Projection of the Glenoid Center Point Within the Glenoid Vault

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Abstract Correct identification of the center point of the glenoid surface guides glenoid component placement. It is unknown whether the center point on the glenoid surface corresponds to the center of the glenoid vault at the medial extent of the glenoid prosthesis. We reviewed 20 consecutive computed tomography scans obtained preoperatively in patients with primary osteoarthritis. A glenoid center point was chosen on the glenoid surface and then projected back into the glenoid vault along the scapular axis and perpendicular to glenoid inclination. The difference from the projection of the glenoid surface center point to the center point at a 1.5-cm depth into the glenoid vault was then measured. The mean deviation of the glenoid center point at a depth of 1.5 cm from the center point at the glenoid articular

surface was 1.7 mm anterior and 3.9 mm inferior. The most common deviation of the center point of the glenoid vault at the projected medial limit of the glenoid prosthesis was slightly anterior and inferior to the center point on the glenoid surface. Identifying the center of the glenoid surface coupled with alignment of the glenoid prosthesis in neutral version and anatomic inclination provides a reliable means to guide placement of glenoid components.

Introduction

Total shoulder arthroplasty restores function and relieves pain for patients with end-stage glenohumeral arthritis. Proper placement of the glenoid component requires critical evaluation of individual glenoid morphology to ensure balance and stability and to enhance long-term survival. Incorrect glenoid version or inclination is associated with glenohumeral instability, which is the most common complication in shoulder arthroplasty, with a reported incidence of 0% to 29% [3, 4, 9, 12]. Solid fixation of the glenoid component has also been noted to enhance the long-term survival of shoulder arthroplasty. Central placement of the keel/pegs within the cancellous bone medial to the glenoid articular surface (the glenoid vault) prevents cortical penetration, which limits the ability to pressurize the cement and potentially compromises initial fixation. Computed tomography (CT) has been used to preoperatively identify the depth, width, and shape of the glenoid vault as well as to characterize wear patterns on the glenoid surface. This information potentially could enhance proper glenoid placement [6, 7, 11]. Our intra-operative experience suggests that by centering the glenoid component pilot hole slightly inferior and anterior to the center of the glenoid surface, then matching the native

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inclination and aligning the component along the scapular axis, the central peg/keel was directed into and fully contained in the deepest portion of the glenoid vault. To our knowledge, no evaluation of the relationship between these two points had been performed by anatomic or radiographic evaluation. We sought to critically evaluate our intraoperative findings by recreating our operative steps using two- and three-dimensional CT images.

We therefore hypothesized the center point as identified intraoperatively on the glenoid surface would not correlate exactly to the center point of the glenoid vault at the medial depth of the central keel/peg of the glenoid component. Additionally, we sought to determine if there was a consistent relationship between these two points to guide the surgeon in the placement of the glenoid component within the glenoid vault.

Materials and Methods

We identified 20 consecutive patients who underwent total shoulder arthroplasty for osteoarthritis. The average age of the patients was 68 years (range, 56–79 years). There were eight men and 12 women with 10 right and 10 left shoulders. All patients had primary osteoarthritis without a history of surgeries or trauma. Wear was defined as posterior when the glenoid erosion was in the posterior half of the glenoid surface and concentric when the wear was in the middle half of the glenoid surface. With group sizes of 14 and six shoulders in the posterior and concentric groups, respectively, we had power to detect only very large differences between shoulder groups. Using a two-sided two-sample t-test at an alpha of 0.05, there is 80% power to detect an effect size of 1.5 or larger in which the effect size is the difference in group means divided by their common standard deviation. According to Cohen, an effect size of 0.8 would be considered large [5].

We routinely obtain a three-dimensional CT study on all patients before total shoulder arthroplasty. All CT images of the shoulder were acquired with a Light Speed Ultra CT (GE Medical Systems, Milwaukee, WI) using a high-resolution shoulder protocol with axial image acquisition (1.25-mm slice thickness, 0.625-mm spacing, bone algorithm, and 15-cm field of view), two-dimensional oblique coronal and oblique sagittal multiplanar, and three-dimensional image reconstruction. The axial image data set was manipulated using an Advantage Windows workstation with 4.2 software (GE Medical Systems) with the Volume Viewer Plus function and two-dimensional reformat layout (Fig. 1).

Two-dimensional coronal and axial images linked to the reconstructed three-dimensional image were simultaneously manipulated to enable selection of the midpoint of

Fig. 1 The figure shows a three-dimensional reconstruction of the scapula with the center point of the glenoid surface defined at the intersection of the lines bisecting the glenoid articular surface.

the glenoid surface in both the superior to inferior direction and the anterior to posterior direction (Fig. 2A–B). This point was then marked electronically on the image. A three-dimensional rotational tool was then used to rotate the image of the glenoid into an oblique sagittal projection that would optimally simulate the intraoperative appearance of the glenoid surface (Fig. 3). The center point chosen, based on the coronal and axial images, was electronically present on this image and then confirmed visually as the surgeon would routinely do intraoperatively. The image was saved and used as the reference for all subsequent measurements.

Using the center point as a reference on the axial image, the alignment axis was established parallel to a line drawn from the center point aligned with the scapular body (the scapular axis) [5]. A line was then drawn from the center point of the glenoid articular surface extending medially for a length of 1.5 cm into the glenoid vault collinear with the scapular axis (Fig. 4). A distance of 1.5 cm was chosen to mimic the medial depth of the central peg/keel of the glenoid component. Glenoid version was then measured using the technique described by Friedman et al. [6] and Walch et al. [11]. The center point reference was then moved medially parallel to the scapular axis for a distance of 1.5 cm. Maintaining the same oblique sagittal image plane and advancing the image medially 1.5 cm then provided a cross-section of the glenoid vault with an

Fig. 2A–B Two-dimensional coronal (A) and axial images (B) have the center point marked on each image. These images (linked to the three-dimensional image) allowed accurate identification of the center of the glenoid surface as identified on the three-dimensional image (Fig. 1).

inclination matching that of the glenoid articular surface and neutral version (Fig. 5). Neutral version was defined as perpendicular to the scapular axis. The projected position of the center point on the image 1.5 cm medial was then electronically recorded and the image saved for later use.

The two saved images were then retrieved to the workstation. A rotational axis was then marked on the glenoid articular surface image coursing from the posterior margin of the coracoid at its intersection with the glenoid

Fig. 3 This two-dimensional sagittal image shows the glenoid articular surface. The rotational axis that runs from the posterior margin of the coracoid as it joins the glenoid surface to the inferior-most aspect of the glenoid is shown. The center point is defined and marked at the middle of the rotational axis and a perpendicular bisecting line is drawn to highlight the central placement.

Fig. 4 An axial image of the glenoid with the 1.5-cm depth line was marked from the center point of the glenoid surface collinear with the scapular axis and extending into the glenoid vault by 1.5 cm.

Fig. 5 Oblique sagittal image of the glenoid vault at a depth of 1.5 cm medial to the glenoid surface is shown. The image alignment matches the inclination of the articular surface and has neutral version (as defined by an image plane perpendicular to the scapular axis). The rotational axis of this image (lines) matches the axis of the surface image. The center point of this image is defined by the midpoint of the rotational axis line as shown by the two bisecting lines. The solid black mark represents the location of the center point from the surface image superimposed on this image. The center point of this image (bisection of the lines) lies slightly anterior and inferior to the center point projected from the surface (dot).

surface to the inferior glenoid in line with the lateral scapular border. The anterior to posterior width, superior to inferior length, and the surface area were measured and recorded. The same rotational axis measurement identified on the glenoid surface image was then used to ensure perfect alignment of the two images as they were superimposed for measurement. The center point of the glenoid vault on this image was then identified and marked. The difference was then measured between the center point of the glenoid surface and the center point 1.5-cm image into the glenoid vault. The center point of the surface was used as the reference and the deviation of the center point within the vault from that on the surface was recorded in the anterior-posterior and inferior-superior directions. The measurements were taken in reference to the rotational axis of the glenoid to avoid any variations resulting from patient positioning (Fig. 6). The surface area of both saved images was estimated using an elliptic area tool manipulated to provide a best fit to the surface.

Confidence intervals of the 95th percentile were calculated based on a *t* statistic using 19 degrees of freedom.

Fig. 6 Superimposed images of the glenoid surface and the 1.5-cm depth show the center point of the articular surface (dot) in relation to the center point of the 1.5-cm image (at the intersection of the red lines).

Results

The mean glenoid version was 12.2° retroversion (range, 1.9° anteversion to 37.9° retroversion). Wear was posterior (14 shoulders) and concentric (six shoulders). Anteroposterior width decreased from an average of 30.3 mm (range, 22.5–36.4 mm) at the articular surface to an average of 11.5 mm (range, 5.6–15.6 mm) at the 1.5-cm level. Superior-inferior length decreased from an average of 44.2 mm (range, 37.2–53.5 mm) at the articular surface to an average of 38.6 mm (range, 18.1–50 mm) at the 1.5-cm level. Deviation of the center point 1.5 cm medial from the center point on the glenoid surface in the anteroposterior direction was measured at a mean and standard deviation of 1.66 mm anterior and 1.39 mm, respectively (range, 0.06 mm posterior to 3.7 mm anterior). Deviation in the superior-inferior direction was measured at a mean and standard deviation of 3.9 mm inferior and 4.3 mm, respectively (range, 10.1 mm inferior to 7.5 mm superior). Ninety-five percent confidence intervals calculated on a *t* statistic were 1.2 mm posterior to 4.6 mm anterior and 12.9 mm inferior to 5.1 mm superior. All center points were within the glenoid vault at the 1.5-cm level (Table 1).

Discussion

Proper glenoid component placement is critical in total shoulder arthroplasty. Central placement of the glenoid

Table 1. Results

Patient number	Gender	Side	Age (years)	Rotational angle	Faceplate image		1.5-cm depth image		Version	Wear pattern	Deviation* anteroposterior	Deviation* superior-inferior
					Anteroposterior dimension	Superior-inferior dimension	Anteroposterior dimension	Superior-inferior dimension				
1	Male	Left	56	35	26.8	44.6	991 12.2	41	RV 3.1	Concentric	1.3	-1.9
2	Female	Left	65	37	30.2	41	1137 9.6	38.6	RV 14.3	Posterior	3	-7.1
3	Male	Right	70	36	35.6	48.6	1306 14.1	50	RV 12.5	Posterior	3.2	-4.4
4	Female	Left	65	44	30.3	46	1032 12.7	45.3	RV 19.2	Posterior	2.2	-2.1
5	Female	Right	65	30	22.5	41.25	668 8.4	28.6	RV 10.6	Concentric	3	-5.6
6	Male	Right	73	21	33.2	51.2	941 13.8	36.4	RV 4	Concentric	1.4	-1.3
7	Male	Right	73	40	34.8	53.5	1375 13	47.9	RV 30	Posterior	0.1	-0.6
8	Female	Left	63	47	27.1	40	820 13	32.6	RV 1.7	Concentric	0.05	-7
9	Female	Right	59	38	30.6	41.4	990 9.3	36.6	RV 4.6	Posterior	0	-8.2
10	Female	Left	64	36	29.7	41.5	846 9.6	36.4	RV 24.7	Posterior	0	-4
11	Female	Left	79	35	29.3	40	699 11.7	40.9	RV 0.2	Posterior	3	-5.3
12	Female	Right	73	33	26.5	37.8	749 5.6	31.1	RV 21.4	Posterior	2	7.5
13	Female	Right	78	36	27.9	37.2	757 9.5	31.3	RV 0.5	Concentric	0.3	-4.2
14	Female	Left	68	44	35.7	47	1175 11	41.8	RV 37.9	Posterior	-0.06	2.7
15	Male	Right	58	40	36.4	50.1	1368 14.8	40.9	RV 10.3	Posterior	3.1	-5.2
16	Male	Left	69	26	31.4	52.8	1247 13.6	51.9	AV 1.9	Concentric	1.2	-10.1
17	Female	Left	70	33	25.6	39.3	807 10.9	32.9	RV 13.7	Posterior	3.7	-1.8
18	Female	Right	74	35	26	41.9	848 8.7	18.1	RV 23.3	Posterior	0	-0.7
19	Male	Right	73	30	31.7	45.6	1154 15.6	42.8	RV 3.4	Posterior	2.6	-8.3
20	Male	Left	72	33	35.4	44	1304 11.7	47.4	RV 11	Posterior	3.3	-9.9

* Deviation is recorded as positive for anterior or inferior and negative for posterior or superior values.

pilot hole on the glenoid surface and alignment of the component along the scapular axis was believed by the authors to optimally position the component. We hypothesized the center of the glenoid surface as seen intraoperatively would differ from the center of the glenoid vault at the medial extent of the glenoid component. Additionally, evaluation of the data for a consistent relationship was sought.

We did not determine interobserver and intraobserver variability in our study. Prior studies of CT analysis of glenoid parameters have noted excellent inter- and intraobserver variability of 1° to 3° and 4°, respectively [11]. Therefore, we do not believe any such variability would have influenced our conclusions.

Our data suggest in a series of osteoarthritic shoulders, the center point determined on the glenoid surface, ideally aligned along the axis of the scapula, closely mirrors the center point of the glenoid vault at the medial extent of the glenoid component. This was the case despite wide variation in wear patterns and glenoid vault morphology.

Glenoid depth based on external bony architecture has been previously reported to average 31.5 mm (range, 26–40 mm) in nonarthritic cadavers [8]. Effective glenoid depth in an osteoarthritic population for the placement of a glenoid prosthesis must be greater than 1.5 cm to accommodate the majority of cemented glenoid components. Glenoid surface morphology is highly variable as a result of bony erosion, humeral head subluxation, and cyst formation. The use of a preoperative CT scan to fully evaluate glenoid surface morphology allows the surgeon to understand the anatomy of the surface with respect to the underlying vault and scapular axis [7, 9].

Scapular axis must be determined by evaluation of the preoperative radiographs, the preoperative CT, or by palpation of the middle of the anterior base of the glenoid vault at the juncture of the upper and lower scapular crura [2, 10, 11]. The width of the glenoid vault in the anterior to posterior dimension narrows from the glenoid surface to the juncture of the upper and lower crura medially. The average glenoid width of the glenoid vault in this study at the 1.5-cm depth was 11.5 mm. Previously reported values in a nonarthritic population at the 2-cm level were 13 mm [12]. Subtle variation from the ideal alignment along the scapular axis increases the risk of cortical penetration.

Using our intraoperative goal of neutral alignment, which varies only slightly from the 2° anteversion initially suggested by Friedman et al. [6], most of the shoulders in this study had a center point on the glenoid surface that was

slightly posterior and superior to the center point at the 1.5-cm depth. During the intraoperative placement of the center point on the glenoid articular surface, the best direction in which to err would be near or slightly anterior and slightly inferior to the center point of the glenoid surface.

Despite substantial differences in glenoid surface morphology, the medial aspect of the prosthesis is experimentally contained within the glenoid vault by identifying the center point of the glenoid surface and aligning the prosthesis collinear with the scapular axis and anatomic inclination. The endosteal dimensions and shape of the glenoid vault are relatively consistent [1] and utilization of this simple technique may improve the reproducibility of anatomic glenoid placement. This confirms the usefulness of the center point of the glenoid as defined intraoperatively for optimizing glenoid placement.

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