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Implant impingement during internal rotation after reverse shoulder arthroplasty. The effect of implant configuration and scapula anatomy: A biomechanical study

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ABSTRACT

Background: Internal rotation after reverse shoulder arthroplasty is essential to perform fundamental daily living activities. The purpose of this study was to examine the impact of anatomical and implant related factors on impingement-free internal rotation of the glenohumeral joint.
Methods: CT-scans of 13 human shoulder specimens with implanted reverse shoulder prostheses were carried out and scapula neck length, lateral pillar angle, and implantation height of the metaglene were measured. Internal rotation testing of all specimens was performed by the use of a robot assisted shoulder simulator. Biomechanical variables were analyzed using a three-way ANOVA. Spearman's rank correlations were performed to determine the relationship between biomechanical and anatomical data.
Findings: The maximum internal rotation angle for a 38 mm centric glenosphere and a standard onlay was 93.4(SD 34.9°). The change of the diameter of the glenosphere resulted in no significant increase of the maximum rotation angle ($P = 0.16$), while change of the glenosphere type from concentric to eccentric ($P = 0.005$) as well as the change of the onlay type from standard to a more shallow one ($P = 0.002$) both had a significant effect on the internal rotation.
The distance between the inferior rim of the metaglene and the inferior aspect of the glenoid ($P = 0.21$), scapula pillar angle ($P = 0.13$) as well as the scapula neck length ($P = 0.81$) showed no significant correlation with the maximum internal rotation angle.
Interpretation: Implant component selection shows strong influence on the impingement-free internal rotation. The use of an eccentric glenosphere and a shallow humeral cup may improve internal rotation after reverse shoulder arthroplasty.

1. Introduction

Reverse shoulder arthroplasty is a well accepted treatment for patients with a symptomatic cuff tear arthropathy, failed total shoulder arthroplasty and sequelae of trauma (Frankle et al., 2005; Guery et al., 2006; Levy et al., 2007a, 2007b; Sirveaux et al., 2004; Wall et al., 2007; Werner et al., 2005). Nonetheless some challenges remain, scapular notching which was originally described by Sirveaux et al. (2004) is the most frequently reported complication in reverse shoulder arthroplasty caused by the reversed implant design concept. Notching is reported with a high prevalence ranging from 44 to 96% (Boileau et al., 2005; Simovitch et al., 2007; Werner et al., 2005). Scapular notching is a consequence of repeated impingement between the humeral implant component and the scapular neck during adduction of the arm which in time results in bony erosion and polyethylene wear of the onlay (Boileau et al., 2005; Simovitch et al., 2007). Impingement can further restrict the range of motion of the arm and notching may lead to early implant loosening caused by bone loss and wear particle induced weakening of the bone-implant interface (Nyffeler et al., 2004; Vanhove and Beugnies, 2004). Because of the proposed mechanical explanation for scapular notching, research groups have investigated surgical, anatomical and implant associated influence factors, with the aim to reduce scapular impingement and notching. Simovitch et al. investigated 77 consecutive shoulders of patients that had developed scapular notching and found a high correlation of inferior notching with the angle between the glenosphere and the scapular neck as well as with the position of the glenosphere on the proximal humerus (Simovitch et al., 2007). In subsequent studies, the influence of glenosphere positioning has been confirmed and several authors have recommended an increased inferior overlap (Gutiérrez et al., 2008; Lévigne et al., 2008; Middernacht et al., 2008). In a biomechanical study on scapular bone models, Chou et al. investigated the range of motion of reverse shoulder prostheses with different glenosphere

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configurations and found eccentric and larger diameter glenospheres to improve the amount of maximum adduction (Chou et al., 2009). Furthermore a, reduced humeral neck-shaft angle and cup depth tends to result in improved adduction deficit in reverse shoulder arthroplasty (Boileau et al., 2005; Gutiérrez et al., 2008).

In most of the clinical and biomechanical studies addressing the notching phenomenon, the factors that influence scapular notching are associated with the impingement of the humeral implant with the scapular bone during arm adduction. Nonetheless, clinically patients often show limited abilities in performing internal rotation tasks after reverse shoulder arthroplasty (Levy et al., 2014; Sirveaux and Mole, 2010; Stevens et al., 2014; Triplet et al., 2014) which may lead to reduced mobility in daily living activities and may limit the ability to perform perineal care, which requires a maximum of internal rotation (Raiss et al., 2007; Sirveaux and Mole, 2010). Possible reasons for this limited function in internal rotation might be soft tissue related, but also could be a result of the reverse biomechanical joint function caused by the implant design, or by impingement of the humeral prosthesis with the scapular bone although these have not been investigated or verified. The purpose of this biomechanical study was therefore to investigate the influence of the glenosphere position and implant design features on the mechanical conflict between the humeral component and the scapula during internal rotation of the arm. Furthermore, in the same context, the effect of the individual scapular anatomy on the internal rotation was evaluated. The hypothesis we posed was that the size and position of the glenosphere, humeral cup depth, and the anatomy of the scapula all have a combined influence on the inferior scapular impingement of reverse shoulder arthroplasty during internal rotation.

2. Methods

2.1. Specimen preparation and mounting

Thirteen human cadaveric shoulder specimens with no radiographic evidence of glenohumeral osteoarthritis or cuff tear arthropathy were obtained for the study (median age 75 years, range 52 to 85). Prior to preparation and biomechanical testing all specimens were evaluated by CT scans defining different parameters of scapula anatomy. The specimens were subsequently thawed at room temperature for 12 h. For fixation of the shoulders in the testing apparatus, the soft tissue of the medial scapula margin to the scapula neck was dissected leaving the lateral portion of the rotator cuff muscles and the musculotendinous junction intact.

For secure attachment to the testing rig, the scapula was first potted in a custom made box using a three component casting resin (Rencast FC 52/53, DT982, Gössl&Pfaff GmbH, Karlskron Brautlach, Germany). The scapula block was rigidly attached to the mounting tower using three threaded rods. The alignment of the scapula was achieved, by defining a vertical plane visually with the plane passing through the superior and inferior angles of the scapula as well as the middle of the glenoid surface. With reference to the plane, the scapula was tilted forward 10° to correspond to its physiologic orientation on the thorax. As a reference for humeral internal and external rotation, a k-wire was aligned parallel to the long axis of the forearm with the elbow in 90° flexion and placed within the diaphysis of the humerus to define neutral rotation of the humerus relative to the scapula plane. The humeral bone was then cut approximately 20 cm distal to the center of the humeral head and potted in a brass cylinder by the use of the casting resin.

The tests were performed using a robot-assisted kinematic simulator. The global coordinate system was defined with the anteroposterior axis normal to the defined plane of the scapula, the superior direction defined in the plane of the scapula and the lateral direction orthogonal to the antero-posterior and vertical directions. The humeral coordinate system was defined as co-directional with the global coordinate system. The origin was located at the geometric center of the humeral head with the humerus orientated in 0° abduction and neutral rotation. This reference location was saved for each specimen in the intact condition and the joint was repositioned at the beginning of every following test condition.

2.2. Testing setup

The test rig consisted of a scapula mount and an industrial robot (KR15 C1, KUKA GmbH, Augsburg, Germany) equipped with a six-component force-moment sensor (FMS) (IpeA, GmbH, Berlin, Germany) to which the humerus is rigidly attached. The robot applies controlled motion and loading to the glenohumeral joint (Fig. 1). The scapula was fixed to the mounting tower by aligning the metaglene of the prosthesis in the sagittal plane. Therefore the specimen was subsequently adjusted after inserting a threaded rod in the central drill hole of the glenosphere (orthogonal to the metaglene). The rod was aligned horizontally by means of a bubble level.

The robot is able to control motion by means of a custom written control software and by the load and moment data provided by the FMS. In the current study a load controlled algorithm was utilized, the robot/FMS system enables measurement of motion with a resolution of 0.02 mm and measurement of joint loading with a resolution of less than 0.3 N force.

A contact pressure film was mounted between the glenoid and the metaglene surface of the specimen to achieve a complete covering of the inferior scapula neck (Tekscan 5051, Tekscan Inc., South Boston, MA) (Fig. 1). After fixation of the Tekscan-film pressure measurements were reset to zero. The measuring range of the Tekscan-film was given with 50 pounds force per square inch (psi) with the resolution defined by a number of 62 pressure sensors per cm^2.

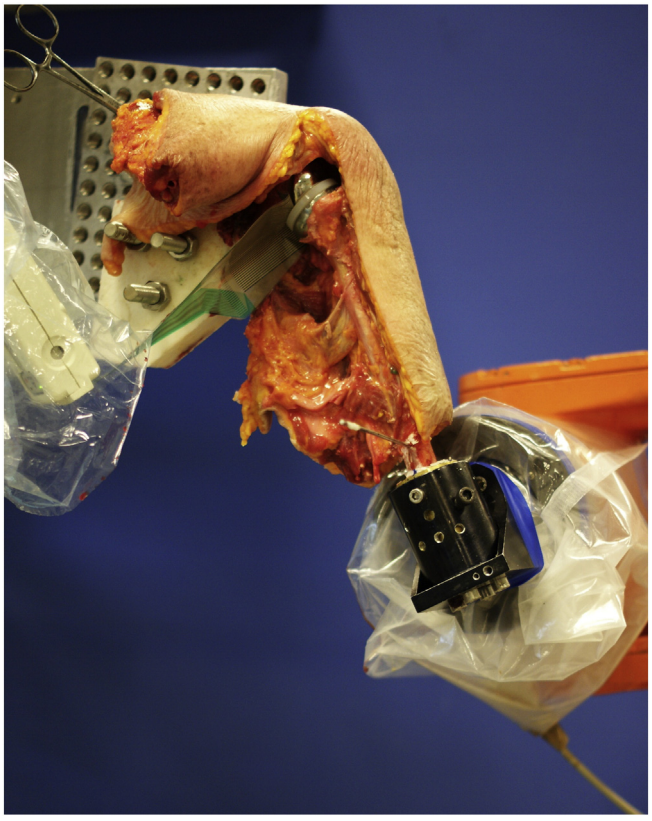

Fig. 1. Robot assisted testing setup: The scapula was rigidly attached to the mounting tower and the humerus was fixed to the wrist of the robot which is equipped with a force-moment sensor. Detection of the impingement was detected by the use of a contact pressure film.