid/bone(foam)/PMMA construct was rigidly held in Box A, which was secured to a rail system that only allowed (±) x-direction motion. The humeral head component was attached to a second rail system that only allowed (±) z-direction motion. In order to achieve this motion, the second rail was connected to the actuator of a load frame system (Mini-Bionix II, MTS Corp, Eden Prairie, MN). A weight/pulley system was utilized to simulate a joint reactive force of 750 N by pulling the glenoid (Box A) against the humeral head component. During testing, the MTS cyclically translated the humeral head to 90% of the superior and inferior subluxation distance (±1 mm from the neutral position). The tests were conducted at 2 Hz for 50K cycles, which represents about 25 high load activities per day for 5 years. In order to measure the rocking-horse displacement of the glenoid components in real-time, 2 spring-loaded linear variable differential transformers (LVDT-GCD-121-050, Schaevitz, Hampton, VA) were mounted on Box A. The movements of the LVDT tips were coupled to the displacements of the superior and inferior edge of the glenoid through a system of frictionless lever arms and threaded pins inserted onto the edges of the glenoid component. A custom LabView program synchronized data collection from the MTS actuator and the LVDTs such that the displacement of the glenoid component was tracked with respect to the bone(foam) material at various levels of humeral head off-center translation. The program collected 10 cycles of data at the start of the testing, after 100 cycles, and then at intervals of every 1000 cycles for the duration of the test. The displacement of the glenoid components at the superior and inferior edges were determined at the neutral, max superior, and max inferior positions of the humeral head for each cycle. The individual cycle displacement values were average over the 10 cycles collected and reported as the glenoid edge displacements at the neutral and max humeral head positions for each iteration of data collected. The micromotion of the glenoid component was computed by subtracting the position of the superior and inferior glenoid edges when the humeral head was at the neutral position from the position of the glenoid edges when the humeral head was at the maximum off-center locations. A student’s t-test was used to compared the micromotion data from the cadaver bone and the bone foam. A oneway ANOVA, followed by Tukey post-hoc where appropriate, was used to compare the micromotion across cycle count within a test material. In all tests p<0.05 was considered significant.

Results: Fig. 2a-b display the glenoid edge displacements versus cycle count. The micromotion when the humeral head was in the maximum superior position is shown in Fig 2a, while micromotion when the humeral head is in the maximum inferior position is shown in Fig 2b. Overall, a similar pattern and magnitude of glenoid micromotion was observed in cadaver bone and bone foam. In all tests there was an initial abrupt increase in the micromotion displacements of the glenoid and as the cycles continued very little additional increase in micromotion was noted. Statistical analysis of the bone foam data revealed that the micromotion at 100 cycles was significantly larger than at 10 cycles, but it was not different from micromotion observed at higher cycles out to 50K cycles. Statistical analysis of the cadaver data indicated there were no differences in the micromotion across cycles, except that compressive micromotion of the superior glenoid edge at cycle counts above 1K were larger than the motion at cycles below 1K. A comparison of glenoid micromotion results in cadaver bone and bone foam indicated that cadaver bone showed significantly larger distraction of the inferior glenoid edge when the humeral head was in the superior position at 10K cycles and greater. There were no other significant differences between the cadaver bone and bone foam results.

Discussion: Similar patterns of rocking-horse loosening were observed for glenoid components cemented in both cadaver bone
and bone foam constructs during the biomechanical tests. When the humeral head was at its maximum superior position, the superior edge of the glenoid component was compressed as the inferior edge of the glenoid was distracted. The opposite motion of the glenoid component was observed when the humeral head was at the maximum inferior position in both materials. In all tests the compression micromotion was larger than the corresponding distraction at the opposite edge of the glenoid. This may be due to deformation of the glenoid component during compression. The greater distraction of the inferior glenoid edge from cadaver bone when the humeral head was at the maximum superior position could possibly be related to the anatomic variation of bone quality and distribution in cadavers as compared to the more uniform bone foam. It is also important to point out that the standard deviation for the micromotion in cadaver bone was about twice as large as the bone foam. This larger spread in the micromotion is likely a contributing factor in the lack of finding significant differences across cycle count in the cadaver bone. The smaller standard deviation in the bone foam highlights that utilizing this more uniform material for rocking-horse tests could allow for differences between glenoid component designs or implantation techniques to be more easily resolved. In all tests most of the increase in the micromotion occurs in the early phase of testing. The lack of significant increases in micromotion occurring as cycle count increased from 1K to 50K may call into question the utility of conducting the rocking-horse loosening tests beyond 1K cycles.

**Significance:** Similar patterns and magnitudes of glenoid rocking-horse loosening occur in cadaver bone and in polyurethane bone foam. The smaller standard deviations noted for micromotion in bone foam indicate this material may be preferred for comparative testing of glenoid designs and techniques. Most of the increases in micromotion occurred in the initial test cycles and therefore future tests may only need to focus on the first 1K cycles to assess glenoid rocking-horse loosening.

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**References:** 1. Anglin et al. Clinical Biomechanics 16(2001) 144-

![Fig. 1: Photo of test apparatus](image-url)
Fig. 2a: Glenoid micromotion with humeral head at max superior position

Fig. 2b: Glenoid micromotion with humeral head at max inferior position

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