J Shoulder Elbow Surg (2016) 25, 1532–1541

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

An anthropometric analysis to derive formulae for calculating the dimensions of anatomically shaped humeral heads

C. Scott Humphrey, MD[a,*], Benjamin W. Sears, MD[b], Michael J. Curtin, MD[c]

[a]*Humphrey Shoulder Clinic, Eagle, ID, USA*
[b]*Western Orthopaedics, Denver, CO, USA*
[c]*St. Luke's Orthopaedics, Boise, ID, USA*

Background: The elliptical shape of the humeral head has been vaguely described, but a more detailed mathematical description is lacking. The primary goal of this study was to create formulae to describe the mathematical relationships between the various dimensions of anatomically shaped humeral heads.
Methods: Three-dimensional computer models of 79 proximal humeri derived from computed tomography scans (white subjects, 47 male and 32 female; ages, 17-87 years) were studied. Linear regression analysis of the obtained humeral measurements was performed, and Pearson correlation coefficient (*R*) values were calculated. To substantiate the results of the linear regression analysis, Welch *t*-test was used to compare various parameters of small, medium, and large humeral heads.
Results: Formulae for calculating humeral head height, diameters of the base of the humeral head in the frontal and sagittal planes, and radii of curvature in the frontal and sagittal planes were derived from the linear regression plots that were found to have strong ($1 \geq R \geq 0.50$) correlations. By Welch *t*-test, differences between the 3 head sizes were statistically significant in each case ($P \leq .022$). The elliptical shape of the base of the humeral head was found to elongate with increasing humeral head size.
Conclusions: Mathematical formulae relating various humeral head dimensional measurements are presented. The formulae derived in this study may be useful for the design of future prosthetic shoulder systems in which the goal is to replicate normal anatomy. This is the first study to describe that the elliptical shape of the base of the humeral head elongates as head size increases.
Level of evidence: Basic Science Study; Anatomy Study; Imaging

Keywords: Humeral head; shape; size; dimensions; elliptical; formula; anthropometry; gender

Most presently available shoulder prosthesis systems use humeral heads that are spherically shaped, yet several previous anatomic studies have documented that the humeral head is ovoid rather than spherical.[2,4,5,7,8,13,14,18] Two recent studies suggest that rotational range of motion and glenohumeral joint

No Institutional Review Board approval was needed for this basic science study using de-identified material.

*Reprint requests: C. Scott Humphrey, MD, Humphrey Shoulder Clinic, 3381 W Bavaria St, Eagle, ID 83616, USA.

E-mail address: humphrey@boiseshoulderclinic.net (C.S. Humphrey).

1058-2746/$ - see front matter © 2016 Journal of Shoulder and Elbow Surgery Board of Trustees. All rights reserved.
http://dx.doi.org/10.1016/j.jse.2016.01.032

kinematics might be improved by employing a prosthetic humeral head that accurately replicates normal human anatomy during shoulder arthroplasty surgery.[5,10] Although the elliptical shape of the humeral head has been vaguely described, a more detailed mathematical description of the shape of the humeral head is lacking and would be useful for the purpose of creating anatomically shaped prosthetic humeral heads.

The primary goal of this study was to create formulae that may be used to mathematically calculate the dimensions of anatomically shaped humeral heads of varying size. A secondary goal was to add to the currently available anthropometry data pertaining to the proximal humerus bone.

Materials and methods

The specimens consisted of de-identified, 3-dimensional (3D) computer models derived from computed tomography scans of 79 proximal humeri from white subjects from the United States and Australia (47 male and 32 female; ages, 17-87 years, with an average age of 56 years). The models were obtained from a second party (Materialise, Leuven, Belgium) and were prescreened to exclude specimens with osteophytes or other obvious degenerative changes.

Bone landmark identification methods and measurement techniques were adapted from a previously published study.[7] Three-dimensional imaging software (Adobe Acrobat 9 Pro; Adobe Systems Incorporated, New York, NY, USA) was used to manipulate and to measure the 3D models. By use of the software, the humeral head of each specimen was virtually resected to mimic the ideal surgical head resection along the anatomic neck as would be done during shoulder arthroplasty surgery. Specifically, the cutting plane for head resection for each humerus model was derived using methodology for the identification of the head equator and other bone landmarks as described by Hertel et al.[7] Measurements of the diameter of the cross section of the base of the humeral head in the frontal plane (D^F) and sagittal plane (D^S) and the distance between the biceps sulcus and the humeral head equator were measured by software directly on the virtual models (Fig. 1). These measurements were recorded to the nearest tenth of a millimeter.

To simulate the radiographic views that had been used to make 2-dimensional measurements in the study by Hertel et al,[7] the 3D models were each rotated on the computer screen to the ideal position, and the image was then printed onto paper (Fig. 2). The scale of the printed images was adjusted to a 1:1 scale based on measurements that were made with the software directly on the virtual models. To obtain the ideal view for frontal plane measurements, each humerus model was oriented such that the head equator was parallel to the computer screen (D^F is coplanar with the head equator), and the plane of the osteotomy for the head cut was oriented perpendicular to the screen. To obtain the ideal view for sagittal plane measurements, the head equator was oriented perpendicular to the computer screen, and the plane of the osteotomy for the head cut was oriented perpendicular to the screen. This method of orientation was used to create and to print simulated radiographic images that were then marked for the purpose of measuring medial offset, posterior offset, head height, surface arc, radius of curvature in the frontal plane, radius of curvature in the sagittal plane, and critical distance (Figs. 2 and 3). Digital calipers were used for measurements on the simulated radiographs, and the measurements were recorded to the nearest tenth of a millimeter.

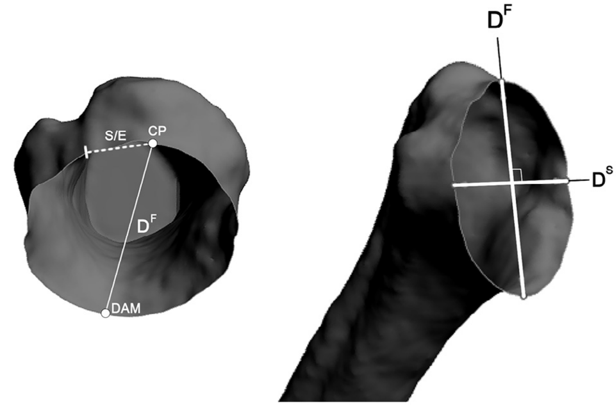

Figure 1 The critical point (*CP*) and the distal articular midpoint (*DAM*) were identified before the virtual head resection while determining the head equator as described by Hertel et al.[7] After head resection, the length of the diameter of the base of the humeral head in the frontal plane (D^F) was measured as the shortest distance between CP and DAM. D^S (the length of the diameter of the base of the humeral head in the sagittal plane) bisects and is perpendicular to D^F. D^F, D^S, and the distance between the bicipital sulcus and critical point (*S/E*) were identified and measured directly on 3D computer models of humeri.

Radii of curvature and the center of rotation of each humeral head in both the frontal and sagittal planes were determined by use of custom-made circular templates that increased in size in 1-mm increments (Fig. 2, *C* and *G*). The long axis of the humeral diaphysis was determined through use of a custom-made, 12-mm by 150-mm rectangular ruler with a cutout slot in the middle for drawing the axis line. The ruler was centered over the humeral image so that the outer border of the ruler was contained symmetrically within the diaphysis in a manner that was meant to simulate insertion of a straight-stemmed prosthesis (Fig. 2, *B* and *F*).

Linear regression analysis was performed, and Pearson correlation coefficient (R) values were calculated to explore correlations between various humeral measurements. The strength of association for the measurement relationships was defined as follows using the absolute value of R: strong ($1 \geq R \geq 0.50$), medium ($0.49 \geq R \geq 0.30$), and weak/negligible ($0.29 \geq R \geq 0$). Positive R values implied a positive correlation, and negative R values implied a negative correlation. Mathematical equations defining the dimensional relationships between humeral head measurement variables were derived from linear regression plot trend lines (Microsoft Excel 2008 for Mac, version 12.3.6; Microsoft, Redmond, WA, USA) that were found to have strong correlations.

To substantiate the results of the linear regression analysis, the specimens were divided into 3 groups based on the head size: small ($D^F < 45.3$ mm), medium (45.3 mm $\leq D^F <$ 50.9 mm), and large (50.9 mm $\leq D^F$). The cutoff points delineating small vs. medium vs. large heads were determined by splitting the range of D^F measurements into equal thirds between the smallest D^F value (39.7 mm) and the largest D^F value (56.5 mm). Welch *t*-test was then used to compare the mean values of humeral head height (HHH), D^S, radius of curvature in the frontal plane (ROC^F), and radius of curvature in the sagittal plane (ROC^S) between the different head sizes. Unequal variance and 2-tailed distribution were assumed, and statistical significance was set at P value $\leq .05$ whenever the Welch *t*-test was used in this study.