Application of the fulcrum axis to estimate the central scapular axis

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Background: Glenoid resurfacing can be a challenging component of total shoulder arthroplasty when significant glenoid retroversion or deformity is present. The purpose of this study was to determine whether a newly designed glenoid-targeting guide using the parallel relationship between glenoid version and an anatomic fulcrum axis could accurately estimate the central axis of the scapula.

Materials and methods: Three orthopaedic surgeons used a newly designed glenoid-targeting guide to place a guide pin into 6 normal Sawbones scapulae (Pacific Research Laboratories, Vashon Island, WA, USA), 6 retroverted Sawbones scapulae, 8 cadaveric scapular specimens, and 5 cadaveric shoulder specimens. Angles of deviation from the central scapular axis and from perpendicular to the fulcrum axis were measured.

Results: The mean pin deviation angle from the central scapular axis and the mean fulcrum deviation angle for the normal Sawbones scapulae were 1.7° (SD, 1.2°) and 2.1° (SD, 1.5°), respectively. For altered retroverted Sawbones scapulae, the mean deviation angles were 1.8° (SD, 1.2°) and 2.8° (SD, 1.6°), respectively. The combined mean pin deviation angle and mean fulcrum deviation angle for cadaveric shoulder specimens were 2.8° (SD, 3.3°) and 2.3° (SD, 2.3°), respectively. The surgeons’ results did not differ significantly whether using Sawbones models, cadaveric scapular specimens, or cadaveric shoulder specimens.

Conclusion: A glenoid-targeting guide based on the relationship of the fulcrum axis and glenoid version can be used to accurately estimate the central scapular axis. Such a tool can be accurate and reliable intraoperatively, aiding in glenoid component placement to within 5° of ideal version, irrespective of glenoid deformity.

Level of evidence: Basic Science Study, Surgical Technique.

Keywords: Fulcrum axis; glenoid deformity; glenoid version; scapular axis; total shoulder arthroplasty

Total shoulder arthroplasty is a robust treatment option for pain relief for patients with severe arthropathies of the glenohumeral joint from either osteoarthritis or inflammatory arthritis. One of the most challenging aspects of total shoulder arthroplasty is achieving the ideal glenoid component position during glenoid resurfacing. Underlying posterior or superior wear of the glenoid surface can significantly alter the normal anatomy, making it difficult for surgeons to align the glenoid component in the ideal version and inclination. Proper alignment is essential for implant stability. Nyffeler et al reported that 4° of deviation from the normal glenoid version results in shifting the force vector 2° from the glenoid’s center. In turn, this alters contact stress on
the joint surface and could lead to glenoid component loosening or instability. Therefore, the stability of the total shoulder implant can be affected by even small misalignment of the glenoid component version. Most techniques for estimating glenoid version today are solely dependent on the surgeon’s experience; this can lead to variations in outcomes of shoulder arthroplasty.

A common method for estimating glenoid version involves using the central axis of the scapular body, which is defined as a line running from the center of the glenoid to the scapular trigonum, or medial border of the scapula. The variability in size and curvature of the scapular body among individuals can lead to variability in the measurement of the glenoid version preoperatively with current imaging modalities such as axillary radiographs and computed tomography (CT) scans. This could explain the wide range of normal glenoid version values reported in the literature, which varies from anteversion of $5^\circ$ to retroversion of $15^\circ$. On average, most individuals are within $5^\circ$ of neutral version. The most reproducible and accurate imaging modalities used to estimate glenoid version are 3-dimensional CT reconstruction, followed by standard CT scans. Standard axillary radiographs are unreliable.

During surgery, the scapular trigonum cannot be used to help orient glenoid component version because it is not accessible intraoperatively. Severe glenoid deformity and wear can make the task of placing the glenoid component in the ideal position even more challenging. Most surgeons would agree that the best glenoid component position would be within $5^\circ$ of the perpendicular plane of the scapular plane. However, the optimal version of the glenoid component for ideal long-term fixation or wear has not been shown.

In a study of 143 cadaveric scapulae, the fulcrum axis, defined as a line connecting the tip of the coracoid to the posterolateral corner of the acromion, was found to be nearly parallel to the glenoid fossa, or within $1.8^\circ$ of the version of the glenoid. Thus, the fulcrum axis is nearly perpendicular to the central axis of the scapula. Therefore, the fulcrum axis can be used to estimate the central axis of the scapular body and, in turn, to estimate the ideal version of the glenoid, independent of any glenoid deformity. The tip of the coracoid and the posterolateral corner of the acromion are 2 surface landmarks familiar to shoulder surgeons that can be used during total shoulder arthroplasty to estimate glenoid version and component placement.

In this study, we used a newly designed glenoid-targeting guide based on the relationship of the fulcrum axis to glenoid version to estimate the central axis of the scapula in both Sawbones (Pacific Research Laboratories, Vashon Island, WA, USA) and cadaveric models. Our hypothesis was that a glenoid-targeting guide based on this relationship would allow the central axis of the scapula to be accurately estimated and would aid in the placement of a glenoid component in the desired version.

### Materials and methods

To test whether the fulcrum axis can estimate the central axis of the scapula, a glenoid-targeting guide was designed at the University of Florida in conjunction with Exactech (Gainesville, FL, USA). The design of the guide was based on the relationship previously described between the fulcrum axis and version of the glenoid surface. It consists of 2 parts: a clamp and a slotted guide to allow placement of a 2-mm guide pin (Exactech) at $90^\circ$ to a line drawn between the tips of the clamp (Fig. 1). The guide was used by 3 orthopaedic surgery fellows familiar with shoulder arthroplasty in experiments (phase 1-3) designed to test its accuracy and to estimate the central axis of the scapula.

### Phase 1

Phase 1A of the experiment involved Sawbones scapulae (No. 1021 Large Left Solid Foam Solid Sawbones; Pacific Research Laboratories). Each orthopaedic surgeon applied a 2-mm guide pin on the Sawbones scapulae using the targeting guide; this was repeated for a total of 6 Sawbones scapulae for each surgeon. The starting point of the pin was pre-marked at the center of the glenoid surface on both the anteroposterior and superoinferior axes. Therefore, each surgeon placed the guidewire at the center of the glenoid, with the version of the wire dictated by the targeting guide on each specimen (Fig. 2).

The Sawbones scapulae were then imaged in the position described by Braunstein et al (Fig. 3, A), with fluoroscopy used to obtain a standardized view of the glenoid (Fig. 3, B). In brief, the Sawbones scapula was positioned so that the glenoid surface was parallel to the fluoroscopic x-ray beams and in line with the most superior and inferior ends of the glenoid. This technique allowed for radiographic landmarks on the scapula to be identified (Fig. 3, C). From these radiographic points, the fulcrum axis and the central axis of the scapula were identified (Fig. 3, D). These points were verified with a pilot experiment in which guide pins were placed through these 2 axes and the same standardized radiographs were taken to confirm that the points on the fluoroscopic images corresponded with the surface landmarks.

Two angles were defined and measured from these radiographic landmarks. The pin deviation angle (PDA) was defined as the absolute deviation angle of the guide pin from the central axis of the scapula (Fig. 4, A). This angle represents the deviation of the guide pin away from the central axis, indicating the accuracy of the targeting guide. The fulcrum deviation angle (FDA), defined as $90^\circ$ minus the angle measured between the fulcrum axis and the pin, is a measure of the accuracy of the guide in placing the guide pin at $90^\circ$ to the fulcrum axis, which is what the guide was designed to do (Fig. 4, B). The results were grouped according to accuracy. Excellent accuracy was defined as within $5^\circ$ of the ideal measurement of $0^\circ$ for both PDA and FDA. Good accuracy was placement within $6^\circ$ to $10^\circ$ of the ideal measurement. Poor accuracy was defined as greater than $10^\circ$ from the ideal measurement (Fig. 5).

Although the accuracy categories were arbitrarily set, glenoid components positioned within $5^\circ$ of neutral version are considered to be ideally placed clinically. Previous studies have shown that there is increased strain on the glenoid component when retroversion exceeds $10^\circ$. These studies suggest that high component
strains could lead to a higher risk of component failure. However, no current studies have determined the ideal glenoid component version that would lead to decreased component wear or long-term stability.

In phase 1B, the procedure described in phase 1A was repeated using Sawbones scapulae that had been pre-altered to have fixed retroversion of 16°. This phase was designed to test the accuracy of the guide irrespective of glenoid deformity. Each surgeon repeated the procedure in each specimen under this new condition.

Phase 2

In phase 2, the experiment in phase 1A was repeated with 8 cadaveric scapular specimens to further assess the accuracy of the glenoid version–targeting guide on cadaveric specimens with natural variation in anatomy.

Phase 3

In phase 3, the experiment described in phase 1A was repeated with 5 full-shoulder cadaveric specimens. This phase was designed to closely mimic the surgical setting, primarily to assess whether the 2 surface landmarks—the coracoid process and the posterolateral corner of the acromion—could be identified while placing the targeting guide.

The 5 full-shoulder cadaveric specimens were mounted on a large C-clamp along the medial border of the scapula, placing the scapula in a position similar to that in a patient in the beach-chair position. Next, a standard exposure of the shoulder was performed through a standard deltopectoral approach, and the glenoid was exposed after a standard proximal humeral osteotomy, as would be performed in a total shoulder arthroplasty procedure. Each participating surgeon then applied the guide pin using the targeting guide as previously described. The center had been pre-marked to maintain consistency. The center was altered by 2 mm inferiorly or superiority in the vertical axis to prevent the same pinhole from being used from one participant to the next. The anterior or posterior deviation of the pin was not affected in our measurements.

Data analysis

Analysis of variance was used to evaluate the interobserver differences, whereas the 95% confidence interval and standard deviation were used to assess the intraobserver differences. The Student t test was used to compare the differences between the group of normal Sawbones scapulae and the group of altered Sawbones scapulae.

Results

Phase 1: Sawbones

The mean PDA and mean FDA for each of the orthopaedic surgeons are shown in Table I. No significant differences in the PDA (P = .54) or FDA (P = .59) were found among the 3 surgeons. The overall accuracy rating was excellent for all deviation angles (Table I).

The results for the altered Sawbones scapulae are also shown in Table I. The mean PDA and mean FDA measures for all 3 orthopaedic surgeons are listed. There were no statistically significant differences in the PDA (P = .09) or FDA (P = .59) among the 3 surgeons. The overall accuracy rating was excellent for all deviation angles (Table I).

The combined mean PDA and mean FDA with the normal Sawbones scapulae for all 3 surgeons were 1.7° (SD, 1.2°) and 2.1° (SD, 1.5°), respectively. With the altered Sawbones scapulae, the combined mean PDA and mean FDA for all 3 surgeons were 2.8° (SD, 1.2°) and 2.8° (SD, 1.6°), respectively. There were no significant differences in PDA (P = .77) or FDA (P = .22) between the normal scapula group and altered scapula group. The overall combined accuracy rating was excellent for both normal and altered Sawbones scapulae (Table I).

Phase 2: cadaveric scapulae

The mean PDA and mean FDA measured by the 3 orthopaedic surgeons for the cadaveric specimens are given in Table II. There were no statistically significant differences in PDA and FDA among the 3 surgeons (P = .18 and
The overall accuracy rating was excellent for all deviation angles except for 1 good rating for the PDA for surgeon 3 (Table II). The combined PDA and FDA values for all 3 volunteer participants were 4.6° (SD, 2.6°) and 2.8° (SD, 1.9°), respectively. The overall accuracy rating for the cadaveric scapular specimens was excellent for both PDA and FDA values (Table II).

### Phase 3: cadaveric shoulders

Mean PDA and FDA values for the cadaveric shoulder specimens for the 3 orthopaedic surgeons are given in Table III. There were no statistically significant differences in the PDA and FDA among the 3 surgeons ($P = .34$ and $P = .60$, respectively). The overall accuracy rating was excellent for all deviation angles (Table III). The combined PDA and FDA values for all 3 orthopaedic surgeons were 2.8° (SD, 3.3°) and 2.3° (SD, 2.3°), respectively. The overall accuracy rating for the cadaveric shoulder specimens was excellent for both PDA and FDA values (Table III).

### Discussion

Total shoulder arthroplasty is a reliable procedure to relieve arthritic pain associated with end-stage glenohumeral

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**Figure 2**  (A and B) Glenoid-targeting guide application onto Sawbones scapula. A 2-mm guidewire can be placed in one of the various slots and adjusted to the center or desired location on the glenoid surface.

**Figure 3**  (A) Specialized x-ray technique described by Braunstein et al. The overall accuracy rating was excellent for all deviation angles except for 1 good rating for the PDA for surgeon 3 (Table II). The combined PDA and FDA values for all 3 volunteer participants were 4.6° (SD, 2.6°) and 2.8° (SD, 1.9°), respectively. The overall accuracy rating for the cadaveric scapular specimens was excellent for both PDA and FDA values (Table II).
arthritis. Glenoid component positioning, specifically obtaining the desired version during the procedure, can be challenging in the face of significant glenoid deformity from the underlying disease. Postoperative instability and glenoid component loosening are major concerns after total shoulder arthroplasty and have been directly related to glenoid component version.13

In this study, we designed a glenoid-targeting guide to take advantage of the fact that the plane of the fulcrum axis is nearly parallel to the plane of normal glenoid version1 and thus indirectly perpendicular to the central axis of the scapula. The study was designed to determine whether this targeting guide could be used to accurately place a guide pin 90° perpendicular to the fulcrum axis and through the center of the glenoid fossa. We hypothesized that this device could be used to reliably estimate the central axis of the scapula.

Our results show that in a Sawbones model, each of the 3 orthopaedic surgeons using the targeting guide achieved excellent accuracy in placing a guide pin within 5° of the central axis of the scapula and within 5° of perpendicular to the fulcrum axis. The low standard deviation and 95% confidence interval range show that the results were reproducible when the technique was repeated by each surgeon. In addition, there were no significant differences in the results among the 3 surgeons, supporting interobserver reliability. When the Sawbones scapulae were altered to have increased glenoid retroversion of 16°, our results showed that intraobserver and interobserver reliability remained good. Overall, the statistical analyses confirmed the repeatability of estimating the central scapular axis using the guide.

Techniques previously proposed for glenoid preparation and version determination are dependent on the surgeon’s experience. In a study by Iannotti et al,7 an experienced orthopaedic surgeon was able to achieve excellent placement (≤5° of optimal) in 7 of 13 cases. The placement was within 10° of optimal in 10 of 13 cases. The placement was judged unsatisfactory in 3 of 13 cases. Moderate to severe deformity (≤10° of preoperative retroversion) was present in 7 of 13 cases. The glenoid placement was within 10° of the optimal position in only 4 of these 7 cases. Thus, even an experienced surgeon could not ensure optimal placement when deformity was present.7

One common surgical technique used to correct glenoid version was described by Matsen et al.11 In this method, the surgeon uses his or her index finger to palpate over the anterior glenoid rim toward the transition point of the glenoid wall and the scapular body. A guide pin is then placed free-hand, starting at the center of the glenoid fossa toward the tip of the surgeon’s finger. Ideally, the guide pin would be in line with the central scapular axis, thus allowing ideal glenoid version to be determined. Despite this being a commonly used technique, Iannotti et al7 showed that with preoperative glenoid deformity of greater than 10° of retroversion, an experienced shoulder surgeon could not accurately correct the deformity and place the component within 10° of neutral version. They concluded that a less experienced surgeon...
might have even greater difficulty achieving optimal glenoid placement using this technique.

Using our glenoid-targeting guide, our orthopaedic surgeons were able to achieve excellent glenoid placement even when the Sawbones scapulae had preoperative retroversion of 16°. In fact, the accuracy of glenoid placement was not significantly different between the normal and altered Sawbones scapulae. However, Sawbones scapulae do not contain soft tissue attachments that can affect the identification of the 2 surface landmarks that define the fulcrum axis: the tip of the coracoid and the posterolateral corner of the acromion. They showed that there is a 0.3° deviation in this parallel relationship for every 1-mm shift from the exact identification of either landmark. In turn, this would alter the relationship of the fulcrum axis and the central axis of the scapula. Therefore, the accuracy of the guide in estimating the central axis of the scapula depends on the surgeon’s ability to identify these 2 surface landmarks.

To show that our results could be applicable to the clinical setting, we applied our glenoid-targeting guide technique to both cadaveric scapulae and shoulder specimens. We achieved excellent accuracy in all cases except 1 case in which a PDA measurement was rated as good. This suggests that even...
with intact soft tissue attachments and natural variation among cadaveric specimens, the use of the glenoid-targeting guide can aid in accurate placement of the guide pin to within 5° of the central axis of the scapula and within 5° of being perpendicular to the fulcrum axis. Our statistical analyses confirm the repeatability of our methods.

Nguyen et al.12 showed that standard methods used by experienced surgeons to estimate glenoid component position were not always accurate in placing the glenoid version within 10° of the neutral or ideal position. In addition, other studies have shown that with greater than 20° of preoperative glenoid retroversion, the alignment of the glenoid component could not be corrected to the neutral position without the consequence of central-peg perforation.6,7 Nguyen et al and Edwards et al3 showed increased accuracy in glenoid component positioning when computer-assisted surgical navigation was used. Our results suggest that our newly designed glenoid-targeting guide using the location of the fulcrum axis can be useful as a low-technology navigation tool for accurate placement of the glenoid component, especially in the face of severe glenoid deformity. However, studies in the clinical setting are needed to validate these results.

**Conclusion**

The glenoid-targeting guide based on the relationship of the fulcrum axis and glenoid version was used to accurately estimate the central scapular axis. The glenoid-targeting guide can be an accurate and reliable tool intraoperatively, aiding in glenoid component placement to within 5° of ideal version, irrespective of glenoid deformity.

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