Quantitative Anatomical Differences in the Shoulder

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Abstract

This study explored the radiographic and anatomical differences in normal shoulders between men and women, as well as factors such as race, height, weight, and age. A total of 205 patients with documented normal anatomical radiographs comprised the study population. Five fellowship-trained orthopedic surgeon reviewers measured head diameter, humeral head size, head to tuberosity distance, greater tuberosity width, neck-shaft angle, surface-arc angle, glenoid neck length, and distance from the lateral acromion process to the greater tuberosity on anteroposterior radiographs with the shoulder in external rotation. After the reviewers identified and marked defined anatomical landmarks, a comprehensive automated calculator was used to compute all parameters. Between men and women, head diameter ($P<.001$), humeral head size ($P<.001$), greater tuberosity width ($P<.001$), distance from the lateral acromion process to the greater tuberosity ($P<.001$), and glenoid neck length ($P<.001$) were significantly different, whereas race was not significantly different for any anatomical parameter. Using Spearman's rho, there was a strong correlation between head diameter/humeral head height and height ($r_s=0.77/r_s=0.68$), weight ($r_s=0.62$), and greater tuberosity width ($r_s=0.66/r_s=0.61$); there also was a strong negative correlation between head to tuberosity distance and neck-shaft angle ($r_s=-0.80$).

This study demonstrated precisely defined proximal humeral anatomical relationships and sizes using an advanced standardized imaging software program. With these data, orthopedic surgeons and implant designers can better understand the anatomy and glenohumeral relationships to re-create when performing total shoulder arthroplasty. [Orthopedics. 2017; 40(3):155-160.]

Re-creating the anatomical glenohumeral relationship is critical to successful results after anatomical total shoulder arthroplasty (TSA). Preoperative planning is crucial in anatomical reconstruction of the shoulder to re-create normal kinematics. Iannotti et al reported the importance of preoperative radiographic assessment to reconstruct the anatomy in addition to the glenohumeral relationships for successful TSA results. Planning can be based on individual TSA results, but through analyzing patient demographics such as sex and race, as well as anthropometric parameters such as height and weight, a general guideline can be generated and has been the basis for most commercial TSA design considerations.

This study explored the radiographic anatomical differences in shoulders between men and women, race, and other factors such as height, weight, and age. A novel systematic program was used for...
the study, with multiple reviewers providing greater reliability and better reproducibility compared with previously published studies. The study hypothesis was that sex and race would have statistically significant variations in shoulder anatomical parameters and glenohumeral relationships within the patient population.

**Materials and Methods**

An institutional retrospective review was completed for all patients with shoulder radiographs documented as normal from 2009 to 2013; patients with fractures, dislocations, dysplasia, and osteoarthitis were excluded. To reduce variability, all radiographs missing a surface calibration marker also were excluded. Anatomical parameters were measured in 205 shoulders (110 men and 95 women); average patient age was 52 years.

The radiographic images were uploaded to an image processing software program, ImageJ (National Institutes of Health, Washington, DC). Before image analysis, each image measurement was calibrated using a surface marker measuring 25 mm in diameter. Humeral head diameter was measured as the diameter of the circle drawn approximating the humeral head (Figure 1A). Humeral head height was measured through the orthogonal distance from the middle of the anatomical neck (defined as a line separating the greater and lesser tubercle from the head of the humerus) to the articulating surface of the humeral head (Figures 1A-B). Head to tuberosity distance was defined as the orthogonal distance from the superior aspect of the greater tuberosity to the top of the humeral head (Figure 1C).

Greater tuberosity width was measured from a line down the longitudinal axis of the humeral diaphysis to the lateral aspect of the greater tuberosity (Figure 1D). Distance between the acromion process and the greater tuberosity was measured from the lateral aspect of the acromion to the greater tuberosity (Figure 1E). Glenoid neck length was defined as the orthogonal distance between the articular surface of the inferior aspect of the glenoid and the lateral column of the scapula (Figure 1F). Neck-shaft angle was measured as the angle subtended by the central intramedullary axis of the humeral shaft and a line orthogonal to the articular segment of the humeral head (Figure 1G). Surface-arc angle was defined as the angle created through the lateral and medial aspect of the anatomical neck and the center of the head (Figures 1A-B).

Five fellowship-trained reviewers measured the parameters on the anteroposterior radiographic view with the shoulder in standardized external rotation. The reviewers identified and marked defined anatomical landmarks, and a comprehensive computerized program then was used to systematically compute all parameters. Measurements were obtained in a uniform fashion for all images to reduce variability and increase accuracy. The Mann-Whitney test was used to evaluate the gender-specific difference, a Kruskal-Wallis test was used to evaluate race-specific differences, and Spearman’s rho was used for an in-depth correlation analysis.

**Results**

Men were significantly taller and weighed more than women, although there was no statistical difference in body mass index (Table 1). There were no differences in the measurements among the reviewers. Between men and women, humeral head diameter, humeral head height, greater tuberosity width, distance between the lateral acromion process and the greater tuberosity, and glenoid neck length all demonstrated statistically significant dif-
ferences ($P<.001$), whereas neck-shaft angle, head tuberosity distance, and surface-arc angle showed no statistically significant differences (Table 2).

Race did not show any statistically significant difference for any anatomical parameter. Total numbers and percentages by race are listed in Table 3.

The in-depth correlation demonstrated a moderate to strong correlation between patient height and humeral head diameter, humeral head height, and greater tuberosity width ($r=0.77$, 0.68, and 0.51, respectively) (Figures 2-3). There was a moderate correlation between humeral head height and humeral head diameter and glenoid neck length ($r=0.43$ and 0.40, respectively). (Figures 4-5). A strong negative correlation also was demonstrated between head to tuberosity distance and neck-shaft angle (Figure 6). As the distance between the humeral head and the tuberosity increased, the neck-shaft angle decreased.

**DISCUSSION**

Re-creating the anatomy and glenohumeral relationships intraoperatively is important for the success of TSA. This includes releasing contracted soft tissues, repairing rotator cuff muscles, reconstructing skeletal anatomy, and correctly placing appropriately sized prosthetic components. Biomechanical studies have shown that altering the placement and size of the articular surface by 4 to 5 mm can modify the kinematics and forces at the glenohumeral joint. To accomplish a successful anatomical TSA, preoperative planning based on the anatomical parameters and glenohumeral relationships is crucial.

Previous studies have demonstrated the importance of re-creating the anatomy and glenohumeral relationships of the shoulder for successful results after arthroplasty. Iannotti et al reported on variables such as radius of curvature, distance between the lateral acromion process and the greater tuberosity, and the greater tuberosity distance to the top of the humeral head, dimensions of the glenoid, and glenohumeral relationships such as the neck-shaft angle. In their study, the average radius of curvature was $25\pm1.9$ mm in men and $21\pm2.1$ mm in women in the coronal plane. In the current study, the radius of curvature was $27.9\pm1.9$ mm in men and $23.7\pm1.6$ mm in women; this difference was statistically significant ($P=.001$ for both).

Similar to the strong correlation ($r=0.77$) of head diameter and patient height in the current study, Iannotti et al demonstrated a strong correlation between the radius of curvature and individual height. There was a strong correlation between humeral head height and individual height in the current study. Iannotti et al also reported a strong linear relationship between neck-shaft angle and head radius, which the current study did not show.

Unlike the current study, in the study by Iannotti et al, a single reviewer measured anatomical parameters in a nonuniform fashion using a combined cohort of cadaveric specimens as well as magnetic
resonance images (MRI) from clinical patients. Given their use of a single reviewer and the inherent variability of the measurement methods used, this could potentially explain the significant differences between the current study and the Iannotti et al study.

Tackett and Ablove, using magnetic resonance arthrography, reported a significant difference between men and women in humeral head height, humeral head width, and humeral head to greater tuberosity distance but found no difference in any other glenohumeral relationships. Although their study used a standard MRI protocol, the measurements were made by a single reviewer, and the average humeral head height was 16.48±1.32 mm in men and 14.23±1.27 mm in women in the coronal plane. In the current study, the average humeral head height was 22.47±2.09 mm in men and 19.12±1.67 mm in women; this difference was statistically significant.

For head to tuberosity distance, Tackett and Ablove reported a statistically significant difference between men and women (P<.001); in the current analysis, the head to tuberosity distance was not significantly different (P=.06) between men and women. In the study by Tackett and Ablove, the average head to tuberosity distance was 9.41±2.09 mm for men and 7.34±1.89 mm for women compared with 8.96 mm and 7.38 mm, respectively, in the current study.

The current study showed a statistically significant difference between men and women for head diameter, humeral head height, greater tuberosity width, distance between the lateral acromion process and the greater tuberosity, and glenoid neck length, whereas no statistically significant difference was found in neck-shaft angle, surface-arc angle, and head to tuberosity distance, although the latter trended toward significance (P=.06). The correlation analysis in the current study demonstrated a strong relationship between the head diameter and humeral head size with height, weight, and greater tuberosity width; this also has been reported in previous studies to varying degrees.

In addition, the current study found a moderate correlation between humeral head diameter and glenoid neck length. The average ratio between humeral head radius and humeral head height was 0.81 mm (range, 0.67-0.96 mm); this is a slightly larger range than previously reported by Hertel et al (range, 0.64-0.77 mm) and Pearl and Volk (0.73±0.04 mm). This finding is a critical consideration for current and future implant designs. Finally, a strong negative correlation was observed between the head to tuberosity distance and the neck-shaft angle.

Notably, the strength of the current study is that a standardized method and
imaging program were used to measure the anatomical parameters and glenohumeral relationships. As opposed to previous studies that used goniometers and imaging tools with 1 to 2 reviewers, the current study used strict measures with multiple reviewers to reduce variability. Five fellowship-trained orthopedic surgeon reviewers were instructed to mark anatomical landmarks of the shoulder, and this was followed by an automated program that measured the parameters. There were no significant differences in measurements between the reviewers. In addition, a calibration surface marker was used to eliminate any variation between radiographic images.

The limitations of this study are inherent within the retrospective nature of the study. Although radiographic images are standardized within the current authors’ institution, the exact shoulder position or degree of external rotation could have varied. In the current study, only 1 radiographic view was used for each patient, whereas other studies have used 2 views. In addition, although the current study found no difference in any anatomical parameter or glenohumeral relationship based on race, this could be due to the patient cohort being predominantly white (68.8%). However, in another study by Churchill et al,11 no statistically significant difference was found in glenoid size, inclination, and version between black and white patients. Finally, although the system used in the current study was found to be more accurate than others in obtaining these measurements, a cost analysis could be completed in future studies to compare the 2 modalities for their cost added value.

The current study is the single largest and most uniformly designed study to assess the demographics of anatomical differences in the nonarthritic shoulder. The anatomical measurements and correlations from this study may be useful in aiding the intraoperative decision-making process using traditional methods and also potentially may improve algorithms for patient-specific instrumentation programs.

CONCLUSION

Although implant companies provide a large combination of TSA implant sizes, the inventory is finite. Surgeons are required to choose from a fixed array of head sizes with corresponding head heights, which potentially could limit their effort to create an anatomical replacement. Additional studies may be of use as implant designers attempt to refine the size ranges provided for varying sexes and patient populations treated with TSA by orthopedic surgeons. This study defined anatomical measurements and correlations that can aid physicians in their intraoperative decision-making process and allow for the development of more anatomical sex-specific implants.

REFERENCES

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