Introduction: Total shoulder arthroplasty (TSA) is the treatment of choice for end-stage arthritis of the shoulder. However, in patients with significant rotator cuff deficiency, shoulder function (especially active abduction) is severely limited even after conventional TSA. To address this issue, a reverse TSA design has been developed with a convex glenoid surface and a highly conforming concave humeral articular surface. This reverse design converts the shoulder joint into a more constrained ball-and-socket articulation. One direct advantage is that the rotator cuff is no longer critical for glenohumeral stability. We developed a computer model of glenohumeral abduction to quantify the biomechanical advantages of a reverse TSA over a conventional TSA.

Materials and Methods: Surface geometry of the humerus and scapula was obtained after segmenting a CT scan of a normal cadaver shoulder in MIMCS (Materialise, Belgium). Computer models of conventional and reverse TSA were generated based on measurements made on current generation TSA components (Fig 1). Rotator cuff muscle (supraspinatus, infraspinatus, teres major) action was simulated at the humeral insertion as the minimum force required for glenohumeral stability during abduction (as a sinusoidal function of abduction angle: maximum at 0° and minimum at 90° of abduction). The deltoid tendon was simulated as a force vector acting on the humerus with magnitude sufficient to abduct the glenohumeral joint at 180°/second. The weight of the arm was reproduced using a force in the direction of gravity representing 5% bodyweight acting 320 mm from the glenohumeral center of rotation. A rigid body dynamic model of shoulder abduction under four conditions was generated using commercially available software ADAMS (MSC.Software): conventional TSA, reverse TSA, reverse TSA with rotator cuff, and reverse TSA without rotator cuff with a center of rotation medialized by 19 mm (as recommended surgically). For validation, glenohumeral contact forces at 15, 30, 45, and 75° of shoulder abduction were compared to those reported in vivo.(1)

Results:

![Figure 1: Model of conventional TSA showing the directions of action of supraspinatus and deltoid muscles.](image1.png)

![Figure 2: Glenohumeral contact forces at 45° abduction.](image2.png)

![Figure 3: Glenohumeral contact forces over the range of abduction (0 to 75°).](image3.png)

Glenohumeral contact forces predicted by the conventional TSA model were very close to in vivo measurements at 15, 30, and 45° (Fig 2, 3). A small reduction in contact forces was seen in the reverse TSA condition without rotator cuff action. Medializing the reverse TSA resulted in a substantial reduction in contact force (at 45 and 75°).

Discussion: The similarity in contact forces in the un-medialized reverse TSA indicates that the mechanical advantage of the reverse design was similar to that of the conventional design. Deactivating the rotator cuff muscle in the reverse TSA condition (to simulate a subject with rotator cuff deficiency) did not materially change contact forces probably because of the compensatory increase in deltoid muscle force. The benefit of reduced contact forces with medialization increased with abduction angles peaking at ~20% at 45 and 75° abduction. This may be because the relative contribution of the deltoid muscle force to glenohumeral compressive force increases with abduction angle.

These results indicate that the major mechanical advantage of the reverse TSA is due to medialization of the center of rotation. In patients with compromised shoulder muscle function, this can enhance postoperative function.