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Arc of motion and socket depth in reverse shoulder implants

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ABSTRACT

Background: Reverse shoulder arthroplasty relies on its congruent ball/socket joint to restore shoulder function. For a simple ball/socket joint, as shown in total hip arthroplasty, range of motion decreases with the increase of articular constraint. We challenge here that this intuitive concept might not be held in reverse shoulder arthroplasty because of the effect of multiple concurrent factors.
Methods: Abduction impingement-free arc of motion in reverse shoulder arthroplasty was examined with a virtual computer model. Six articular constraints, defined by normalized socket depths, were simulated. Four concurrent factors: glenosphere diameter, lateral offset of glenosphere from the glenoid surface, humeral neck-shaft angles, and locations of the glenosphere on the glenoid surface, were also studied, which composed a total of 81 combinations and 486 individual conditions.
Findings: Three distinct classes of arc of motion relative to the articular constraint were revealed: I – arc of motion decreased with increased constraint (57%), II – arc of motion with a complex relationship to constraint (37%), and III – arc of motion increased with increased constraint (6%).
Interpretation: Classes II and III were counter-intuitive which could be caused by impingement on the acromion associated primarily with superior positioning. Surgeons may need to be aware of it when the glenoid component has to be placed superiorly. The detailed motion/constraint relationship will further help engineers improve the design in reverse shoulder arthroplasty.

1. Introduction

Reverse shoulder arthroplasty (RSA) has been increasingly used in the treatment of pseudoparalysis which is developed from severe rotator cuff deficiency. By utilizing a congruent glenosphere–humerosocket articulation, RSA provides a stable fulcrum for the remaining musculature which helps to restore this loss.

One of the major concerns in RSA is the variation of functional outcomes after implanting this non-anatomic prosthesis. Range of motion after RSA has been shown to vary from 30° to 180° in active elevation and from 10° to 65° in external rotation (Valenti et al., 2000). This variation in outcomes may be a result of changes in primary arcs of motion and the inherent impingement points attributable to differences in prosthetic design or modification of surgical technique. The most common impingement point is between the medial edge of the humerosocket and the lateral edge of the scapula. This impingement of the implant on the inferior scapular neck has been noted as the mechanism for the development of scapular notching (Sirveaux et al., 2004). Typically, the impingement, referred to as an adduction deficit, occurs when the arm is in a resting position. Progressive scapular notching has been demonstrated to a variable degree radiographically correlating with poorer clinical outcomes (Sirveaux et al., 2004; Valenti et al., 2000). It has even been implicated as the cause of failure in several patients (Simovitch et al., 2007).

Impingement may also result in the introduction of prosthetic wear particles, creating additional concerns for the surgeon (Nyffeler et al., 2004). Retrieval studies from total hip arthroplasty have offered evidence linking impingement to accelerated wear and dislocation from levering-out (Burroughs et al., 2001; Malik et al., 2007). Recent work involving RSA shoulders has shown a dramatic decrease in patients pain relief between years 5 and 7 (Guery et al., 2006). Thus, for long-term clinical success of RSA, it is not only necessary, but critical to have a better understanding of the underlying mechanism associated with maximizing the impingement-free arc of motion.

Extensive research in total hip arthroplasty has revealed a decrease in the impingement-free range of motion as articular constraint increases (Burroughs et al., 2001; Malik et al., 2007). This suggests that maximizing the impingement-free arc of motion occurs at the expense of ball/socket joint constraint. However, direct translation of the results from hip arthroplasty to RSA may not be straightforward because of the intrinsic differences in their anatomic structures and the non-anatomic reversed nature of RSA. In addition, understanding the relationship between the

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impingement-free arc of motion and articular constraint poses some unique challenges in RSA. Recent studies have demonstrated a number of concurrent design and surgical factors, including glenosphere placement on the glenoid, prosthetic size and prosthetic shape, which can affect the impingement-free arc of motion (Gutiérrez et al., 2007, 2008c). Without simultaneously analyzing these factors, it is impossible to formulate a rationale regarding how articular constraint contributes to the impingement-free arc of motion in RSA.

In this study, we investigated how articular constraint would affect the abduction impingement-free arc of motion with a computer-simulated virtual shoulder model. Articular constraint was defined by the normalized humerosocket depth (socket depth/radius). The simulation also included the concurrent factors of glenosphere diameter, lateral center of rotation (CoR) offset of the glenosphere from the glenoid, humeral neck-shaft angles and position of the glenosphere on the glenoid surface. We hypothesized that the impingement-free range of motion would decrease as articular constraint increased.

2. Methods

2.1. Computer model

A computer aided design program, SolidWorks© (COSMOSMotion add-in, SolidWorks Corporation, Concord, MA; USA), was used to simulate humeral abduction/adduction in relation to the glenoid in the scapular plane of the RSA. The simulation was based on the algorithms similar to those reported in the literature (Gutiérrez et al., 2007, 2008a), where impingement between the humerosocket and the scapula, and the humerus and the scapula were modeled using 3D contact properties (steel (dry) – this being the closest available option in COSMOSMotion to cortical bone) in SolidWorks©. Range of motion in each simulation was thus defined from where the simulation stopped superiorly to where it stopped inferiorly due to the 3D contact properties. The model included a scapula, a mounting block for the scapula, a glenosphere, a humerosocket, and a humeral shaft fixed in a humerus. The scapula and humerus were imported from CT scan images of a left large Sawbones shoulder model (Pacific Research Laboratories, Vashon, WA; USA). The images were converted into a stereo lithography file by the program Mimics (The Materialize Group, Leuven; Belgium), and then imported into SolidWorks©.

Abduction impingement-free arc of motion was measured by total degrees of abduction from inferior impingement on the scapula to superior impingement on the acromion in relation to the glenoid. Inferior impingement was defined by an adduction angle that kept the humerus from resting in a vertical position, i.e. the arm coming to rest at the side of the body. Any adduction past this point, or less than zero degrees, was noted as no adduction deficit since it was not anatomically possible.

2.2. Anatomical validation

The model was anatomically validated prior to the virtual simulation by comparing the geometry of the scapula and humerus with 11 randomly selected patients who had CT scans performed preoperatively (eight rotator cuff deficiency with glenohumeral arthritis and three rotator cuff deficiency with glenohumeral arthritis after previous rotator cuff surgeries. Average age = 79.9; Min: 56, Max: 85). Seven parameters previously defined in the literature were used: glenoid height, glenoid width, glenoid depth, glenoid retroversion, glenoid inclination, distance from coracoid base to articular surface, and humeral head radius (Iannotti et al., 1992; Karelse et al., 2007).

2.3. Mechanical validation

The model was mechanically validated by comparing the abduction impingement-free arc of motion in the virtual simulations to an identically constructed experimental model previously reported in the literature (Gutiérrez et al., 2007) for 27 combinations including three CoR lateral offsets (0, 5 and 10 mm), three ball/socket diameters (30, 36 and 42 mm), and three humeral neck-shaft angles (130°, 150° and 170°). The glenosphere was placed on the center of the glenoid without tilting following a definition of the glenoid center line for central screw fixation (Bicos et al., 2005).

2.4. Virtual simulation

The impingement-free arc of motion was examined under six articular constraints defined by the humerosocket depth "*d*" normalized by its radius "*R*" (d/R): 0.08, 0.22, 0.32, 0.44, 0.56 and 0.68 (Fig. 1). The use of the normalized depth rather than the absolute depth directly associated this parameter with the translational stability. It was previously demonstrated that translational stability ratio r_s of a ball–socket joint tested under a normal compressive force F_n and a shearing dislocation force F_s was given by (Tammachote et al., 2007; Anglin et al., 2000):

$$r_s = \frac{F_s}{F_n} = \frac{\tan\theta + \mu}{1 - \mu \cdot \tan\theta} \quad (1)$$

where μ is the coefficient of friction between the ball and socket, and θ is the incident angle between the ball and socket edge. For RSA, θ is determined as (Gutiérrez et al., 2008b):

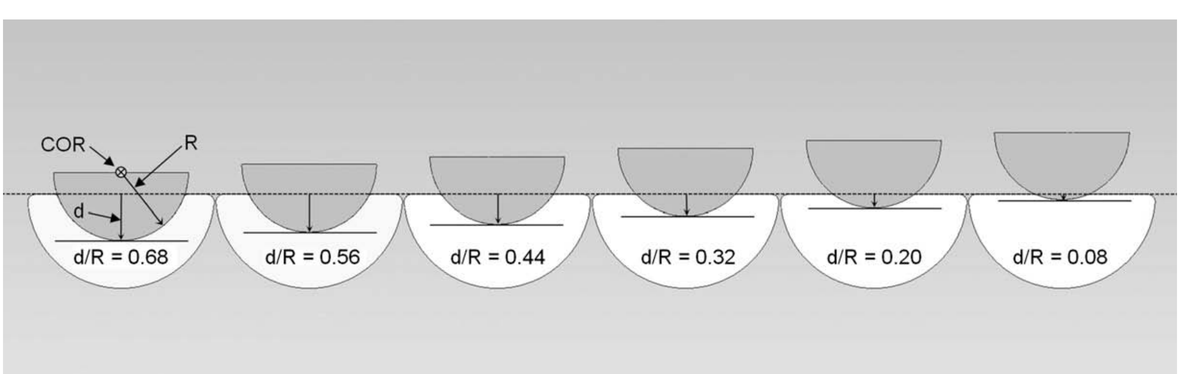

Fig. 1. Illustration of the six different depth of sockets selected in this study.