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ORIGINAL ARTICLE

A comparison of onlay versus inlay glenoid component loosening in total shoulder arthroplasty

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Background: Glenoid component loosening is common in total shoulder arthroplasty (TSA), often resulting from the mechanical interaction of glenohumeral components. This cadaveric study was performed to evaluate and to compare commercially available onlay and inlay glenoid prosthetic designs with respect to loading characteristics and loosening.

Methods: Sixteen prescreened cadaveric shoulders (8 matched pairs) underwent either onlay or inlay TSA. We created a custom glenohumeral loading model and used cycles of 5 mm anterior-posterior humeral translation to simulate a rocking-horse loosening mechanism for all testing. Articular TekScan measurements were performed with 9.1 kg (88.9 N) of glenohumeral compression before and after TSA. Fatigue testing was performed with 34.0 kg (333.6 N) of glenohumeral compression using high-definition video to document gross glenoid loosening. Testing ended with gross loosening or a maximum of 4000 cycles. Mean contact area, pressure, and joint reaction force were used to compare the 2 glenoid designs.

Results: In both implant types, contact area decreased and pressure increased after TSA ($P < .0001$). Force increased at the onlay component edge only ($P = .0012$) compared with native glenoid testing. Force was greater in the onlay vs. the inlay implants ($P < .0001$). During fatigue testing, all onlay glenoid components exhibited gross loosening at a mean of 1126 cycles (range, 749-1838), whereas none of the inlay glenoid components exhibited gross loosening ($P < .0001$).

Conclusion: The inlay glenoid implant exhibited biomechanical characteristics favoring stability and decreased loosening compared with the onlay glenoid implant in this cadaveric model.

Level of evidence: Basic Science Study; Biomechanics

Keywords: Glenoid component loosening; total shoulder arthroplasty; inlay glenoid component; onlay glenoid component; glenoid implant design; biomechanical testing

Glenoid loosening remains a common complication of total shoulder arthroplasty (TSA). All types of traditional onlay glenoid prostheses exhibit signs of loosening at a high rate, even with optimally placed components.[19,20,23,24] Optimizing

No Institutional Review Board approval was required for this cadaveric study.

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implant survivorship is a fundamental part of all arthroplasty research and development in orthopedics. Glenoid implant design has often attempted to restore native anatomy, with focus on minimizing micromotion at the bone-implant interface.[9,18] It is generally accepted that implant micromotion <150 μm is necessary for bone ingrowth.[11] Metal-backed and all-polyethylene glenoid designs, with varying backside conformations, have each attempted to optimize fixation to bone. Metal-backed glenoids have unacceptably high failure rates and higher failure rates than all-polyethylene glenoids in multiple studies.[2,17,18,24] All-polyethylene glenoid designs use backside keels or pegs to enhance fixation to bone. Although the literature is contradictory, it appears that pegged glenoids show superior survivorship to keeled glenoids.[14,20,26]

Glenoid loosening is especially concerning in younger patients, who have a longer life expectancy and higher demands. The "rocking-horse" mechanism of loosening occurs when the humerus translates on the glenoid in any plane, producing edge loading, which can result in opposite edge liftoff and component loosening.[1,7,18,21] Repetitive eccentric rim loading by the humeral head results in a torque on the implant, applied tensile stress, and opposite edge glenoid implant liftoff at the bone-implant interface.[7,18] Various recent follow-up studies have reported on glenoid loosening after TSA. Radiolucent lines are a radiographic finding consistent with component loosening. At 2 to 10 years of follow-up, radiolucent lines are present in 30% to >75% of TSAs, whereas gross implant position shift with clinical failure requiring revision is found in 2% to >10% of TSAs.[2,5,6,16,28] Published rates of loosening emphasize the need for improvements in glenoid component design.[19,21]

Compared with the traditional onlay glenoid design, a glenoid prosthesis that is inset, or an "inlay design," may possess better biomechanical characteristics with respect to mechanical loosening. It may exhibit less gross loosening because of implantation in the native glenoid within a bone socket.[8] To our knowledge, there is only one widely commercially available inlay glenoid prosthesis. The purpose of this study was to compare 2 available TSA systems with similar published indications for the treatment of glenohumeral degenerative joint disease and osteonecrosis. We focus on the loading characteristics and resistance to loosening of a traditional onlay glenoid implant compared with an inlay glenoid implant. We hypothesized that in this matched pair cadaveric TSA model, the inlay glenoid implant will exhibit greater resistance to loosening and superior biomechanical characteristics compared with the onlay glenoid implant.

Materials and methods

Specimens

Eight fresh frozen, male, cadaveric shoulder matched pairs were thawed and prescreened grossly and with high-resolution computed tomography to rule out pre-existing bone disease that could potentiate prosthetic failure. The mean age of the donors was 59.86 years (range, 54-65 years). Each shoulder was dissected free of all soft tissues, leaving the glenoid labrum and bone stock intact. All scapulae were prepared identically, with removal of the coracoid process, acromion, and inferior angle to allow accommodation within resin cement fixation blocks. Humeral shafts were potted in metal fixation cylinders, such that the superior extent of resin cement was approximately 6 cm below the inferior articular margin. The specimens were frozen and stored in a standard freezer at an average temperature of −18°C.

Arthroplasty procedures

All component implantations were performed by a single, experienced orthopedic surgeon, exactly according to manufacturers' guidelines and published techniques. All backside pegs were cemented; all cement was pressurized and allowed to fully mature before any testing. The right-sided shoulders were implanted with all-polyethylene pegged onlay glenoids (size, 46 mm) with backside cement fixation and humeral (46 × 16-mm neutral head) component (Turon system; DJO Global, Vista, CA, USA). The left-sided shoulders were implanted with all-polyethylene round, pegged inlay glenoids (size, 20 mm) with backside cement fixation and uncemented humeral (head size range, 48 × 44 to 56 × 52 mm) components (Ovo system; Arthrosurface, Franklin, MA, USA), with head sizes determined by humeral head bone anatomy per the company's recommended sizing methods.

Testing procedure

An experimental glenohumeral loading model and 2 testing protocols were created with a materials testing machine (Instron Model 8874; Instron, Norwood, MA, USA) using a 1 kN load cell (Dynacell; Instron) and cycling software (WaveMatrix; Instron) (Fig. 1). Our testing methods and TekScan protocol were adopted and tailored from prior similar studies.[8,15,21,25] Glenohumeral contact area (A) and pressure (P) were measured using a digital pressure sensor (Model 5051; TekScan, Inc., South Boston, MA, USA) placed on the glenoid articular surface (Fig. 2). Sixty degrees of glenohumeral abduction in the scapular plane and neutral rotation was used for all testing as this position has been shown to be able to successfully quantify glenohumeral joint kinematics.[15] A 2-point method was performed, using 4.5 and 13.6 kg of compressive force, to calibrate the TekScan sensors for each specimen. The center starting point for each glenoid was set using TekScan output mapping, ensuring that the starting point was equidistant from each opposing glenoid edge. For all 3 protocols, the humeral component was cycled on a stationary glenoid component, translating 5 mm in an anterior and posterior direction from the centered starting point along the y-axis (Fig. 3), yielding raw data. Table I provides a summary of our testing protocols. Joint compression forces were based on prior studies evaluating glenohumeral loads occurring with activities in wheelchair-bound patients.[25] During testing protocol 1, preimplantation and postimplantation glenohumeral contact area and pressure were measured using 9.1 kg (88.9 N) of compressive force and shear at the glenohumeral articulation, within our defined zones of interest. Postimplantation testing was performed before fatigue testing. Anterior and posterior glenoid rim regions of interest were designated zones A_1 through D (Fig. 4), where the glenohumeral articulation resulted in rim loading. Fatigue testing protocol 2 was used to assess for glenoid component gross loosening with 34 kg (333.6 N) of joint