



Version and inclination obtained with 3-dimensional planning in total shoulder arthroplasty: do different programs produce the same results?



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ABSTRACT

Background: Our purpose was to compare the output of glenoid measurements with 2 commercially available preoperative 3-dimensional (3D) total shoulder arthroplasty planning systems. The hypothesis was that there would be no difference in product-derived measurements between the systems.

Methods: Preoperative 3D computed tomography scans of 63 consecutive patients undergoing primary arthroplasty were analyzed using 2 product-derived techniques: Blueprint and VIP. Glenoid version and inclination measurements with each system were blinded and statistically compared, and the amount of variance was recorded.

Results: Glenoid version based on Blueprint was $-10.9^\circ \pm 9.0^\circ$ (range, -41° to 14°) compared with $-9.3^\circ \pm 8.2^\circ$ (range, -36° to 8°) for VIP ($P = .04$). Inclination was $9.0^\circ \pm 8.8^\circ$ (range, -12° to 29°) with Blueprint compared with $9.7^\circ \pm 6.1^\circ$ (range, -6° to 22°) for VIP ($P = .463$). For version, the difference between the 2 systems was less than 5° in 44 cases (69.8%), 5° - 10° in 12 cases (19.0%), and greater than 10° in 7 cases (11.1%). For inclination, the difference was less than 5° in 34 cases (54.0%), 5° - 10° in 17 cases (27.0%), and greater than 10° in 12 cases (19.0%). We found no differences in glenoid version or inclination based on glenoid morphology between the 2 systems ($P = .908$) and no differences between patients with the most severe arthritis and posterior wear ($P = .202$).

Conclusions: There is considerable variability between preoperative measurements obtained for 3D planning of shoulder arthroplasty with the use of Blueprint and VIP. Given that implant choice and desired component positioning are based on preoperative measurements, further study is needed to evaluate the differences between the measurements obtained with different techniques.

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Proper component positioning is an important part of achieving good outcomes in both anatomic total shoulder arthroplasty (TSA) and reverse shoulder arthroplasty (RSA). In TSA, excessive retroversion and superior inclination have been associated with higher rates of clinical failure.^{7,10,20} Likewise, in RSA, the position and inclination of the glenoid baseplate placement may affect outcomes.⁵ However, the conventional methods of plain radiographic analysis and 2-dimensional (2D) computed tomography (CT) analysis often result

in misrepresentation of glenoid version and inclination compared with 3-dimensional (3D) CT scans.^{3,6,15} Furthermore, a freehand reaming technique frequently results in deviation from the planned component placement.¹²

The use of 3D planning software and the subsequent patient-specific instrumentation (PSI) based on these analyses has recently emerged as a technique for more accurately defining glenoid anatomy and transferring a desired preoperative plan to the surgical procedure for component placement. Multiple studies have shown that PSI improves component placement compared with freehand techniques, particularly in the setting of glenoid deformity.^{8,9,18} These studies have compared preoperative and postoperative placement based on a given software system. However, different software systems are

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available. Most preoperative planning systems use manual measurements based on the midglenoid and scapular landmarks to assess glenoid version and inclination. An automated system that uses a best-fit sphere technique (Blueprint; Wright Medical, Memphis, TN, USA) is also available. However, limited information is available about the differences between the measurements obtained with these techniques (automated and manual systems).

The purpose of this study was to compare glenoid version and inclination values obtained for 3D planning in shoulder arthroplasty using an automated best-fit sphere system (Blueprint) versus a manual landmark-based software system (VIP; Arthrex, Naples, FL, USA). The hypothesis was that there would be no difference in version or inclination measurements obtained with the 2 systems.

Materials and methods

We performed a retrospective review of patients undergoing TSA at 2 institutions during a 6-month period from November 2015 to May 2016. The inclusion criteria included primary TSA for primary glenohumeral arthritis or RSA for failed rotator cuff repair or rotator cuff arthropathy and a preoperative CT scan with a minimum slice thickness of 1 mm that included the entire scapula. The exclusion criteria included revision arthroplasty or lack of an adequate preoperative CT scan.

Digital Imaging and Communications in Medicine files of each CT scan were obtained. On the basis of 2D CT images, glenoid morphology was classified by 1 investigator (P.J.D.). For patients with a preoperative diagnosis of failed rotator cuff repair or rotator cuff arthropathy, glenoid morphology was classified in the coronal plane according to the Sirveaux classification.¹⁷ For patients with a preoperative diagnosis of primary glenohumeral arthritis, glenoid morphology was classified in the axial plane according to the Walch classification.¹

Next, glenoid version and inclination were analyzed with 2 different preoperative planning software systems according to each manufacturer's protocol. First, the CT scans were analyzed with an automated preoperative planning program (Blueprint). This software automatically isolates voxels that are specific to the scapula using image recognition technology. A best-fit plane is defined by considering these voxels as a point cloud used to define the scapular plane. The program also uses a best-fit sphere technique for the glenoid to isolate the point cloud of the glenoid rim. Version and inclination are then automatically calculated by the computer software by comparing the best-fit sphere of the glenoid with the horizontal and vertical planes of the scapula, respectively. Because the process is automated, no manual subtraction of bone fragments is performed with this system. However, after the creation of the automated 3D reconstructions, 1 reviewer (PJD) visually inspected the reconstructions for any missing bony segments or extra glenoid fragments and recorded their presence as yes or no.

Second, the CT scans were analyzed with a preoperative planning program that relies on manual identification of scapular landmarks followed by digital measurement (VIP). Analysis of these CT scans was performed according to the manufacturer's protocol by a trained and certified software engineer who was blinded to the results of the automated program. Digital Imaging and Communications in Medicine images were uploaded into this system and reformatted into 3D representations. The proximal humerus was manually subtracted by the engineer. Landmarks were placed on the scapula trigonum, the inferior angle, and the center of the glenoid to determine the plane of the scapula.¹⁶ The transverse scapula line was defined as a line between the trigonum and the center of the glenoid. Three landmarks were placed on the glenoid fossa to define the plane of the glenoid. Glenoid version and inclination were then determined based on the glenoid plane relative to the scapular plane. This midglenoid

approach has previously been validated by comparing this 3D analysis with external measurements on cadavers.¹³

Statistical analysis

Values of version and inclination were calculated as mean and standard deviation. A *t* test was used to compare values between the 2 groups. Significance was set at $P < .05$. Analysis was performed with Microsoft Excel (Microsoft, Redmond, WA, USA). In addition, version and inclination values were compared for each CT scan and classified as follows: less than 5°, 5°–10° difference, or greater than 10° difference. We chose 5° because it was considered clinically relevant and because it was previously used as the threshold for the difference between systems.⁴ Finally, to evaluate the influence of humeral head subtraction on measurements, scans with a clean view of the glenoid were compared with those with spurious bone fragments remaining or missing sections on the 3D CT scans (owing to lack of subtraction of the humeral head). This was evaluated in the primary arthritis group given that this diagnosis has the most joint space narrowing.

Results

Study group

A total of 93 CT scans were taken during the study period in patients undergoing primary shoulder arthroplasty. Of these CT scans, 63 were of adequate slice thickness and were evaluated by both preoperative planning systems. The mean patient age was 68.8 years (range, 44–89 years). Twenty-seven CT scans were available in patients with rotator cuff arthropathy or failed rotator cuff repair. In this group, the Sirveaux classification was E0 in 17 (63.0%), E1 in 9 (33.3%), and E2 in 1 (3.7%). Thirty-six CT scans were available in patients with primary glenohumeral arthritis. In this group, the Walch classification was A1 in 11 (30.6%), A2 in 3 (8.3%), B1 in 12 (33.3%), and B2 in 10 (27.8%). No glenoids were classified as Walch type C.

Overall measurements

The mean version based on Blueprint was $-10.9^\circ \pm 9.0^\circ$ (range, -41° to 14°) compared with $-9.3^\circ \pm 8.2^\circ$ (range, -36° to 8°) based on VIP ($P = .04$). The mean inclination was $9.0^\circ \pm 8.8^\circ$ (range, -12° to 29°) based on Blueprint compared with $9.7^\circ \pm 6.1^\circ$ (range, -6° to 22°) based on VIP ($P = .463$).

Variance between systems

For version, the measured difference between the 2 systems was less than 5° in 44 cases (69.8%), 5°–10° in 12 cases (19.0%), and greater than 10° in 7 cases (11.1%). For inclination, there was a measured difference between the 2 systems of less than 5° in 34 cases (54.0%), 5°–10° in 17 cases (27.0%), and greater than 10° in 12 cases (19.0%). In 12 cases (19%), both version and inclination varied by 5° or greater between the 2 systems. In 36 cases (57%), either version or inclination varied by 5° or greater; in 15 cases (24%), either varied by greater than 10°.

Glenoid morphology was evaluated in the groups with and without variance in version or inclination of 5° or greater. In the primary arthritis group, version or inclination varied by 5° or greater in a similar proportion of type A (57.1%) and type B (54.5%) glenoids ($P = .908$). Likewise, in the cuff arthropathy group, version or inclination varied by 5° or greater in a similar proportion of E0 (58.8%) and E1 or E2 (60.0%) glenoids ($P = .952$).

In the primary arthritis group, 25 CT scans (69.4%) in the Blueprint group were considered to have a clear view of the glenoid, and 11 CT

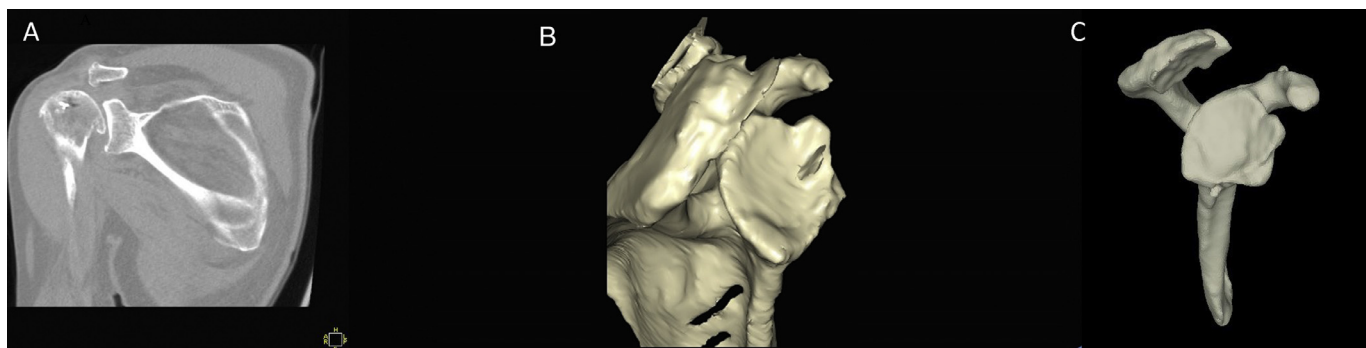


Figure 1 Comparative 3-dimensional (3D) representations of a 67-year-old man with rotator cuff arthropathy. (A) Two-dimensional computed tomography shows superior migration, joint space narrowing, and a large humeral head osteophyte. (B) The 3D representation from the automated system shows extra glenoid fragments likely from lack of humeral head osteophyte subtraction. (C) A 3D representation produced with manual subtraction of humerus. Version and inclination varied by 7° each between the automated and manual systems.

scans (30.6%) were noted to have extra bone fragments or missing segments on the automated 3D reconstructions. Measurements were compared between the 2 systems to evaluate whether the difference in the technique of humeral head subtraction influenced glenoid measurements. Version varied between Blueprint and VIP by 5° or greater in only 19.4% of the “clean” scans (7 cases) compared with 45.5% of those with extra bone fragments on the glenoid fossa or sections missing from the glenoid fossa (5 cases) on the automated 3D reconstruction ($P = .111$). Inclination varied by 5° or greater in 30.6% (11 cases) versus 36.4% (4 cases) ($P = .736$). Either version or inclination varied by 5° or greater in 36.1% of the clean scans (13 cases) compared with 63.6% of the scans with extra bone fragments or missing glenoid face sections (7 cases) ($P = .132$).

Discussion

The findings of this study did not support our hypothesis that there would be no difference between automated and manual 3D preoperative planning systems regarding assessment of glenoid inclination and version. In more than 50% of cases, either inclination or version varied by 5° or more, and in nearly 25% of cases, inclination or version varied by greater than 10°. These findings may have important implications for preoperative planning and PSI in shoulder arthroplasty.

It is well accepted that glenoid component position is important for optimizing outcomes after TSA and RSA. Such placement begins with preoperative analysis of radiographic studies. In recent years, there has been a transition in preoperative planning of shoulder arthroplasty from plain radiographic analysis to 2D CT analysis and, finally, 3D CT analysis. Nyffeler et al.¹⁵ showed that version was more accurately represented with a 2D CT scan than with plain radiographs. However, both plain radiographs and 2D CT can produce variations based on the angle or slice orientation.^{2,6} Subsequently, multiple studies have shown that the accuracy of glenoid assessment is further improved with 3D CT compared with 2D CT.^{3,6,11} On the basis of these findings, several commercially available software systems have been developed to provide preoperative determination of glenoid version and inclination, followed by a plan with or without PSI to transfer the desired position of the glenoid component to the actual surgical procedure.

Most planning systems are based on reformatting of 2D CT scans to create 3D reconstructions that can be used to orient the scapula, manually identify pertinent landmarks, and subsequently measure inclination and version. Another reported option is the automated system evaluated in this study. This technique is appealing in that images can be uploaded and the system provides immediate analysis without the need for a software engineer to manually subtract the humerus and orient the scapula. It is interesting that we found substantial variations in output for glenoid inclination and version

between the automated software (Blueprint) and manually corrected (VIP) techniques. Overall, version varied by only 1.6°, and inclination was not different between the 2 groups. However, in evaluating the differences for each CT scan, there were frequently differences of 5° or more for version and/or inclination. Version varied by 5° or more in 30% of cases, and inclination varied by 5° or more in 46% of cases. In 56% of cases, either version or inclination varied by 5° or greater; in 24%, either varied by greater than 10°. Our findings are also supported by a recent study by Chalmers et al.⁴ They compared the analysis of 31 type B2 glenoids performed with 2D CT with manual measurement, 3D CT scans with manual measurement, and an automated software system (Blueprint). In 48% of cases, the difference in version between the 2D CT scan and the 3D CT scan was greater than 5°. In 94% of cases, the difference in inclination was greater than 5°. As in our analysis, inclination did not vary between the 3D CT scans and the automated system in terms of mean values. However, in contrast to the comparison between 2D CT scans and corrected CT scans, they did not report how often the corrected CT scans and automated system varied by greater than 5°.

Given the precision necessary in glenoid component positioning during shoulder arthroplasty, it is important to understand these differences obtained on preoperative planning. Furthermore, preoperative measurements have a substantial impact on choice of implant.¹⁹ Several factors may account for the differences observed between the 2 methods in our study. We attempted to evaluate whether glenoid morphology would impact the results and did not see a difference in the frequency with which the 2 systems varied based on glenoid morphology for primary arthritis or cuff arthropathy. This finding suggests that factors other than glenoid morphology account for the variances. Rather, the variances may be owing to the differences in technique between the 2 systems.

First, the automated system treats the glenoid as a best-fit sphere. This is then compared with the scapular plane based on image recognition technology. The exact algorithm for the image recognition of the scapular plane with the automated system is proprietary. In contrast, a manual 3D system estimates version of the glenoid based on the midpoint. Three points are placed on the glenoid to define the glenoid fossa, the scapula trigonum is marked visually, and the relationship between the scapular plane and the midpoint is used to calculate version. Thus, there are differences in how the glenoid is treated, and there may be differences in how the scapula is treated. Lewis and Armstrong¹⁴ previously compared version measurements between a midglenoid technique and best-fit sphere technique in 20 specimens and reported that the difference was never more than 4°. However, they used nonpathologic specimens and the scapula was treated the same in each technique, with manual identification of landmarks.

Finally, the results may be influenced by factors not related to the glenoid or scapula including joint space narrowing and humeral head

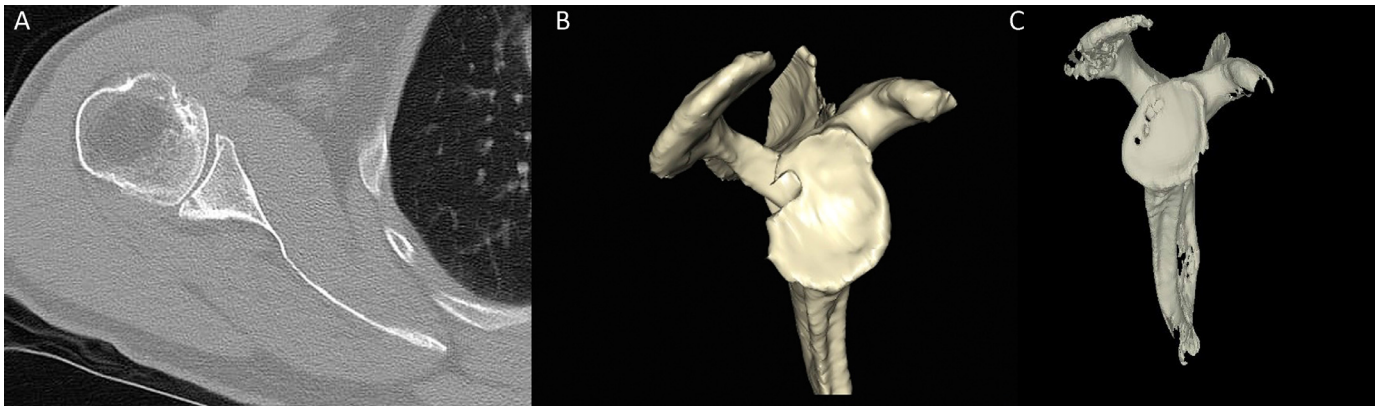


Figure 2 Comparative 3-dimensional (3D) representations of a 65-year-old man with primary glenohumeral arthritis. (A) An axial 2-dimensional computed tomography cut shows a glenoid cyst in the posterior glenoid. (B) The 3D representation from the automated system has a moderate segment of the glenoid missing as a result of the cyst. (C) The 3D representation obtained with manual subtraction of the humerus shows a smaller segment of missing glenoid. Version varied by 7° between the automated and manual systems.

osteophytes. With a manual technique, an engineer subtracts the proximal humerus from the analysis to visualize the glenoid. With the automated system, subtraction is performed by the software program. If the humeral head is not completely subtracted, the result may be extra fragments on the glenoid that may influence the results. Conversely, over-subtraction of the humerus may lead to holes or missing sections on the glenoid fossa. With the automated system, we observed 11 cases of primary arthritis (30.6%) in which there were either extra glenoid fragments or subtracted glenoid segments, which may have influenced the results (Figs. 1 and 2). Version varied between Blueprint and VIP by 5° or greater in only 19.4% of the clean scans (7 cases) compared with 45.5% of those with scans affected by humeral head subtraction (5 cases) on the automated 3D reconstruction. Although this difference did not reach statistical significance with the numbers studied, we believe that the magnitude of difference is noteworthy and suggests that analyses of version and inclination are influenced by the method of humeral head subtraction.

The strength of this study is the independent comparison of glenoid measurements between the 2 planning systems. The analysis of each was blinded so that the manual measurements were not affected by the outcome of the automated system. However, several limitations exist. First, although we compared results by glenoid pathology, the numbers in each group were small. It is possible that complex deformity or specific morphology would affect the results, and further study is needed to evaluate this. Nonetheless, the CT scans analyzed represent a consecutive series of patients and are not biased by selection criteria toward severe deformity. Second, we did not examine the ability of either system to achieve a desired operative plan. Previous studies have individually evaluated each system regarding the ability to establish a plan that is transferrable to the surgical environment and reported that these systems are accurate. Third, we did not evaluate intrarater and inter-rater reliability for the manual measurement system. Finally, we did not provide an analysis of the “true” glenoid version or inclination. We were not attempting to prove superiority of 1 technique over another. Each method may have advantages and disadvantages. Our goal was simply to determine whether the 2 systems obtain a similar starting point for analysis of the glenoid. Further study is needed to evaluate how the differences in the systems translate clinically. Additional analysis that may be translational to a traditional method of a “freehand” preparation of the glenoid for prosthetic placement would be the correlation of the exact starting point identified by each method, as well as the ability to correlate the paleoglenoid to the proper component position.

Conclusions

There is considerable variability between preoperative measurements obtained for 3D planning of shoulder arthroplasty with the use

of 2 commercially available systems. Given that implant choice and desired component positioning are based on preoperative measurements, further study is needed to evaluate the differences between the measurements obtained with different techniques.

Disclaimer

Drs. Denard, Provencher, Romeo, Parsons, and Dines are consultants for Arthrex Inc., Dr. Ladermann is a consultant for Wright Medical Inc.

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