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# Contact mechanics of reverse total shoulder arthroplasty during abduction: the effect of neck-shaft angle, humeral cup depth, and glenosphere diameter

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**Background:** Implant design parameters can be changed during reverse shoulder arthroplasty (RSA) to improve range of motion and stability; however, little is known regarding their impact on articular contact mechanics. The purpose of this finite element study was to investigate RSA contact mechanics during abduction for different neck-shaft angles, glenosphere sizes, and polyethylene cup depths.
**Methods:** Finite element RSA models with varying neck-shaft angles (155°, 145°, 135°), sizes (38 mm, 42 mm), and cup depths (deep, normal, shallow) were loaded with 400 N at physiological abduction angles. The contact area and maximum contact stress were computed.
**Results:** The contact patch and the location of maximum contact stress were typically located inferomedially in the polyethylene cup. On average for all abduction angles investigated, reducing the neck-shaft angle reduced the contact area by 29% for 155° to 145° and by 59% for 155° to 135° and increased maximum contact stress by 71% for 155° to 145° and by 286% for 155° to 135°. Increasing the glenosphere size increased the contact area by 12% but only decreased maximum contact stress by 2%. Decreasing the cup depth reduced the contact area by 40% and increased maximum contact stress by 81%, whereas increasing the depth produced the opposite effect (+52% and –36%, respectively).
**Discussion:** The location of the contact patch and maximum contact stress in this study matches the area of damage seen frequently on clinical retrievals. This finding suggests that damage to the inferior cup due to notching may be potentiated by contact stresses. Increasing the glenosphere diameter improved the joint contact area and did not affect maximum contact stress. However, although reducing the neck-shaft angle and cup depth can improve range of motion, our study shows that this also has some negative effects on RSA contact mechanics, particularly when combined.

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**Keywords:** Reverse total shoulder arthroplasty; RSA; glenosphere diameter; neck-shaft angle; humeral cup constraint; contact mechanics; finite element analysis; FEA

Reverse shoulder arthroplasty (RSA) is an accepted treatment for end-stage rotator cuff tear arthropathy, as well as for fracture and failed shoulder arthroplasty.[3,7-9,18,21,23,30] RSA implants typically incorporate a low-coverage ball-in-socket articulation that, during shoulder motion, is regularly subjected to shear loading.[1,16] Increased shear loading has been shown in total hip arthroplasty to result in migration of the articular contact patch toward the rim of the cup with associated increases in articular contact stress.[15] This effect would be exacerbated in RSA because of the comparatively lower cup depth, which reduces the distance between the contact patch and the rim.

In certain instances, the inferior edge of the polyethylene cup may come into contact with the scapula, resulting in scapular impingement, which causes damage and excessive wear to the inferomedial rim of the cup.[5,19] To avoid impingement yet still maintain a good range of motion, surgical techniques and RSA implant design parameters can be modified.[26] Inferior placement of the glenosphere and an increased glenosphere diameter help mitigate the risk of scapular impingement by offsetting the articular surface inferiorly and increasing the distance between the scapula and the inferomedial edge of the polyethylene cup.[17,20,26] Reducing the RSA neck-shaft (N-S) angle and decreasing the cup depth also reduce the chance of scapular impingement by decreasing the inferior overlap of the polyethylene cup under the glenosphere, thereby reducing the potential for contact with the scapula.[13,20,22] However, although such alterations to RSA implant parameters reduce the risk of scapular impingement, they can also increase articular shear loading. This may result in the generation of high contact stresses that promote excessive wear and potentially contribute to scapular notching via wear particle–induced osteolysis.[27] There has been some recent interest shown in the wear testing of RSA implants,[14,24,28] although the effects of changing RSA implant parameters on wear have not been fully investigated.

In RSA the location of the contact patch on the polyethylene cup is mainly a product of (1) joint load angle, which is prescribed by a variety of factors including but not limited to arm position, muscle activity, and inertial effects; (2) implant N-S angle; (3) glenosphere diameter; and (4) cup constraint—the latter three of which are controlled by implant design geometry. N-S angles vary among current RSA implant systems, most commonly ranging between 135° and 155°. Lower angles provide greater adduction range of motion by rotating the humeral cup in the direction of abduction relative to the humeral shaft, reducing the angle at which scapular impingement can occur.[6,10,12,29] In terms of glenosphere diameter, typically, a smaller 36- or 38-mm diameter and a larger 40- or 42-mm diameter are offered, with larger sizes used for patients with larger bone geometries.[2,4,6,10,12,26,29] Cup depth can also vary from a standard depth to either a deeper, more constrained polyethylene insert or a shallower, less constrained polyethylene insert; the former attempts to improve stability by increasing the force required to dislocate the joint, and the latter is purported to increase mobility by reducing impingement.[13]

Although the effects of changing the N-S angle, glenosphere diameter, and polyethylene cup depth have been investigated for shoulder range of motion, the influence of changing these implant design characteristics on contact mechanics, and thus potentially the long-term performance of an RSA, have yet to be investigated. Therefore the objective of this study was to use finite element analysis (FEA) to evaluate the effect of the RSA N-S angle, glenosphere diameter, and polyethylene cup depth on RSA contact mechanics over the range of joint load angles that are to be expected during abduction and in the absence of scapular impingement. This will provide further insight into the effects of changing these parameters and may show that improving implant range of motion may come at the cost of less favorable contact mechanics, thus affecting the long-term performance of the RSA. Our hypothesis was that higher N-S angles, larger glenosphere diameters, and increased cup constraint would provide improved RSA contact mechanics because of the resulting reduced cup shear loading and increased cup depth.

## Materials and methods

To investigate the contact mechanics of RSA implants having varying design parameters, the resultant joint load angles with respect to both the glenosphere and humeral cup (Fig. 1) during the abduction of cadaveric RSA-reconstructed shoulders were determined. This calculation was performed by using the joint compression and shear data reported by Ackland et al[1] and Kwon et al[16] during the abduction of unloaded arms. The angle of abduction was converted to the humeroscapular angle using the 2:1 ratio between humeral and scapular rotation used by both studies. This provided specific resultant joint load angles for each of the 14 abduction angles[1,16] that were required to satisfy static