ARTICLE IN PRESS

JSES Open Access ■■ (2017) ■■–■■

Contents lists available at ScienceDirect

JSES Open Access

journal homepage: www.elsevier.com/locate/jses

Anatomic variations in glenohumeral joint: an interpopulation study

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ARTICLE INFO

Keywords:
Shoulder
humerus
glenoid
prosthesis
total shoulder arthroplasty
interpopulation study
morphometry
gender variation

Level of evidence: Anatomy Study, Imaging

Background: This study focused on the unique aspect of investigating shoulder morphometric differences between 2 distinct populations.
Methods: We used 90 computed tomography images of cadaveric shoulders for this study; 45 scans belonged to the South African (SA) cohort (49.74 ± 15.4 years) and the rest were Swiss (CH; 53.8 ± 21 years). The articulating surfaces of the glenohumeral joint were extracted, and their morphometric features, such as head circular diameter, glenoid and humeral head radius of curvature, head height, and humeral height, were measured.
Results: The mean interpopulation difference in the circular diameter of the humerus was 2.0 mm ($P = .017$) and 1.86 mm ($P > .05$) in the anterior-posterior and superior-inferior directions, respectively. The difference in the radius of curvature between the populations was 1.17 mm ($P = .037$). The SA shoulders were found to be longer than the CH shoulders by 8.4 mm ($P > .05$). There was no significant difference in the glenoid radius of curvature. The SA shoulders had higher glenohumeral mismatch ($P = .005$) and lower conformity index ($P = .001$) in comparison to the CH shoulders.
Conclusion: This study presents anatomic differences between African and European glenohumeral articulating surfaces. The results suggest that the glenohumeral geometry is both gender and population specific, and future joint replacements may be designed to address these differences.

Anatomic total shoulder arthroplasty (ATSA) surgically replaces the arthritic articulating surfaces of the glenohumeral joint (GHJ),[39] in the presence of intact rotator cuffs, with an anatomic total shoulder prosthesis (ATSP).[3,19,20,28,30,32,49] Although the current design of the ATSP has been successful in alleviating shoulder joint pain and restoring the functionality of the joint, underlying complications, such as glenoid component loosening and humeral head subluxation, reduce the success of this surgical intervention.[4,19,21,22,25,28,33,40,45,46,56] The initial design of the ATSP as proposed by Neer was aimed toward mimicking the anatomy of the GHJ.[9] Since then, modifications have been made to accommodate the head inclination angle and retroversion angle, and implants have also become more modular to accommodate reverse shoulder prostheses.[5,23,31,42] The current trend followed by various shoulder prosthesis manufacturers (eg, DePuy Synthes [West Chester, PA, USA], Global Shoulder System; Tornier [Bloomington, MN, USA], Aequalis prosthesis) is to provide surgeons with humeral heads of various heights.[54] Keeping in mind the evolution of the shoulder prosthesis design, it can be predicted that future prosthesis designs will likely be patient specific as seen in knees.

In sub-Saharan Africa, shoulder arthritis is a common joint disease.[2,41] Orthopedic-related disorders feature in the top 10 burden of diseases in South Africa.[14,59] Annually, around 5000 ATSPs are implanted in South Africa, and most of the prostheses used are imported. The average annual trade deficit for the South African medical industry including orthopedic implants is ZAR 8 billion.[51] Postsurgical complications and implant failure are also common. Worldwide, 21%-32% of ATSAs have to be revised because of postsurgical complications like glenoid loosening.[4,8,25,50] The “rocking horse” effect has been identified as one of the main causes of glenoid loosening.[33,55] Improper understanding of shoulder anatomy, which varies according to the geographic location of the population,[11,34,57] may result in nonanatomic alignment of the prosthesis, leading to uncharacteristic kinematics and finally failure of the implant.[8,23,37]

The shoulder geometry of the native South African (SA) population has rarely been studied. Along with this, keeping in mind the financial burden, there is a need to develop ATSPs specific to the native SA population. This aim of this study was to measure and to compare the GHJ morphometric features of native SA and native Swiss (CH) populations.

The Department of Surgery Research Committee of the University of Cape Town approved this study: Project 2013/060.
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https://doi.org/10.1016/j.jses.2017.11.007
2468-6026/

Materials and methods

Experimental setup

A database of 90 humeri and scapulas (average age, 50.9 ± 17.9 years) was created from upper body (hip and above) computed tomography (CT) scans of 90 embalmed cadavers. Of the 90 shoulders, 45 belonged to the CH data set and the other 45 belonged to the SA data set. Any scan with visible bone spur, deformation, or fracture was rejected. Details about the data sets are provided in Table I.

The raw data (Digital Imaging and Communications in Medicine) from the CT scans were reconstructed to create 3-dimensional (3D) models of the humerus and the glenoid using the Mimics (Materialise, Leuven, Belgium) program (Fig. 1) by applying a process similar to that detailed by Bryce et al.[10] The 3D model of the humerus was exported to SolidWorks (Dassault Systèmes, Vélizy-Villacoublay, France) as a mesh file. In the 3D computer-aided design software, the humeral articular surface was separated by performing an in silico ATSA (Fig. 2). This was performed under the guidance of a single trained surgeon specialized in ATSA, adhering to the surgical technique described by Duquin et al.[17]

The retrieved humeral head was assigned an independent coordinate system to facilitate the retrieval of the morphometric features. A feature extracting pipeline was generated to calculate the anterior-posterior (AP) and superior-inferior (SI) circular diameter (Fig. 3) and the height of the articular surface using MATLAB (MathWorks, Natick, MA, USA). A sphere-fit algorithm was implemented to calculate the spherical radius of curvature (RoC) of the humeral head and the glenoid fossa (Fig. 4). The mismatch in the RoC was measured by calculating the difference between the glenoid fossa RoC and the humeral head RoC.[53] The conformity index was given by the ratio of the glenoid RoC over the humeral head RoC. The humerus height was measured by calculating the length of a line passing through the center of the humeral shaft, perpendicular to the line joining the distal condyles, toward the humeral head.

Table I
Information of the computed tomography scans obtained for the current study

	Swiss data set	South African data set
Racial distribution	Caucasian	NonCaucasian
Acquired from	SICAS Medical Image Repository	University of Cape Town Cadaver Laboratory
Age (y)	53 (19-90)	49 (20-82)
Male:female	20:25	26:19

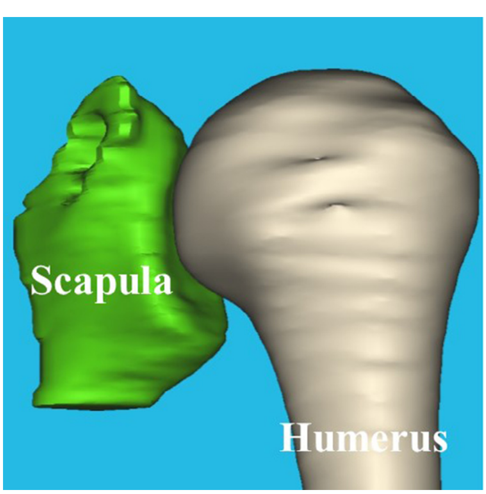

Figure 1 Three-dimensional reconstructed models of the humerus and glenoid.

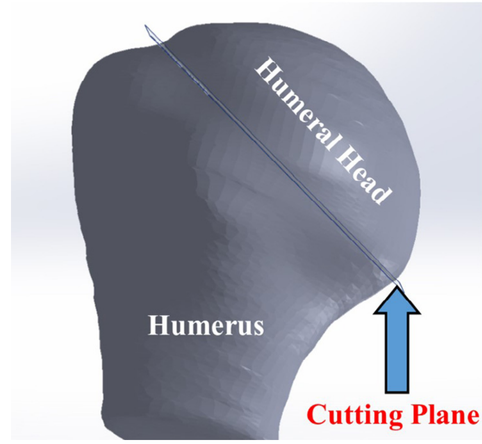

Figure 2 The in silico surgical process to retrieve the humeral head from the reconstructed humerus.

Automatic detection of morphometric features was implemented as it has less chance of encountering human error compared with manual measurements.[5,10]

Statistical analysis

The statistical analyses were performed in R software package. The observed data were separated, into various data sets, according to their country of origin (CH and SA), position in the body (left and right), and gender (male and female). Of the 90 reconstructed shoulders, 2 reconstructed heads were found to be not suitable (fractured) for the morphometric feature extraction process. Shapiro-Wilk tests were performed to analyze the distribution of the observations for each of the parameters in each data set. Along with the tests for normality, quantile-quantile plots were generated to support the tests. To determine whether the observed differences, between the data sets, were significant, *t*-tests were performed for the normally distributed parameters and Wilcoxon signed rank tests for the rest. A 2-tailed post hoc power analysis was performed for the 2 population and gender groups using G*Power[18] for a value of $\alpha = .05$.

Results

The obtained results are divided into population-, bilateral-, and gender-specific variations. Each variation is further divided into subdivisions according to the studied morphometric features.

Interpopulation variations

The average circular diameters in the AP and SI axes were found to be 44.6 ± 4.1 mm and 49.7 ± 4.5 mm, respectively, for the SA population and 46.6 ± 3.5 mm and 51.6 ± 4.6 mm for the CH population. The observed difference in the AP direction was found to be significant ($P < .05$), but the difference in the SI direction was not significant ($P > .05$). The average CH population was found to have larger spherical RoC (24.4 ± 2.5 mm) for the humeral head, but the glenoid RoC (30.3 ± 5.1 mm) was smaller than that of the SA population, whose average humeral head RoC and glenoid RoC were measured to be 23.2 ± 2.6 mm and 31.1 ± 3.9 mm, respectively. The difference in the humeral RoC was found to be significant ($P < .05$), but the difference in glenoid RoC was not significant ($P > .05$). The average SA humerus (323.4 ± 21.9 mm) was found to be larger than the average CH humerus (315.0 ± 21.1 mm). An average difference of about 8.4 mm was observed. This difference was found not to be

Please cite this article in press as: Roopam Dey, Steven Roche, Theo Rosch, Tinashe Mutsvangwa, Johan Charilaou, Sudesh Sivarasu, Anatomic variations in glenohumeral joint: an interpopulation study, JSES Open Access (2017), doi: 10.1016/j.jses.2017.11.007