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ORIGINAL ARTICLE

An analysis of proximal humerus morphology with special interest in stemless shoulder arthroplasty

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Background: Shoulder arthroplasty evolution has resulted in the shortening of traditional stemmed humeral components. Newer stemless implants rely on structures that maintain fixation in the metaphyseal region of the proximal humerus. Whereas the overall morphology of the proximal humerus is well understood, the advent of stemless implants requires that additional geometric measures be assessed. This study's purpose was to introduce new anatomic measures to assist with the design of stemless implants.

Methods: Using computed tomography data from 98 subjects (nonarthritic [n = 41], B2 osteoarthritic [n = 26], and symmetric osteoarthritic [n = 31]), shifts in proximal canal direction, bounding diameters along the canal, and canal depth beneath the center of the humeral resection plane were quantified. Traditional articular aspect ratio terms (ie, resection diameter, humeral head height) were also quantified. All measures were reported relative to a humeral coordinate system relevant to stemless implants.

Results: Humeral depth, gender, and osteoarthritis were found to have effects on the measured parameters. Of these factors, gender was the most prominent, as men presented with significantly larger canal diameters and depths than women did ($P < .001$). Osteoarthritis had less of a significant impact on results ($P < .001$), with the attributed differences in canal path direction and articular aspect ratio being small in absolute value. Canal diameter was found to change significantly as a function of depth beneath the resection plane ($P < .001$).

Conclusions: This work quantified 3 new morphologic terms relevant to proximal humerus stemless arthroplasty. Together, these outcome measures help define the spatial limits for stemless humeral arthroplasty in an implant-relevant coordinate system.

Level of evidence: Anatomy Study; Imaging

Keywords: Shoulder arthroplasty; stemless; canal sparing; osteoarthritis; proximal humerus; gender effect

Shoulder replacement, or arthroplasty, was first popularized in the 1950s by Neer, using a Vitallium implant to treat comminuted fractures of the proximal humerus.[14] For the proximal humerus, hemiarthroplasty involves replacing the humeral head; total arthroplasty involves replacing both the humeral head and the glenoid.[15] The incidence of shoulder

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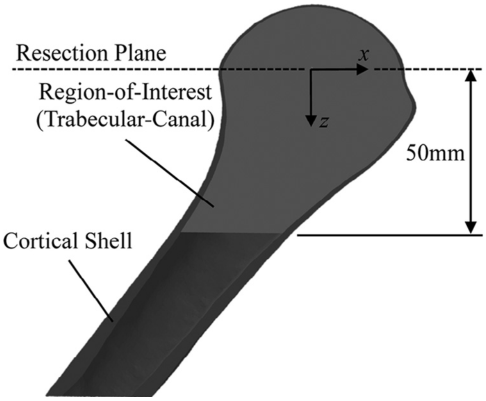

Figure 1 The division between the cortical shell and the trabecular-canal. The region of interest for the proximal humerus, as it pertains to stemless implant design, is the trabecular-canal directly below the resection plane.

arthroplasty has been increasing; in 2008, nearly 47,000 shoulder arthroplasty procedures were conducted in the United States,[13] and as of 2011, this number rose above 66,000.[24] With more shoulder arthroplasty procedures being performed, implant performance and longevity are becoming evermore important issues that could have an impact on outcomes and costs.

The extramedullary anatomy of the proximal humerus (ie, overall length, neck-shaft angle, degree of retroversion, humeral head height, radius of curvature, and head offset) is well understood.[1,2,6,9-12,17,18,20-22,27,28] Studies have sought to better quantify the overall shape of the humerus to comprehend structural changes that take place over time in response to activity, arm dominance, and aging. It has been suggested by Robertson et al that morphologic variability is also an important factor that should influence implant design and selection.[21] Accordingly, the humeral morphologic parameters quantified in the literature typically relate to the design of either the humeral implant stem or the head component. For example, there has been substantial research on quantifying the neck-shaft angle of the proximal humerus[2,9,18,28] because traditional implants seek fixation by a stem press fit into the diaphyseal portion of the humeral canal. However, with the advent of shorter implants for humeral head reconstruction, the humeral geometry of interest is expanding.

In recent years, implant manufacturers have reduced the length of traditional stemmed humeral implants.[3-5,7,8,19,23,25] This reduction of implant stem length is most evident in the new generation of "stemless" implants, which seek fixation in the most proximal region of the post-resected humeral metaphysis. The metaphyseal characteristic of stemless implants allows fixation and central positioning in the sub-resection region of the proximal humerus, irrespective of the neck-shaft angle, the degree of retroversion, or the location of the humeral canal.[4] Accordingly, the primary region of interest for the placement and fixation of stemless proximal humerus implants is the bone directly beneath the humeral head resection plane (Fig. 1). It follows that it is important to understand the spatial limits of the region of the proximal humerus in which the implant is placed. However, the morphology of this region of interest has not been well quantified in the literature. Therefore, the spatial limits of this region of interest must be defined by measuring the shifts in the proximal canal direction, the bounding diameters along the canal, and the canal depth beneath the center of the resection plane. The purpose of this anatomic study was to quantify morphologic parameters of interest relevant to the design of stemless implants in the proximal humerus.

Materials and methods

Shoulder computed tomography (CT) scans were obtained from 98 subjects. Each was visually inspected for osteoarthritis (OA) by an experienced shoulder surgeon (G.S.A.) and classified into 1 of 3 OA conditions: nonarthritic (25 men, 71 ± 16 years; 16 women, 70 ± 12 years), Walch type B2 OA (11 men, 64 ± 11 years; 15 women, 69 ± 7 years), or symmetric (Walch type A) OA (15 men, 62 ± 11 years; 16 women, 69 ± 14 years) using a clinically reliable method.[16,26] The nonarthritic scans were obtained from a database of cadaveric CT scans, whereas OA scans were preoperative scans from patients who later underwent shoulder arthroplasty.

CT Digital Imaging and Communications in Medicine data were reconstructed using Mimics Research software (version 19; Materialise, Plymouth, MI, USA), and the proximal humerus was manually isolated from the surrounding soft tissues using masking features available within the software program. Each humerus was then manually divided into 2 regions corresponding to (1) the cortical shell and (2) the combination of trabecular bone and canal (ie, trabecular-canal) (Fig. 1). The same shoulder surgeon (G.S.A.) then identified the location for the articular resection plane and inferior-medial and superior-lateral points on the humeral head resection plane. These points were used to construct a proximal humerus coordinate system that the authors thought would best describe the proximal humerus in a manner relevant to shoulder reconstruction with a stemless implant. The coordinate system consisted of an x-axis directed from the inferior-medial point toward the superior-lateral point along the resection plane, a y-axis directed anteriorly, and a z-axis perpendicular to the resection (positively directed into the remaining bone; $z = 0$ corresponding to the resection plane) (Fig. 2). The use of a subject-specific anatomic resection plane, as opposed to a standard cut at 30° of retroversion, was done to highlight the independence of the stemless implant from the humeral canal.

To quantify the outcome measures of interest, the 3-dimensional point cloud data for voxels corresponding to both the cortical shell and trabecular-canal were exported as text files and were analyzed using custom LabVIEW scripts (National Instruments, Austin, TX, USA). The trabecular-canal was divided into 13 slices (3 above the resection plane, 10 below the resection plane), each 5 mm thick, with divisions parallel to the humeral head resection plane. The geometric center (x_o, y_o, z_o) of each slice was then quantified by averaging the coordinates of all points within each slice to determine the frontal plane (ie, x-z values) and sagittal plane (ie, y-z values) directional changes along the canal path. At each point along the canal path, the fitted canal diameter ($\varnothing_{Canal}$) was determined by positioning a circle (parallel to the resection plane) at the canal path center point and expanding its diameter as large as possible without any part of the circle exceeding the inner canal (ie, endosteal surface).