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Determination of humeral head size in anatomic shoulder replacement for glenohumeral osteoarthritis

Ari R. Youderian, MD[a,*], Eric T. Ricchetti, MD[b], Meghan Drews[b], Joseph P. Iannotti, MD, PhD[b,c]

[a]*Illinois Bone and Joint Institute, LLC, Morton Grove, IL, USA*
[b]*Department of Orthopaedic Surgery, Orthopaedic and Rheumatologic Institute, Cleveland Clinic, Cleveland, OH, USA*
[c]*Cleveland Clinic Lerner College of Medicine, Case Western Reserve University, Cleveland, OH, USA*

Background: We hypothesized that a sphere mapped to specific preserved nonarticular landmarks of the proximal humerus can accurately predict native humeral head radius of curvature (ROC) and head height (HH) in the osteoarthritic, deformed humeral head.
Methods: Three consistent nonarticular landmarks were defined with a 3-dimensional sphere (and 2-dimensional circle in midcoronal plane) placed along the articular surface in 31 normal cadaveric humeri. Side-to-side differences in ROC and HH were determined in 22 pairs of normal shoulders. Using the nonarticular landmarks and sphere method, 3 independent blinded observers performed 2 sets of measurements in 22 pairs of shoulders with unilateral glenohumeral osteoarthritis. The predicted native ROC and HH in the pathologic shoulder were compared with the normal side control.
Results: The mean side-to-side difference in normal shoulders was 0.2 mm (ROC) and 0.6 mm (HH). In the unilateral osteoarthritis cases, the intraobserver mean differences for the normal side were 0.3 mm (ROC) and 0.9 mm (HH). The pathologic side ROC and HH, defined by the sphere, exhibited intraobserver differences of 0.5 mm (ROC) and 1.0 mm (HH). The mean side-to-side differences between the normal and pathologic sides were 0.5 mm (ROC) with concordance correlation coefficient of 0.95 and 1.3 mm (HH) with concordance correlation coefficient of 0.66.
Conclusion: A sphere mapped to preserved nonarticular bone landmarks can be used for accurate preoperative measurement of premorbid humeral head size and therefore the selection of an anatomically sized prosthetic head. This is applicable postoperatively, as is a circle method for 2-dimensional assessment of anatomic humeral reconstruction in the coronal plane.
Level of evidence: Anatomy Study, Imaging.

Keywords: Anatomic shoulder replacement; humeral head size; glenohumeral arthritis; shoulder arthroplasty; preoperative planning; humerus templating; sphere model; 3D CT scan

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*Reprint requests: Ari R. Youderian, MD, Illinois Bone and Joint Institute, LLC, 9000 Waukegan Road, Suite 200, Morton Grove, IL 60053, USA.
E-mail address: ayouderian@gmail.com (A.R. Youderian).

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The native humeral head size is defined by the humeral head radius of curvature (ROC) and humeral head height (HH). Humeral HH is defined as the perpendicular linear distance from the anatomic neck to the apex of the humeral head. The humeral head is not a perfect sphere, and its ROC in the anteroposterior (AP) dimension (axial plane) is smaller than that of the superoinferior (SI) dimension (coronal plane), with an average ratio of 0.92.[3,9,15,16] In the setting of advanced glenohumeral osteoarthritis, the humeral head is deformed by loss of humeral HH and peripheral osteophytes, making it difficult to preoperatively define the anatomically correct prosthetic humeral head size. Moreover, a validated and reproducible method of determining a correctly sized and positioned prosthetic humeral head has not been presented. Preoperative implant templates are available, but a valid method for applying them to the preoperative radiographs to define anatomic head sizing or placement has not been validated. Most important, inaccurate selection of a prosthetic humeral head or position can result in overstuffing or undersizing of the reconstructed joint and can lead to poor outcomes, including shoulder stiffness, rotator cuff tearing, poor subscapularis tendon healing, and increased glenoid component wear or loosening and instability.[6,8,14,20-22]

Boileau and Walch described the relationship between the humeral head articular surface and the entire proximal humerus using a circle in the AP plane.[3] The authors reliably demonstrated that humeral head articular surface in the AP plane represented a circle in more than 88% of specimens and used this model to determine anterior-posterior offset from the humeral shaft to the center of rotation of the humeral head. These authors did not define the relationship of the humeral circle to the nonarticular surface landmarks of the proximal humerus.

We hypothesized that a three-dimensional (3D) sphere or a two-dimensional (2D) circle in the coronal plane of the humerus, superimposed on 3 specific landmarks of the nonarticular surface of the proximal humerus, would accurately predict humeral head ROC and HH in glenohumeral osteoarthritis. Together, these 2 measurements define the size of the articular portion of the humeral head and therefore the anatomically correct size of the prosthetic head.

Materials and methods

Overview of methods

The research consisted of 3 phases:

1. Definition of the relationship of a sphere (3D) and a circle (2D) placed onto the articular surface of the normal humeral head to determine the most consistent extra-articular bone landmarks that contacted either the sphere by 3D computed tomography (CT) or the circle on the midcoronal plane of the humerus. This was performed in scans of 31 unpaired cadaveric humeri.
2. Determination of the variability in side-to-side measurements of humeral head ROC, HH, and neck-shaft angle (NSA) in 22 pairs of normal shoulders.
3. Use of the sphere and circle method to determine the normal humeral head size from the pathologic condition in 22 pairs of shoulders with unilateral end-stage osteoarthritis. The method was validated by comparing the measured normal humeral head size in the pathologic shoulder with the measured head size in the patient's opposite normal shoulder.

Defining the spherical model

CT scans were performed on 31 normal unpaired cadaver humeri to define the relationship of the humeral articular surface to preserved landmarks of the proximal humerus and thereby to define a best fit sphere or circle model. These CT scans were generated from a randomly selected subset of normal cadaver specimens obtained from the Cleveland Museum of Natural History (Hamann-Todd Human Osteological Collection, Cleveland, OH, USA) with variable NSA measurements and were originally used for a previously published study at our institution.[10] Specimens were equal in number of males and females, ages 30 to 80 years, and free from traumatic or degenerative changes. Scans were performed with a 64-detector CT scanner (SOMATOM Sensation 64; Siemens Medical Solutions, Malvern, PA, USA) with 1-mm axial increments and a B60 reconstruction kernel.

By 3D CT simulation software (OrthoVis, Cleveland Clinic, Cleveland, OH, USA),[5-7,12,17-19] a digital sphere was best fit to the normal proximal humerus articular surface with both the 3D and 2D orthogonal images (Fig. 1). The sphere was matched to the central spherical articular surface of the humerus in both the midcoronal and midaxial planes. The humeral head is rarely a perfect sphere. In this study, the larger superior-inferior dimension defined in the midcoronal plane was used to determine the size of the sphere. The plane of the anatomic neck was defined by placing 3 points along the anatomic neck of the 3D image, superiorly, inferiorly, and anteriorly. The placement of the best fit sphere to the articular surface of the humeral head demonstrated 3 consistently preserved landmarks of the proximal humerus that would reliably confirm appropriate sizing and placement of the sphere: (1) the lateral cortex below the flare of the greater tuberosity, (2) the medial footprint of the rotator cuff on the greater tuberosity, and (3) the medial calcar at the anatomic neck (Fig. 1, *B*). The best fit sphere appears as a circle on the 2D images and follows the arc of curvature of the articular surface in the normal specimen. The midcoronal CT scan provides a 2D method for fitting of a circle and would correlate with a 2D anterior to posterior radiographic image of the proximal humerus.

HH was measured as the perpendicular distance from the anatomic neck plane to the apex of the sphere. This linear measurement was made on the 2D coronal image that captured the apex of the humeral head (Fig. 1, *B*). NSA was measured as the angle between the plane of the anatomic neck and the long axis of the humeral diaphysis, which was defined by a proximal and distal point in the center of the intramedullary canal (Fig. 2).

Determination of side-to-side variability using the sphere model on normal (paired) specimens

Side-to-side variations in ROC, HH, and NSA were measured in 22 pairs of normal shoulders (paired right and left sides), not used to develop the spherical model and its relationship with preserved proximal humeral landmarks, randomly selected from our CT