J Shoulder Elbow Surg (2015) 24, 1774-1781

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

Mechanical tradeoffs associated with glenosphere lateralization in reverse shoulder arthroplasty

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Background: Scapular notching in reverse shoulder arthroplasty occurs in up to 97% of patients. Notching is associated with decreased strength and reduced motion and may lead to long-term failure due to polyethylene wear. Many implant systems lateralize the glenosphere to address scapular notching, but the mechanical tradeoffs of lateralization have not been rigorously evaluated. We hypothesized that lateralization would decrease bony impingement but also decrease the mechanical advantage of the deltoid.

Methods: Finite element models were created using the same implants with different amounts of glenoid lateralization: 5 mm of medialization to replicate glenoid erosion, as well as 2.5, 5, 7.5, and 10 mm of lateralization. Tests were performed with static and dynamic scapulae for motion in either the coronal or scapular plane. The angle of impingement between the scapula and the humeral polyethylene was recorded, as was the deltoid force required to elevate the arm.

Results: Increasing lateralization decreased impingement while increasing the deltoid force required to elevate the arm. Differences were found between the static and dynamic scapulae, with the dynamic scapula model having increased humeral adduction before impinging. The impingement angle was also substantially affected by the bony prominences on the inferior scapula, showing how individual bony anatomy can affect impingement.

Conclusion: Lateralization is effective in increasing impingement-free range of motion but also increases the deltoid force required to perform identical tasks. In addition, impingement is determined by scapular motion, which should be included in all shoulder models.

Level of evidence: Basic Science Study, Computer Modeling.

Keywords: Glenospere lateralization; reverse shoulder arthroplasty; deltoid force; impingement; scapular notching; finite element analysis

The success of reverse shoulder arthroplasty (RSA) has led to expansion of its indications from cuff tear arthropathy (CTA)[9,10,12,13] to any condition of the shoulder in which the rotator cuff is deficient.[1,2,4,5,13,15,18,19,21,28,29] RSA was traditionally only performed in elderly patients, but there has been a shift in use to younger populations.[11]

Institutional review board approval was received for the collection of patient data that were used for data inputs into our model (IRB No. 201211724).

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1058-2746/$ - see front matter © 2015 Journal of Shoulder and Elbow Surgery Board of Trustees.
http://dx.doi.org/10.1016/j.jse.2015.06.011

As a result, RSA use has increased by 7% to 13% annually since 2007, currently comprising 37% of the shoulder arthroplasty market,[6] and this use is expected to continue to grow.[26]

A recent systematic review of the complications from RSA unfortunately showed that this is a procedure with high complication rates.[34] The global problem rate was 44%, and the complication rate was 24%. The most common problem was scapular notching, which occurred in 35% of patients, and the most common complication was instability (4.7% of patients). Although problems were defined as not being likely to affect the patient's final outcome, the long-term consequences of polyethylene wear from scapular notching have not been determined and this wear may in fact influence the long-term outcome. Many of the most commonly cited problems and complications were attributable to a poor or incomplete understanding of the mechanical implications of a given implant design or implant placement.

Scapular notching has been reported to occur after RSA in 31% to 97% of patients, often within 6 months of surgery.[32] Scapular notching is a result of mechanical impingement of the medial rim of the humeral component against the scapular neck when the arm is adducted, and it is thought to be a risk factor for glenoid loosening, instability, and implant wear. Clinically, scapular notching has been found to result in decreased postoperative strength,[14,19] decreased Constant scores,[24,25] decreased active range of motion,[23,24] and increased pain.[23] Polyethylene wear and osteolysis have not yet been reported to be causes of failure; however, only midterm results have been published to date. Retrieval studies have shown relatively high rates of polyethylene wear in patients with scapular notching,[7] and it is a reasonable concern that this will cause long-term failures.

One solution to notching is to lateralize the glenosphere, either by changing the glenosphere design or by placing bone graft between the baseplate and the remaining glenoid.[3] However, lateralization involves a mechanical tradeoff[17] because it decreases the moment arm of the deltoid,[14] possibly resulting in decreased active range of motion and strength. There is also associated with lateralization an elevation of stress at the glenoid-baseplate interface,[22,27] which can lead to glenoid failure. The clinical and mechanical implications of these modifications to implant design and use are not yet well understood. In addition, modifying the center of rotation is but one of a number of recently proposed design changes, each likewise with largely unexplored mechanical consequences.

Hoenecke et al[14] recently used musculoskeletal modeling software to better characterize the changes in the risk of impingement and deltoid efficiency associated with lateralization of the glenosphere (6 mm and 13 mm of lateralization were studied). They found that lateralization of 13 mm was required to fully avoid impingement, but compared with the baseline positioning, this amount of lateralization resulted in a 20% increase in the muscle force (primarily the deltoid) required to abduct the shoulder to 90°. While providing important new information, the modeling approach used by Hoenecke et al was insufficient to evaluate what happens mechanically during impingement or how surgical technique may influence the development of stress at the interface between the polyethylene humeral component and the medial border of the scapula. By coupling finite element analysis with inverse dynamics modeling, stress, pressure, and strain can be computed. Knowledge of these mechanical metrics, which cannot be obtained using an inverse dynamics package alone, will be critical in understanding impingement and wear.

The long-term objective of our research is to better understand the mechanical tradeoffs in RSA so that implant design and placement can be optimized to avoid complications and improve longevity of the joint replacement. The specific objective of this study was to develop a complementary finite element and musculoskeletal modeling approach to better understand the effects of glenosphere medialization and lateralization on the resulting shoulder mechanics.

Methods

A finite element contact model of RSA patterned on the Tornier Aequalis RSA System (Tornier, Montbonnot, France) was created. By use of this baseline hardware design, varying configurations of medialization and lateralization were studied. The first configuration used medialized positioning of the glenosphere to reflect the constraints of pre-existing glenoid erosion, as is often seen in CTA patients. To study lateralization, the bony increased-offset (BIO) technique was modeled, in which a bone disk harvested from the humeral head is implanted behind the glenosphere.[3] This made it possible to use the same implant for all configurations and to thereby decrease the effect of confounding variables in our analysis. Four different lateralizations were studied using BIO grafts of different thicknesses: 2.5, 5, 7.5, and 10 mm.

The geometries of a 29-mm sized glenosphere, baseplate, and humeral implant were captured using a NextEngine 3D Laser Scanner HD (NextEngine, Santa Monica, CA, USA). Idealized geometric surfaces (cones, spheres, cylinders) were fit to the scans using Geomagic Studio Software (Geomagic USA, Morrisville, NC, USA). Scapular and humeral geometries were obtained by segmenting bony surfaces from computed tomography scans of the female cadaver from the Visible Human Project (National Library of Medicine, Bethesda, MD, USA [http://www.nlm.nih.gov/research/visible/visible_human.html]). The tracing was performed within OsiriX DICOM (Digital Imaging and Communications in Medicine) viewing software (Pixmeo, Geneva, Switzerland) using an Intuos pen tablet/display (Wacom Technology, Vancouver, WA, USA). Under the supervision of a shoulder surgeon (C.M.H.), the implants were placed in the bone models within Geomagic following manufacturer-recommended guidelines. Care was taken not to perforate the cortical boundary of the scapula with the central post of the glenosphere baseplate, and the humeral stem was centered within the shaft of the humerus.