Geometric Analysis of the Proximal Humerus in Elderly Japanese Patients: Implications for Implant Selection in Reverse Shoulder Arthroplasty

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The implants used in reverse shoulder arthroplasty were originally designed for white patients; thus, they might not be optimal for smaller Asian patients. The selection of reverse shoulder arthroplasty systems is limited in Japan. The purpose of this study was to measure the geometry of the proximal humerus in elderly Japanese patients to inform implant selection according to humerus size. This study included 155 shoulders from 148 patients 50 years or older who underwent computed tomography for shoulder disorders other than arthritis and trauma. There were 67 male and 81 female patients with mean ages of 68 and 66 years, respectively. The humeral head diameter, head height, neck-shaft angle, neck diameters, and osteotomy diameters for 155° inclination implants were measured using surface models created from computed tomography scans. The mean diameter of head curvature, humeral head height, and neck-shaft angle were 48.2 mm, 19.8 mm, and 136° for male patients and 42.4 mm, 17.1 mm, and 136° for female patients, respectively. The mean mediolateral and anteroposterior neck diameters were 46.9 mm and 43.7 mm for men and 41.6 mm and 38.4 mm for women, respectively. The mean mediolateral and anteroposterior osteotomy diameters were 42.2 mm and 41.2 mm for male patients and 38.6 mm and 36.7 mm for female patients, respectively. There were significant differences between the sexes in all measurements except neck-shaft angle. Humeral implants with 155° inclination will not fit the humerus of smaller Japanese women. Thus, implants with anatomical inclination and an onlay humeral tray may be a better choice for smaller patients. [Orthopedics. 2017; 40(3):e485-e490.]

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proximal humerus in elderly Japanese patients using 3-dimensional surface models created from computed tomography scans to inform implant selection based on humeral size.

**MATERIALS AND METHODS**

### Patient Selection

Institutional review board approval was obtained for this study. The authors retrospectively investigated patients who had computed tomography scans performed at their institution between April 2014 and March 2015. Patients who were 50 years or older without inflammatory joint diseases (osteoarthritis and rheumatoid arthritis, infectious diseases, or cuff tear arthropathy), prior fractures or dislocations of the glenohumeral joint, and congenital deformities of the shoulder girdle were included in this study. Thus, a total of 155 shoulders in 148 patients were included in this study. There were 67 men (70 shoulders) with a mean age of 68 years (range, 53-82 years) and 81 women (85 shoulders) with a mean age of 66 years (range, 50-89 years). Mean heights and weights were 166 cm (range, 153-183 cm) and 68 kg (range, 49-95 kg) and 155 cm (range, 142-173 cm) and 54 kg (range, 40-80 kg) for men and women, respectively.

### Image Acquisition and 3-Dimensional Modeling of the Proximal Humerus

The patients had shoulder computed tomography scans obtained with a 16-detector computed tomography system (Alexion; Toshiba, Tochigi, Japan). The scanning parameters were as follows: image matrix, 512x512; pixel size, 0.468x0.468 mm; and slice pitch, 0.3 mm. The scans included approximately two-thirds of the humerus. Computed tomography scans were segmented, and 3-dimensional surface models of the proximal humerus were created (ITK-SNAP; Penn Image Computing and Science Laboratory, Philadelphia, Pennsylvania).

### Humeral Measurements

A single surgeon (K.M.) performed all measurements using Geomagic Studio software (3D Systems, Rock Hill, South Carolina) with an anatomical coordinate system. First, the origin of the coordinate system was set at the center of the curvature of the humeral head by applying a best-fit sphere. Second, the Y-axis was set so that it was parallel to the humeral shaft, approximating the shaft as a cylinder. Third, the anatomical neck plane was determined as the best-fit plane by selecting 3 points on the neck: a point on the junction between the articular surface and greater tuberosity and points on the margin of the articular surface in the anteroinferior and posteroinferior part. Finally, the Z-axis was set so that it was parallel to the intersecting line formed by the neck plane and the plane perpendicular to the Y-axis. The X-axis was perpendicular to both the Y-axis and the Z-axis and directed medially (Figure 1).

The diameter of the best-fit sphere of the head was defined as the diameter of curvature of the head (humeral head diameter). A line was created perpendicular to the neck plane through the origin, and the neck-shaft angle (NSA) was calculated as the angle between the line and the Y-axis in the XY-plane. The humeral head height (HH) was calculated as the distance between the points on the neck plane and the humeral head that were intersected by the line (Figure 2).

The neck diameters were measured using models with the humeral head removed above the anatomical neck plane (Figures 3A-B). The maximum neck width parallel to the XY-plane was defined as the mediolateral (ML) neck diameter, and the maximum neck width parallel to the XZ-plane was defined as the anteroposterior (AP) neck diameter (Figure 3C). To measure the diameters of the osteotomy plane for humeral implants with...
155° inclination, models simulating the osteotomy were also created (Figures 3A and 3D). The humeral head was resected above the plane at a 25° angle to the XZ-plane and perpendicular to the XY-plane, and the ML and AP diameters of the osteotomy plane were measured.

Measurement Variability
To investigate intra- and interobserver variability for these measurements, the authors used models from 20 randomly selected patients. For intraobserver variability, a single surgeon (K.M.) measured 3 times at 1-week intervals, and the intraclass correlation coefficient (1,1) was determined for each parameter. For interobserver variability, 2 surgeons (K.M., S.H.) independently measured the images, and the intraclass correlation coefficient (2,1) was determined for each parameter.

Statistical Analyses
Statistical analysis was performed using PASW version 17.0 software (SPSS Inc, Chicago, Illinois). Unpaired t tests were used to compare values in men and women, and Pearson’s correlation coefficient was used to assess the relationships between parameters. Stepwise multiple regressions were also used to detect parameters related to osteotomy diameters. The level of significance was set at P<.05.

RESULTS
Intra- and interobserver variabilities for each parameter are summarized in Table 1. Both intra- and interobserver variabilities were excellent in all parameters except head height.

Measurement results are displayed in Table 2. There were significant differences between the sexes in all parameters except neck-shaft angle (P<.001 for all). The mean ML osteotomy diameters were 4.7 and 3.0 mm smaller than the mean ML neck diameters in men and women, respectively. The mean AP osteotomy diameters were 2.5 and 1.7 mm smaller than the AP neck diameters in men and women, respectively.

Correlations among the parameters are shown in Table 3. The ML and AP osteotomy diameters were correlated with all other parameters, including patient height, in both male and female patients.
The ML and AP neck diameters were also correlated with all the other parameters except neck-shaft angles. The neck and osteotomy diameters tended to be smaller in women than in men of the same height (Figures 4-5).

To identify parameters related to osteotomy diameters, stepwise multiple regressions were performed with height, neck-shaft angle, and the corresponding neck diameter as independent variables. Neck-shaft angle and neck diameter were related factors for both ML and AP osteotomy diameters (Table 4). The regression equations for the ML and AP osteotomy diameters indicated good coefficient of determination (men, $R^2=0.71$ and 0.49, respectively; women, $R^2=0.72$ and 0.68, respectively).

**Discussion**

This study investigated the 3-dimensional geometry of the proximal humerus in elderly Japanese patients and identified several associated parameters such as neck diameter and neck-shaft angle. This study also measured the osteotomy diameters of the proximal humerus.
diameters for humeral implants with 155° inclination and revealed that the mean ML and AP osteotomy diameters were 42.2 and 41.2 mm for men and 38.6 and 36.7 mm for women, respectively. Multiple regression analysis revealed that the osteotomy diameters were predictable based on neck-shaft angle and neck diameter.

A limitation of this study was that the subjects were not healthy volunteers but rather elderly patients with age-related degenerative changes. The authors studied elderly patients because of difficulty recruiting a sufficient number of healthy volunteers and to avoid radiation exposure among young, healthy subjects. During measurement, the authors found that some patients had tiny osteophytes around the humeral head, likely due to aging or pathologic changes. Although the authors were careful, osteophytes may have influenced their measurements. However, the authors think that their study population may also be considered a strength because it is similar to that of individuals who were candidates for RSA. Other strengths of this study included the relatively large number of subjects and the high intra- and interrater variabilities of the method of measurement.

There have been several studies on the geometry of the proximal humerus in non-Asian populations; most included subjects of both sexes and the reported neck diameters ranged from 42 to 51 mm.9,14 A few studies have also analyzed the geometry of the proximal humerus in Asian populations, including Thai, Chinese, and Japanese individuals, and have reported mean neck diameters ranging from 38.6 to 44.6 mm.5,7 The current study’s results are in line with those of previous studies regarding humeru measurements. Although there were differences between the studies regarding the methods of measurement, studies on Asian humeri, including the current study, suggest that they are smaller than humeri in white individuals.

Reported neck-shaft angles have ranged from 130° to 139° in white individuals.9,12,14 Among Asian populations, Aroonjarattham et al5 reported a mean neck-shaft angle of 127.6° in Thai subjects and Zhang et al7 reported a mean neck-shaft angle of 132.4° in Chinese subjects. Among Japanese subjects, Matsumura et al6 reported an average neck-shaft angle of 135°, similar to the finding in the current study. Differences between reports may be due to differences in measurement methods, and the mean neck-shaft angle may be approximately 135° without considering racial differences.

**Table 4**

<table>
<thead>
<tr>
<th>Osteotomy Diameter</th>
<th>Regression Equation</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ML</td>
<td>$0.337 \times (\text{neck-shaft angle}) + 0.785 \times (\text{ML neck diameter}) - 40.286$</td>
<td>0.71</td>
</tr>
<tr>
<td>AP</td>
<td>$0.248 \times (\text{neck-shaft angle}) + 0.617 \times (\text{AP neck diameter}) - 19.412$</td>
<td>0.49</td>
</tr>
<tr>
<td>Female</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ML</td>
<td>$0.258 \times (\text{neck-shaft angle}) + 0.828 \times (\text{ML neck diameter}) - 30.954$</td>
<td>0.72</td>
</tr>
<tr>
<td>AP</td>
<td>$0.222 \times (\text{neck-shaft angle}) + 0.605 \times (\text{AP neck diameter}) - 16.772$</td>
<td>0.68</td>
</tr>
</tbody>
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Abbreviations: AP, anteroposterior; ML, mediolateral.  
$^a$Coefficient of determination.
Several articles have analyzed differences in humeral geometry based on sex; however, none have reported differences associated with subject height.\textsuperscript{5,13,14} The current study found that women had smaller humeri than did men of the same height. For example, the predicted AP neck diameter was 38.9 mm for a 160-cm–tall woman vs 43.1 mm for a 160-cm–tall man, based on the linear regression equations (Figure 4B). This observation suggests that implant size should not be determined on the basis of patient height alone.

To the best of the authors’ knowledge, no studies have measured osteotomy diameters for humerus implants with 155° inclination. The authors found that the osteotomy diameters were 2 to 5 mm smaller than the neck diameter and were related not only to the neck diameter but also to the neck-shaft angle. The regression equation for the ML osteotomy diameter may be useful for preoperative prediction using plain radiographs because these parameters can be measured on the AP view of the shoulder.

Some humeral trays of RSA implants are approximately 38 mm in diameter regardless of the inclination angle, whereas other systems have a larger diameter. Any type of RSA implant can fit the humerus of most Japanese or Asian men. However, RSA implants with 155° inclination will not fit the majority of Japanese women because their mean AP osteotomy diameter is only 36.7 mm. Because the mean AP neck diameter of Japanese women is 38.4 mm, implants with anatomical inclination will fit most Japanese women. For smaller humeri with AP neck diameters less than 38 mm, implants with onlay humeral trays may be a better choice. They may overhang the neck, but may avoid risk of damage to the tuberosities and residual rotator cuff tenons such as the teres minor due to reaming of the metaphysis.\textsuperscript{15} Dysfunction of the teres minor can result in poor functional outcomes in those patients who have undergone RSA.\textsuperscript{16} Although implants may be chosen according to the size of the humerus, the results of this study indicate that implants sized to fit Asian individuals should be provided for each RSA system for better surgical and functional outcomes.\textsuperscript{17,18} The current data can be further used to develop a proper design for RSA implants for Asian patients.

**CONCLUSION**

The authors analyzed the geometry of the proximal humeri in elderly Japanese patients and observed that this population has smaller humeri than do white individuals. Reverse shoulder arthroplasty humeral implants with 155° inclination will not fit the humeri of smaller Japanese women. Implants with anatomical inclination and an onlay humeral tray may be a better choice for smaller patients. Humer al implants with a smaller diameter should be developed based on the geometry of the Japanese humerus.

**REFERENCES**