ARTICLE IN PRESS

J Shoulder Elbow Surg (2017) ■■, ■■–■■

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

ORIGINAL ARTICLE

The effect of glenoid component version and humeral polyethylene liner rotation on subluxation and impingement in reverse shoulder arthroplasty

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Background: A previously validated finite element modeling approach was used to determine how changes in glenoid component version and polyethylene liner rotation within the humeral component affect the arm abduction angle at which impingement between the inferior glenoid and the polyethylene liner occurs as well as the amount of subluxation generated by that impingement.
Materials and Methods: Five glenoid component versions (5° anteversion; neutral; 5°, 10°, and 20° retroversion) and 7 polyethylene liner rotations (20° and 10° anterior; neutral; 10°, 20°, 30°, and 40° posterior) were considered, resulting in 35 different clinically representative models. The humerus was internally and externally rotated and extended and flexed, and the resulting impingement and subluxation were measured. To further analyze more global trends and to identify implantations least prone to subluxation, polyethylene liner rotation was additionally varied in coarser 30° increments across the entire 360° range.
Results: All subluxation caused by impingement occurred during external rotation and extension, and external rotation produced nearly 10-fold more subluxation than extension. Neutral glenoid component version was associated with the least amount of subluxation for all polyethylene liner rotations. Posteriorly rotated polyethylene liners, which place the thick inferior region of the component away from the scapula, produced the least amount of subluxation. The 90° and 120° posterior liner rotations produced no subluxation, whereas the 30° and 60° anterior liner rotations produced the greatest amount of subluxation.
Conclusion: These results indicate that rotating modern radially asymmetric humeral polyethylene liners posteriorly can reduce the risk of subluxation leading to dislocation and increase external rotation range of motion.
Level of evidence: Basic Science Study; Computer Modeling

Keywords: Reverse shoulder arthroplasty; impingement; subluxation; dislocation; scapular notching; finite element analysis; humeral liner rotation

The indications for reverse shoulder arthroplasty (RSA), originally intended only for an older, less demanding population suffering from cuff tear arthropathy,[11-13,15] have expanded during the past decade. Clinical successes in restoring arm

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Institutional Review Board approval was not required as no study of human subjects was performed.

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1058-2746/$ - see front matter © 2017 Journal of Shoulder and Elbow Surgery Board of Trustees. All rights reserved.
http://dx.doi.org/10.1016/j.jse.2017.03.027

abduction and elevation function have provided confidence to expand RSA indications to proximal humeral fractures, deficient bone with intact cuff, cancer, and many others.[3-6,15] In 2007, shoulder arthroplasty was found to be growing at the same rate as knee and hip arthroplasty or higher,[9] and RSA was recently found to account for 42% of total shoulder arthroplasties.[29]

Unfortunately, RSA has also been associated with high complication rates,[1-5,21,22,30] with the 2 most common complications being scapular notching and instability.[10,30] Scapular notching is a phenomenon in which the inferior aspect of the glenoid is eroded and the inferior rim of the humeral polyethylene liner is severely worn. Scapular notching is thought to be due to direct impingement between the humeral polyethylene and glenoid bone. Although concerning, scapular notching can be monitored and assessed over time radiographically and is commonly a cause for revision only when the glenoid erosion jeopardizes the glenosphere fixation or distorted polyethylene geometry produces instability.[1,3,17,18,27,30] Prosthetic instability leading to dislocation is the most common complication, reported as 38% of all complications after RSA.[1] In addition, instability can be difficult to effectively address, with Chalmers et al reporting only 44% of early dislocations remaining stable after revision surgery and Frankle et al reporting nearly identical outcomes with closed reduction and revision surgery.[1,8,25,28]

Several new RSA implants have been introduced with specific design features intended to combat these common complications. One of the new design features is an asymmetric humeral polyethylene liner, a departure from the original Grammont style design.[6] These polyethylene liner geometries vary between designs, but many feature thicker inferior regions and thinner superior regions. These changes in polyethylene liner design are thought to reduce the likelihood of scapular notching by lateralizing the humerus and increasing the impingement-free range of motion (ROM).

The influence of these design features on abduction and adduction ROM has been studied,[26] but there has been little investigation of how this design change affects impingement-free ROM in other motions, especially those where direct contact of the humeral polyethylene liner on the inferior glenoid is likely. Furthermore, with the introduction of these asymmetric designs, a new surgical variable, humeral polyethylene liner rotation, has been introduced. This variable is vital to study for 2 reasons. First, literature provided by medical device companies implies that neutral polyethylene liner rotation is ideal for all patients and motions. However, this may not be the case, and tradeoffs may need to be made to ensure that impingement or dislocation does not occur because of the individual patient's anatomy or motion differences. Second, if there is an ideal liner rotation, the effect associated with not setting the rotation precisely at that position must be determined.

Building on our previous finite element (FE) analyses of RSA,[16,23] the goal of this study was to determine the effect of humeral polyethylene liner rotation on impingement-free ROM and the subluxation that would be generated after impingement during humeral external rotation/internal rotation (ER/IR) and extension/flexion. The influence of glenoid component version on impingement-free ROM and subluxation was also studied. We hypothesized that neutral glenoid component version and neutral polyethylene liner rotation would produce the largest arc of motion before impingement and the smallest amount of subluxation or instability.

Materials and methods

A previously validated FE modeling approach for studying lateralization in RSA was used in the current study.[16,23] Briefly, the surface geometries of the scapula and the humerus were generated from segmentations of the female cadaver of the Visible Human Project. Bone segmentations were performed with OsiriX Digital Imaging and Communications in Medicine viewing software (Pixmeo, Geneva, Switzerland) using an Intuos pen tablet/display (Wacom Technology Corporation, Vancouver, WA, USA). Computer models of the 36-mm Aequalis Ascend Reverse Flex implant system were provided by Tornier (Wright Tornier, Memphis, TN, USA).

Hexahedral FE meshes were created in TrueGrid 3.1.3 (XYZ, Pleasant Hill, CA, USA) consisting of a 15-mm section of glenoid bone, the glenosphere, the humerus implanted with a humeral implant at 0° version relative to the bone, and the polyethylene liner insert. To minimize computational time, the substantially stiffer metallic glenosphere and humeral stem were modeled as rigid. Bone and polyethylene elements were modeled as deformable, with linearly elastic material properties assigned.[16,23] In addition, two springs were placed symmetrically about the joint center to replicate the soft tissue tension of the reconstructed capsule, similar to previous studies.[16,23] Finally, a series of slip ring connector elements with passive deltoid muscle stiffness values were modeled to represent the deltoid as a cable and pulley system.[20,24] All FE analyses were completed using Abaqus/Explicit 6.14-2 (Dassault Systèmes, Vèlizy-Villacoublay Cedex, France).

From this baseline FE model, additional models with parametrically varied glenoid component version and polyethylene liner rotation within the humeral component were created. The glenoid version was defined by first creating a transverse plane oriented normal to the superior/inferior axis. The plane was placed through the center of the glenoid, measured as the distance halfway between the most inferior and superior points on the glenoid face (Fig. 1). On this transverse plane, a scapular axis was defined from the most medial scapular bone to the center of the glenoid.[7,14] The plane normal to this scapular axis at the very base of the glenoid fossa was defined as the neutral plane. Finally, the most inferior and most superior bony points lying on this cut plane were connected to define the glenoid version axis. Using Geomagic Studio Software (3D Systems, Rock Hill, SC, USA) to manipulate surface geometries, glenosphere placement on the neutral plane was performed under supervision of a fellowship-trained shoulder surgeon (C.M.H.) following manufacturer-recommended guidelines. To create FE models with various amounts of glenoid version, the cutting plane was rotated in 5° increments about the glenoid version axis. The humeral polyethylene liner rotation was varied by rotating the superior aspect of the polyethylene liner anterior or posterior within the humeral stem tray. For this study, 5 different glenoid version (5° anteversion, neutral, 5° retroversion, 10° retroversion, 20° retroversion) and 5 different humeral