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Kinematic impact of size on the existing glenohumeral joint in patients undergoing reverse shoulder arthroplasty

Andres F. Cabezas [a], Sergio Gutiérrez [a], Matthew J. Teusink [b], Daniel G. Schwartz [c], Robert U. Hartzler [d], Brandon G. Santoni [a], Mark A. Frankle [d,*]

[a] Phillip Spiegel Orthopaedic Research Laboratory, Foundation for Orthopaedic Research and Education, Tampa, FL 33637, USA
[b] University of Nebraska Medical Center, 981080 Nebraska Medical Center, Omaha, NE 68198, USA
[c] The Sports Medicine Clinic, 10330 Meridian Ave. N, Suite 300, Seattle, WA 98133, USA
[d] Florida Orthopaedic Institute, 13020 N Telecom Pkwy, Tampa, FL 33637, USA

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ABSTRACT

Background: Glenohumeral relationships in reverse shoulder arthroplasty patients have not been previously reported. The purpose of this study was to quantify and compare the shoulder spatial relationships and moment arms. Measurements were used to define general size categories and determine if sizes scale linearly for all metrics.

Methods: Ninety-two shoulders of patients undergoing primary reverse shoulder arthroplasty for functionally-deficient massive rotator cuff tear without bony deformity or deficiency were evaluated using three-dimensional CT reconstructions and computer-aided design software. Multiple glenohumeral relationships (including moment arm) were measured and evaluated for size stratification and linearity. Generalized linear modeling was used to investigate how predictive glenoid height, coronal humeral head diameter, and gender were of greater tuberosity positions.

Findings: The 92 shoulders were grouped based on glenoid height: small (<33.4 mm), medium (33.4–38.0 mm), and large (>38.0 mm). All relationships varied between groups. The humeral head size, glenoid width, lateral offset, and moment arm all independently increased linearly ($r^2 \geq 0.92$) but the rate of increase varied (slope range: 0.59–1.92). Glenoid height, coronal humeral head diameter and gender predicted the greater tuberosity position within mean 1.09 mm (standard deviation (SD) 0.84 mm) of actual position in 90% of the population.

Interpretation: Distinct groups exist based on the size of the glenoid in shoulder arthroplasty patients. Shoulder modeling should account for size groups, sex, and non-uniform linear scaling of morphometric parameters. Prediction of the greater tuberosity offset can be made using sex and size parameters. Clinical implications include appropriate prosthetic size selection and avoiding large deviations in non-anatomic reconstructions.

1. Introduction

Reverse shoulder arthroplasty (RSA) is an effective treatment for patients who suffer from shoulder pain and dysfunction associated with a variety of shoulder pathologies including severe rotator cuff deficiency with or without glenohumeral arthritis (Cuff et al., 2008; Frankle et al., 2005; Gerber et al., 2009; Guery et al., 2006; Matsen et al., 2007; Sirveaux et al., 2004; Wall et al., 2007; Werner et al., 2005). Both the indications for reverse shoulder arthroplasty and the number of commercially available reverse shoulder arthroplasty systems with different sizes and shapes of implants continue to expand. Furthermore, both prosthetic design and technique have been shown to affect clinical outcomes such as post-operative glenohumeral range of motion and biomechanical properties such as deltoid moment arm (Boileau and Walch, 1997; Gutierrez et al., 2008; Henninger et al., 2012).

Given the multitude of considerations during prosthetic reconstruction (e.g., patho-anatomic problems such as bone loss, bone deformity, alterations from removal of failed previous implants), it may be difficult to select the optimal implant. We have observed clinically that occasionally there is a mismatch between patient size and prosthetic options. To better understand how individual shoulder size varies in patients treated with primary reverse shoulder arthroplasty, we sought to analyze a cohort of patients who were treated solely for severe rotator cuff deficiency (based on clinical history and physical exam), and therefore did not have arthritic joint changes, bone loss, or boney deformity. We hypothesized that the patients' shoulder sizes could be grouped into several distinct size categories and that the structures (humeral head

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[*] Corresponding author at: Florida Orthopaedic Institute, 13020 N Telecom Pkwy, Tampa, FL 33637, USA.
E-mail address: mfrankle@floridaortho.com (M.A. Frankle).

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size, glenoid size, etc.) and glenohumeral relationships (glenoid to COR distance, acromion to greater tuberosity distance, etc.) would scale linearly. An improved understanding of the range of shoulder sizes in patients undergoing RSA will provide the surgeon with critical information for implant selection that provides appropriate soft-tissue tension and mechanical advantage.

2. Methods

Standard preoperative CT scans (1.25 mm slice thickness) of 92 non-consecutive patients with severe rotator cuff deficiency treated by the senior author with primary RSA between 2008 and 2011 were reviewed. All patients had little to no glenohumeral wear, osteophytes, osseous defects, deformity, or fracture as determined by an experienced orthopedic surgeon. This exclusion criterion served to improve the ease and accuracy of identifying anatomic landmarks for morphological study. The CT scans were imported into Mimics 14.12 (Materialise, Leuven, Belgium) and 3D renderings of the patients' humerus and scapula were generated. These models were then imported into the computer assisted drawing (CAD) program SolidWorks (Dassault Systemes, Véilzy-Villacoublay, France) as distinct entities in order to measure the individual anatomic morphology and their interdependent relationships.

2.1. Definition of landmarks and coordinate systems

An independent coordinate system for each scapula was defined using anatomic landmarks in accordance with Frankle et al. (2009) (Fig. 1A, B). This coordinate system (Fig. 1B) was used to define the coronal plane (YZ), axial plane (XZ), and sagittal plane (XY). An additional landmark, the most lateral point (furthest along Z-axis) of the acromion, was marked for the purpose of calculating the moment arm of the middle deltoid, as described below.

An independent coordinate system for each humerus was defined using anatomic landmarks and best fit circles along the humeral model's geometry (Figs. 1 and 2). First, the humeral shaft axis was created by passing a line through the centers of two best-fit ellipses drawn inside an axial view perpendicular to the diaphysis. The proximal ellipse was at least 15 mm below the humeral head, with the most distal ellipse at least 5 mm below that. The coronal plane was then defined using the shaft axis line and the estimated most lateral point on the greater tuberosity chosen using the 3D virtual model. Next, the coronal center of the humeral head was defined by a circle best fit to the articular margin in the defined coronal plane. The axial plane was defined as orthogonal to the coronal plane, intersecting with the shaft axis line and center of the aforementioned best fit coronal plane circle.

2.2. Quantification of the pathologic and normalized glenohumeral relationships

Anatomic relationships were measured in accordance with methods previously described (Iannotti et al., 1992; Jeong et al., 2009). Measurements of the humeral head diameter were facilitated by overlaying best-fit circles in the defined coronal and axial planes (Fig. 2A, C, Table 1). Humeral articular arc was defined in the coronal plane by choosing the endpoints of the articular margin (β in Fig. 2B). Neck shaft angle was defined as the angular measurement between the shaft axis and the anatomic neck line (α in Fig. 2B). The neck shaft and articular arc were used to determine the humeral head thickness (line **KJ** on Fig. 2A), which was exclusively used to compare the methodology to existing works. The humeral coronal center was assumed to be the center of the best fit circle in the defined coronal plane.

The shoulder's scapular coordinate system with native pathologic humerus position was aligned to the global coordinate system, placing the scapular origin at (0, 0, 0). Glenoid measurements were taken in the scapular inferior–superior axis for glenoid height and anterior–posterior axis for glenoid widths (Fig. 2D, Table 1). Glenoid width measurements were taken from the midpoint of both the defined upper and lower half of the glenoid, as determined from the glenoid height (quarter height). The humerus was then virtually transformed to an anatomic, non-pathologic state (Fig. 1D–E) by aligning the humeral axial and coronal planes (Fig. 1C) with the scapular axial and coronal planes, respectively (Fig. 1B). Cartilage thickness for the non-pathologic state was modeled for all patients as a 4 mm gap between the humeral head and glenoid (Fig. 2A) (Ciccone et al., 2000; Graichen et al., 2003; Hodler et al., 1995; Yeh et al., 1998). The coordinates for all pre-defined points (Fig. 2, Table 1) were recorded.

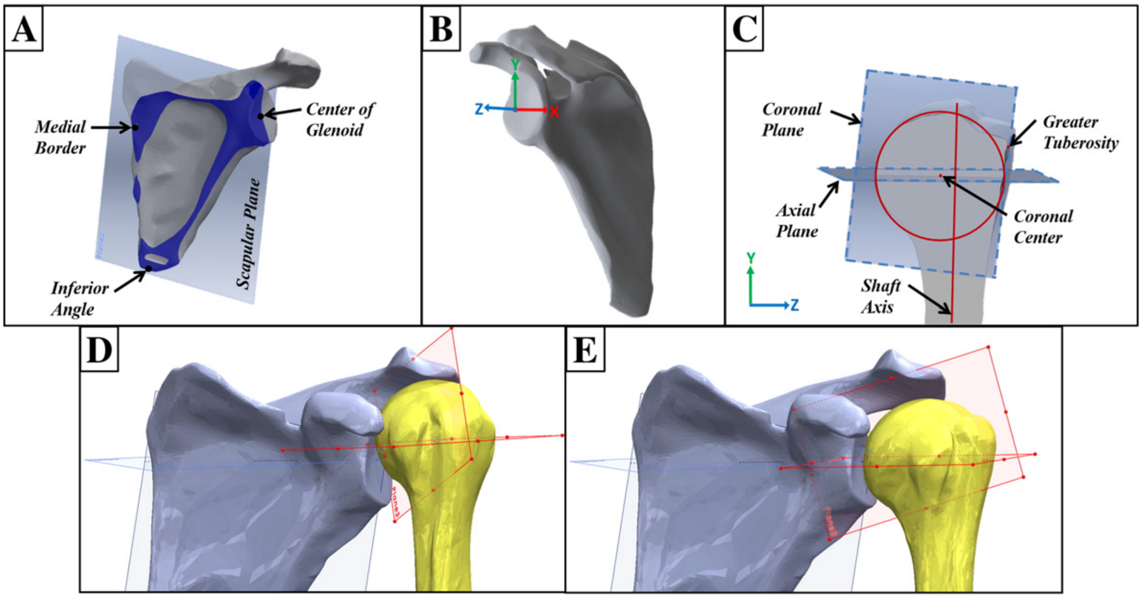

Fig. 1. (A) Scapular plane (YZ plane) developed for each patient using points from the three anatomic landmarks depicted. (B) The scapular coordinate system established via the intersections of the orthogonal planes to scapular plane, with origin being the center of glenoid. (C) Humeral landmarks of the greater tuberosity and shaft axis were used to create the humeral coronal plane and the orthogonal axial plane. (D) Pathologic humeral position depicting the out of plane rotation of the humerus relative to the scapular planes. (E) Alignment of the humeral coronal and axial planes with the scapular plane coordinate system.