ARTICLE IN PRESS

JSES Open Access ■■ (2018) ■■-■■

Contents lists available at ScienceDirect

JSES Open Access

journal homepage: www.elsevier.com/locate/jses

Trabecular bone density distribution in the scapula relevant to reverse shoulder arthroplasty

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ARTICLE INFO

Keywords:
Scapula
bone density
arthroplasty
shoulder
glenoid
reverse

Level of evidence: Anatomy Study Imaging

Background: How trabecular bone density varies within the scapula and how this may lead to more optimal reverse shoulder arthroplasty (RSA) screw placement has not been addressed in the scientific literature. The 3 columns of trabecular bone within the scapula adjacent to the glenoid fossa, one extending through the lateral border, a second into the base of the coracoid process, and a third extending into the spine of the scapula, were hypothesized to be of relatively similar density.

Methods: Two-dimensional axial computed tomography (CT) images of 19 fresh frozen cadaver specimens were obtained. Digital Imaging and Communications in Medicine (DICOM; National Electrical Manufacturers Association, Rosslyn, VA, USA) image files of the CT scanned scapulae were imported into Mimics 17.0 Materialise Software (Leuven, Belgium) for segmentation and 3-dimensional digital model generation. To determine the distribution of trabecular bone density, Hounsfield unit (HU) values in the scapulae gray value files obtained from Mimics were filtered to remove any cortical bone. HU values of 650 define the corticocancellous interface in CT image data and were considered to be cortical bone. Analyses of variance with post hoc Bonferroni tests were used to determine statistical differences between the intra- and inter-regions of bone density comparisons.

Results: The base of the coracoid process was statistically significantly less dense than the spine and the lateral border of the scapulae examined ($P < .05$).

Discussion/Conclusion: The higher-quality bone in the spine and lateral border, compared with the coracoid regions, may provide better bone purchase for screws when fixing the glenoid baseplate in RSA.

Reverse total shoulder arthroplasty (RSA) is a reliable treatment option for patients presenting with a deficient rotator cuff, severe arthritis, or failed prior shoulder prostheses.[4,8,10,11,19,20,28] Unfortunately, glenoid component loosening is a common mode of failure[10,12,14,18,23] and has been reported as the most common need for revision surgery in RSA.[14] Optimal screw positioning is important for long-term success of the prosthesis and to prevent glenoid component failure.[28]

Several studies have investigated the effects of screw placement on baseplate fixation while taking the morphology of the scapula into account.[8,9,11,18-20,28] These studies indicate that surgeons should attain maximum screw length, far cortical fixation, and screw placement in the best quality bone available when performing RSA.[6,8,9,11,19,20,28] To accomplish this, information on scapular morphology and bone quality is required; however, few studies targeting optimal screw placement have taken bone density into account.[11,28]

Although numerous studies have aimed to characterize the osseous anatomy of the scapula, few have focused on quantitatively analyzing bone quality to suggest optimal screw placement in RSA.[3,5,11,25,35] There are 3 columns of bone extending from the glenoid base. These 3 structures include the scapular spine, lateral border, and base of the coracoid process.[11,19,22,28] A study conducted by DiStefano et al[11] determined the areas of thickest cortical bone in the scapula were present in these columns, although only a comparatively small area in the base of the coracoid is thick. This led to the question of how internal bone density varies within the scapula and how this may lead to more optimal RSA screw placement.

The aim of this study was to quantify the relative anatomic distribution of trabecular bone density in regions of the scapula adjacent to the glenoid accessible to screw fixation in RSA surgery. We hypothesized that the 3 columns of trabecular bone within the scapula adjacent to the glenoid fossa would have similar average bone density

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https://doi.org/10.1016/j.jses.2018.06.002
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Please cite this article in press as: Matt A. Daalder, et al., Trabecular bone density distribution in the scapula relevant to reverse shoulder arthroplasty, JSES Open Access (2018), doi: 10.1016/j.jses.2018.06.002

and that the density within each region would be consistent throughout.

Materials and methods

Specimens and image acquisition

Fresh frozen forequarters from 19 deceased donors (8 men, 9 women, 2 unknown), with a mean age of 70 years (range, 33-98 years), were thawed, and computed tomography (CT) scanned using a Lightspeed+ XCR 16-slice CT scanner (General Electric, Milwaukee, WI, USA). The entire scapula and humerus were scanned with a tube current of 120 kVP and 100 mA, and voxel size of (0.625 mm × 0.625 mm × 0.625 mm).

Image processing

Digital Imaging and Communications in Medicine (DICOM; National Electrical Manufacturers Association, Rosslyn, VA, USA) image files of the CT-scanned scapulae were imported into Mimics 17.0 software (Materialise Software, Leuven, Belgium) for segmentation and 3-dimensional (3D) digital model generation. Segmentation was used to generate 3D tessellated surface mesh models and masks of the scapulae containing 3D voxel locations and corresponding Hounsfield units (HU). To facilitate comparison, all left scapulae were mathematically converted to right scapulae.[36]

The trabecular and cortical bone of the scanned scapulae were isolated from other tissues, and the scapulae segmentation masks were filled to ensure all material was accounted for when the 3D digital models were created. To increase model fidelity, the segmented specimen masks and 3D models were visually inspected for any discontinuities and were further segmented until proper anatomic representation of the specimens was achieved.

We defined a previously established anatomic coordinate system to facilitate comparison across specimens.[34] Briefly, the coordinate frame was defined by a computer-assisted designed quadripod aligned manually to points on the supraglenoid and infraglenoid tubercles, and the trigonum spinae. The Y axis (superior-inferior) was defined by the line connecting the supraglenoid and infraglenoid tubercles, and the Z axis (medial-lateral) was defined by the line connecting the trigonum spinae to the center of the glenoid. The X axis (anterior-posterior) was defined as the axis orthogonal to the Y-Z plane. The coordinate system was then used to align the 3D surface models and corresponding voxels (Fig. 1).

Regions of interest (ROIs) within each scapula were defined and extracted for comparative analysis of the trabecular bone. The volumetric ROIs were determined based on potential RSA glenoid baseplate screw positioning. These included the base of the coracoid inferior to the suprascapular notch, the base of the coracoid lateral to the suprascapular notch, an anterior and posterior portion of the scapular spine, an anterosuperior portion of the lateral border, and an inferior portion of the lateral border. The ROIs were determined visually on the surface mesh model of each scapula displayed in MATLAB (MathWorks, Natick, MA, USA). The ROIs were bounded by X, Y, and Z coordinates, and the corresponding voxels were extracted from the segmentation masks as per defined standard protocol (Table I) and subsequently registered to the surface model to check for accuracy (Figs. 2–7).

Outcome measures

HU values in the scapula and their associated voxels were filtered to remove any cortical bone: all voxels with a HU value of 0 to 650 were kept, whereas all other HU values in the file were removed from the pool of data. HU values of 650 were chosen as the upper bound because studies have shown this number defines the corticocancellous interface in CT image data.[1,13,29]

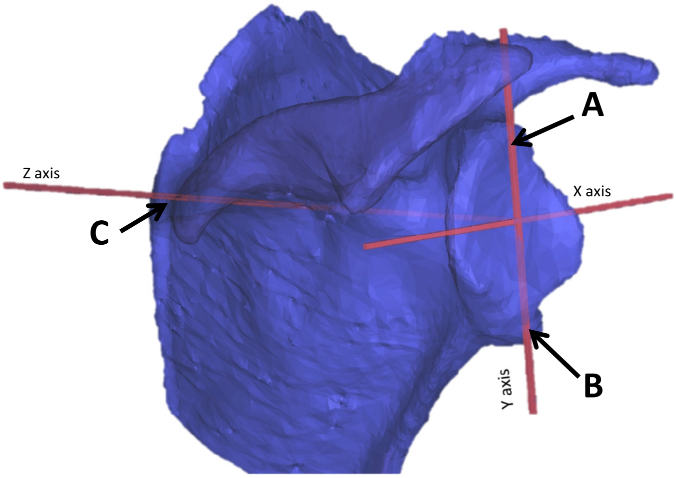

Figure 1 Quadripod oriented with respect to the supraglenoid (*A*) and infraglenoid (*B*) tubercles and the trigonum spinae (*C*) of a model scapula in Mimics software (Materialise Software, Leuven, Belgium). The 3 points on the quadripod define the origin of the coordinate system (near the middle of the glenoid surface), a point along the X axis (anterior to posterior) and a point along the Y axis (superior to inferior). The Z axis passes medial to lateral through the trigonum spinae.

Statistical analyses

One-way analyses of variance with post hoc Bonferroni tests were used to compare the mean HU values within and between the 3 columns of the scapula. Specifically, inter-regions comparisons included the mean HU values of the coracoid ROIs, scapular spine ROIs, and lateral border ROIs. Intraregion comparisons included the anterior spine compared with the posterior portion of the scapular spine, the anterosuperior portion of the lateral border compared with the inferior portion of the lateral border, and the base of the coracoid inferior to the suprascapular notch compared with the base of the coracoid lateral to the suprascapular notch. An α value of <0.05 was considered statistically significant.

Results

Across specimens, the mean HU values of the ROI in the scapula ranged from 238.1 ± 48.0 HU to 335.2 ± 29.6 HU (Table II, Fig. 8). There were statistically significant inter-region differences between the mean HU values in the regions of interest ($P < .001$, Table III); however, there were no significant intra-region differences in trabecular bone density distribution within regions of the coracoid ($P = .99$), the lateral border ($P = .99$), or the spine ($P = .90$).

We found that regions of the coracoid were significantly less dense than all other ROIs. The superior coracoid was significantly less dense than the inferior and anterosuperior lateral border (–25.6% [$P < .001$] and –20.8% [$P < .001$]), as well as the posterior and anterior scapular spine (–29% [$P < .001$] and –23.8% [$P < .001$]). The inferior coracoid was also significantly less dense than the inferior and anterosuperior lateral border (–20.1% [$P < .001$] and –15% [$P = .004$]), as well as the posterior and anterior scapular spine (–23.7% [$P < .001$] and –18.1% [$P < .001$]). The inferior lateral border was no denser than both areas of the spine ($P = .99$), whereas the anterosuperior lateral border density was not significantly different than the posterior spine ($P = .07$) or the anterior spine ($P = .99$). There was no significant difference between the spine and lateral border ($P = .99$).

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