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Biomechanical comparison of reverse total shoulder arthroplasty systems in soft tissue–constrained shoulders

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Background: Numerous studies have examined the biomechanics of isolated variables in reverse total shoulder arthroplasty. This study directly compared the composite performance of two reverse total shoulder arthroplasty systems; each system was designed around either a medialized or a lateralized glenohumeral center of rotation.
Methods: Seven pairs of shoulders were tested on a biomechanical simulator. Center of rotation, position of the humerus, passive and active range of motion, and force to abduct the arm were quantified. Native arms were tested, implanted with a Tornier Aequalis or DJO Surgical Reverse Shoulder Prosthesis (RSP), and then retested. Differences from the native state were then documented.
Results: Both systems shifted the center of rotation medially and inferiorly relative to native. Medial shifts were greater in the Aequalis implant ($P < .037$). All humeri shifted inferior compared with native but moved medially with the Aequalis ($P < .001$). Peak passive abduction, internal rotation, and external rotation did not differ between systems ($P > .05$). Both reverse total shoulder arthroplasty systems exhibited adduction deficits, but the RSP implant deficit was smaller ($P = .046$ between implants). Both systems reduced forces to abduct the arm compared with native, although the Aequalis required more force to initiate motion from the resting position ($P = .022$).
Conclusion: Given the differences in system designs and configurations, outcome variables were generally comparable. The RSP implant allowed slightly more adduction, had a more lateralized humeral position, and required less force to initiate elevation. These factors may play roles in limiting scapular notching, improving active external rotation by normalizing the residual rotator cuff length, and limiting excessive stress on the deltoid.
Level of evidence: Basic Science Study, Biomechanics.

Keywords: Reverse shoulder arthroplasty; biomechanics; shoulder simulator; kinematics

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Reverse total shoulder arthroplasty (rTSA) is used to reduce pain and to improve function in cases of rotator cuff arthropathy, 4-part proximal humerus fractures, inflammatory arthritis, and revision shoulder arthroplasty.[7,18,26,44] Early rTSA designs included a lateral offset of the glenosphere to maintain the anatomic joint center of rotation (COR), but these designs suffered from early implant loosening due to high shear stress and torque at the glenoid interface.[6,13] In the 1980s, Grammont placed the glenosphere in a more medial and inferior position with the COR of the joint at the face of the glenoid.[16,17] This allowed improved glenoid fixation and limited shear and torque loading[6,13] but predisposed the implant to scapular notching in up to 95% of patients.[5,36,38,46]

Scapular notching is likely to result when a medialized joint geometry allows the humeral component to impinge on the lateral border of the scapula in adduction. This impingement may lead to progressive bone loss inferior and posterior to the glenoid.[36] Recent rTSA designs have reintroduced a lateralized COR offset along with improved glenoid fixation to provide humeral clearance and potentially to mitigate impingement on the scapula. This has been shown to reduce the incidence of notching to <20%.[4,9] A lateralized COR has also been purported to improve joint stability and external rotation range of motion (ROM).[4,9]

Whereas COR offset is the most widely studied variable in rTSA designs, system-wise configurations can differ significantly across the spectrum of rTSA manufacturers. The influence of humeral neck-shaft angle, humeral version, superior/inferior glenoid positioning and tilt, glenosphere diameter, and joint tension has been studied both clinically and in the laboratory.[1,8,12,21,23,27,28,31,33-35,40-43] Despite the extensive literature supporting that rTSA variables can individually affect ROM, joint stability, and the potential for impingement and scapular notching, no study has directly compared the composite performance of rTSA systems, including all the design differences unique to each system, in a soft tissue–constrained cadaveric model. In contrast to bone surrogate and computational models, cadaver studies include the effects of soft tissue tension, anatomic variability, and surgical technique on the outcomes of the arthroplasty.

Therefore, the purpose of this study was to compare the performance of two commonly used rTSA systems, the Aequalis reversed shoulder (Tornier, Edina, MN, USA) and the Reverse Shoulder Prosthesis (RSP, DJO Surgical, Austin, TX, USA), in paired cadaver upper extremities by use of a biomechanical shoulder simulator. In contrast to studies explicitly examining unique rTSA parameters, the systems were chosen to represent medialized (Tornier) and lateralized (DJO) COR systems along with all variables inherent to each system (e.g., neck-shaft angle, humeral offset, glenosphere size). The outcomes from native joints were compared with those after rTSA; each implant was assembled to represent the most commonly implanted configuration for all system variables for the respective implant. Outcome metrics for this comparison were joint COR, humeral offset, abduction/adduction ROM, rotational ROM, and forces to elevate the arm.

Materials and methods

Specimen preparation

Fourteen fresh-frozen, paired upper extremities were obtained from 7 female donors (mean ± SD; age, 54 ± 9 years; body weight, 56.0 ± 12.3 kg). All cadavers were free of disease, and the joint capsule was not vented until rTSA implantation. Specimen preparation has been previously described.[27,28] Briefly, scapulae were embedded in a polymer resin, and computed tomography scans were acquired to verify the orientation of the scapula within the block. Spectra cords were affixed to the deltoid tuberosity to simulate the anterior, middle, and posterior heads of the deltoid. Three spectra cords were also sutured to the humeral insertions of the subscapularis, supraspinatus, and infraspinatus/teres minor (IS/TM) with No. 2 FiberWire (Arthrex, Naples, FL, USA). To quantify the position of the scapula under fluoroscopy, 3 metal beads (2-mm diameter) were embedded in the cortex along the lateral acromion, tip of the coracoid, and midpoint of the spine of the scapula. Two beads were implanted in the cortex along the lateral aspect of the proximal humerus on the greater tubercle.

Shoulder simulator

Specimens were tested on a biomechanical shoulder simulator (Fig. 1).[27,28] Scapulae were mounted in the machine with the neutral plane of the glenoid tilted 10° superiorly,[3,10] the scapula tilted 10° anteriorly,[30,47] and the plane of the scapula[10] parallel to the middle deltoid line of action. Deltoid lines were routed through pulleys suspended from the machine frame and positioned with reference to the coracoid, acromion, and scapular spine. Anatomic landmarks were located by palpation. Rotator cuff lines were routed along the midline surface of the respective muscle bellies.[30,47] Bicortical pins in the humerus and ulna were used to externally fix the elbow, straight or at 90°. The wrist was splinted in neutral rotation with self-adhesive wrap to stabilize the forearm.

Three stepper-driven linear actuators (Bimba, Monee, IL, USA) applied excursion to the deltoid lines to elevate the arm. In-line load cells (Omega Technologies, Stamford, CT, USA) recorded the applied force. A motion capture system recorded arm position by diode arrays mounted to the elbow hardware and machine frame (Optotrak 3020, Northern Digital, Waterloo, ON, Canada). The system was controlled by a custom LabVIEW application (v8.0, National Instruments, Austin, TX, USA).

Experimental protocol

The experimental protocol was adapted from previous reports.[27,28] Two percent body weight was applied to each line of action, either through actuators on the deltoid or as static weight suspended over pulleys on the rotator cuff lines.[15,32,39,49] These loads kept the glenohumeral joint reduced throughout the ROM and allowed active actuator excursion to track the desired motion profile