JSES International 6 (2022) 413–420

Contents lists available at ScienceDirect

JSES International

journal homepage: www.jsesinternational.org

Commercial 3-dimensional imaging programs are not created equal: version and inclination measurement positions vary among preoperative planning software

Robert A. Waltz, MD, CDR, MC, USN[a,b,c], Annalise M. Peebles, BA[b], Justin J. Ernat, MD[a,b,d], Stephanie K. Eble, BA[e], Patrick J. Denard, MD[f], Anthony A. Romeo, MD[g], Petar Golijanin, MD, MBA[h], Scott M. Liegel, PA[a], Matthew T. Provencher, MD, MBA, CAPT(ret), MC, USNR[a,*]

[a]The Steadman Clinic, Vail, CO, USA
[b]Steadman Philippon Research Institute, Vail, CO, USA
[c]Naval Health Clinic Annapolis, United States Naval Academy, Annapolis, MD, USA
[d]University of Utah, Salt Lake City, UT, USA
[e]Dartmouth Geisel School of Medicine, Hanover, NH, USA
[f]Southern Oregon Orthopedics, Medford, OR, USA
[g]Department of Orthopaedic Surgery, DuPage Medical Group, Chicago, IL, USA
[h]University of Texas at Austin, Dell School of Medicine, Austin, TX, USA

ARTICLE INFO

Keywords:
Computed tomography
Glenoid
Version
Inclination
Preoperative planning
Shoulder

Level of evidence: Basic Science Study; Validation of Computer Modeling Software

Background: Variability exists between total shoulder arthroplasty preoperative planning software (PPS) systems for glenoid angular measurements. The purpose of this study is to locate the region on the glenoid at which inclination and version are measured on the PPS modalities of Blueprint and VIP.

Methods: Preoperative computed tomography scans of 30 consecutive patients undergoing primary arthroplasty were analyzed using two PPS systems (VIP and Blueprint) to independently obtain glenoid version and inclination measurements through their respective protocols. Three-dimensional equivalent images were independently analyzed utilizing open-source OsiriX DICOM software by two board-certified orthopedic sports medicine surgeons measuring glenoid version and inclination along ten equal intervals of the glenoid from superior to inferior and anterior to posterior. Manual version and inclination measurements were compared to both the VIP and the Blueprint measurements, and variances were analyzed by calculating root mean square error (RMSE). The closest interval (1-10) to the VIP and Blueprint measurement was identified for both version and inclination to determine the region of the glenoid both software programs obtained their measurements.

Results: Mean glenoid retroversion manually measured using OsiriX was 13.5° compared with 15.1° recorded by Blueprint ($P = .516$) and 12.2° by VIP ($P = .621$). Mean inclination using OsiriX was 5.5°, compared with 7.1° ($P = .314$) and 9.0° ($P = .024$) recorded by Blueprint and VIP, respectively. RMSE for version between Osirix and VIP was 4.65°, for Osirix and Blueprint was 4.44°, and for VIP and Blueprint was 4.45°. RMSE for inclination between Osirix and VIP was 6.43°, for Osirix and Blueprint was 5.25°, and for VIP and Blueprint was 5.13°. For version, VIP measurements most frequently aligned with the inferior quadrant of the glenoid (n = 13) with a median interval of 7, while Blueprint aligned with the superior quadrant of the glenoid (n = 13) with a median interval of 4. Inclination measurements aligned with the posterior quadrant of the glenoid for both VIP (n = 19) and Blueprint (n = 15) with a median interval of 8.

Conclusion: PPS systems for shoulder arthroplasty vary in the region of the glenoid for which version and inclination are measured, which may affect the absolute values generated. Location of version measurement was different among the two commercial software programs, with VIP corresponding

This study was approved by the Vail Health Institutional Review Board (IRB Study Number: 2020-035).

The views expressed in this article are those of the authors and do not reflect the official policy or position of the Department of the Navy, the Department of Defense, or the United States Government. No financial basis exists specifically related to this study.

*Corresponding author: Matthew T. Provencher, MD, MBA, MC USNR (ret), The Steadman Clinic, 181 W. Meadow Drive, Vail, CO 81657, USA.
E-mail address: mprovencher@thesteadmanclinic.com (M.T. Provencher).

https://doi.org/10.1016/j.jseint.2022.01.006

closest to the most inferior region of the glenoid, while Blueprint to the most superior one. Further research should assist in determining the version and inclination variations among commercial planning software.

Glenoid orientation assessment in the setting of glenohumeral osteoarthritis is essential in preoperative planning for either total shoulder arthroplasty (TSA) or reverse shoulder arthroplasty (RSA). Excessive glenoid retroversion has been shown to result in component loosening and clinical failure if not adequately recognized and addressed, though the threshold of retroversion is still debatable.[7,10,11,21,23] Excessive glenoid inclination can result in rotator cuff failure in TSA and can have a significant effect on biomechanics in RSA, potentially compromising outcomes.[11,14,18,24]

Though methods have been described to measure glenoid version and inclination on plain radiographs, computed tomography (CT) has been shown to be more accurate, especially with the use of 3-dimensional (3D) reconstruction or reformatting software.[4,5,15-17,20] The recent emergence of 3D preoperative planning software (PPS) and more widespread use of patient-specific instrumentation manufactured based on individual CT scans has been shown to improve recognition of complex glenoid deformity and thus improve implant placement and accuracy.[8,9,12,13,25,26]

There is, however, variability in the methods of 3D planning systems which include both fully automated volumetry-based systems as well as semiautomated systems which rely on the manual input of standard anatomic landmarks to then allow the software algorithm to generate the measurements.[1-3] A previous study evaluated differences in version and inclination between two commercially available PPS systems, Blueprint (Wright Medical, Memphis, TN, USA) and VIP (Arthrex, Naples, FL, USA), and found a 5° or greater difference in version and inclination in 30.2% and 46% of cases, respectively.[2] Even validated manual methods on 3D reconstructed or reformatted CT scans are not standardized as to the superior-inferior location of version measurement or anterior-posterior location of inclination measurement.

The purpose of this study is to locate the region on the glenoid at which inclination and version are measured on the PPS modalities of Blueprint and VIP. The hypothesis was that both systems would obtain values that associate with the manual measurements obtained from the central aspect of the glenoid.

Methods

Thirty consecutive patients who underwent TSA or RSA by the senior author between April 2018 and September 2020 with preoperative CT scans were retrospectively reviewed. Inclusion criteria included a preoperative CT scan which included the entire scapula with a minimum slice thickness of 1 mm, primary TSA for primary glenohumeral arthritis, or RSA for failed rotator cuff repair or rotator cuff arthropathy. Patients were excluded from the cohort if they underwent revision arthroplasty or did not have an adequate CT scan. Basic demographic data were recorded, and all patients were deidentified for analysis.

Patients underwent a glenohumeral CT scan with 0° gantry angle, 140-kVP strength, with minimum slice thickness of 1 mm. Field of view (FOV) included the entire scapula and proximal one-third of the humerus. All CT scans were uploaded into two different PPS systems to independently obtain glenoid version and inclination measurements utilizing each manufacture's protocol.

The first analysis was performed using VIP PPS (Arthrex, Naples, FL). This program relies on manual identification of scapular landmarks followed by digital measurement and is performed by a certified software engineer employed by the manufacturer. As previously described, Digital Imaging and Communications in Medicine (DICOM) CT scans are uploaded and reformatted into 3D images, the humerus is subtracted, and landmarks are identified on the scapula to include the scapula trigonum, the inferior angle, and the center of the glenoid to determine the plane of the scapula and transverse scapula line.[2,20] The plane of the glenoid is then determined by placing three landmarks on the glenoid fossa. This allows glenoid version and inclination to be calculated using a mid-glenoid approach and has been previously validated.[15]

The second analysis was performed using the Blueprint PPS (Wright Medical, Minneapolis, MN, USA). This automated software isolates voxels specific to the scapula using image recognition technology independent of a manual engineer input. A best-fit plane is then defined using these voxels to define the plane of the scapula, and similarly a best-fit sphere is defined to determine the glenoid rim. Version and inclination are then automatically calculated by using the software by comparing the best-fit plane of the glenoid to the horizontal and vertical planes of the scapula.

The CT scans were then independently analyzed by two board-certified orthopedic sports medicine surgeons with 11 years of cumulative independent practice experience utilizing open-source DICOM software OsiriX MD, version 12.0.0 64-bit (Pixmeo, Geneva, Switzerland). The deidentified images were uploaded into the software and reformatted using the OsiriX MPR 3D reformatting feature.

Image reformatting

OsiriX software allows the user to reformat standard 2-dimensional (2D) CT images into 3D equivalent sagittal, axial, and coronal images that can be simultaneously manipulated in all three planes. Altering one plane affects the other two and allows for more accurate orthogonal orientation of the scapula for obtaining both version and inclination measurements.

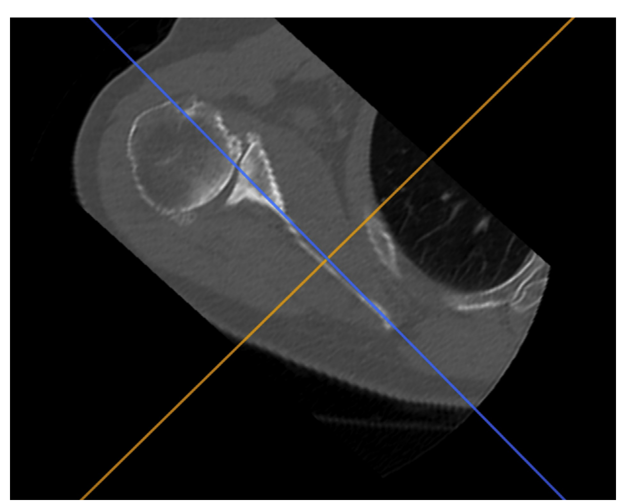

Figure 1 Two-diemnsional axial CT converted into MPR 3D format aligned in reference to the scapular plane. *3D*, 3-dimensional; *CT*, computed tomography.

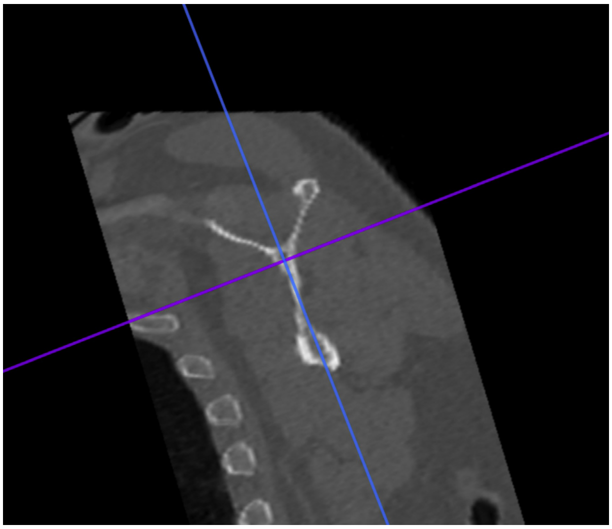

Figure 2 Sagittal CT image aligned with the vertical axis parallel to the vertical axis of the scapula. *CT*, computed tomography.

After converting the 2D images into MPR 3D format, the axial image was first aligned in reference to the scapular angle (Fig. 1). Next, the sagittal image was aligned with the vertical axis parallel to the vertical axis of the scapula (Fig. 2). This aligned the scapular body with the sagittal plane and thus allowed sequential measurements of glenoid version along the long axis of the glenoid from superior to inferior in a standardized method. Additionally, glenoid inclination measurements were standardized with the scapula aligned vertically for anterior to posterior inclination measurements.

Glenoid version measurement

Glenoid version was measured according to the method previously described by Friedman et al and utilized on 3D reformatted CT scans as described by Gross et al.[4,5] A line was drawn from the native anterior rim of the glenoid to the native posterior rim excluding osteophytes. A second line along the transverse axis of the scapula was then drawn from the center of the glenoid to the medial end of the scapula. The angle tool in OsiriX was used to determine the angle between the transverse scapula line and the glenoid (Fig. 3). Ninety degree was subtracted from this value with negative angles considered retroversion and positive angles considered anteversion. A total of 10 equally spaced measurements were obtained by each reviewer from superior to inferior starting 3 mm from the superior glenoid rim to 3 mm from the inferior glenoid rim.

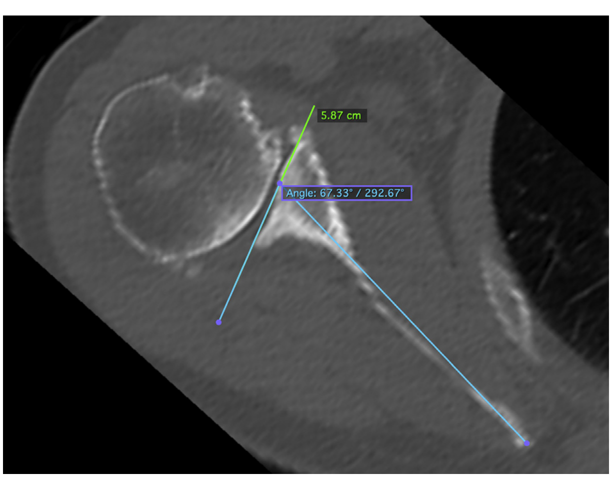

Figure 3 The angle tool in OsiriX used to determine the angle between the transverse scapula line (*blue*) and the glenoid (*green*). Ninety degree is subtracted from this value, with negative angles considered retroversion and positive angles considered anteversion.

Figure 4 The angle between the floor of the fossa (*blue*) and the glenoid (*green*) is measured using the angle tool in OsiriX. Ninety degree is subtracted from this measurement to obtain inclination values.

Glenoid inclination measurement

Glenoid inclination was measured utilizing the method described by Maurer et al due to its resistance to scapular rotation and good inter-rater reliability.[16] Using the corrected coronal images, a line was drawn from the native superior rim of the glenoid to the native inferior rim excluding osteophytes. A second line was drawn along the deepest point of the supraspinatus fossa which represents the floor of the fossa. The angle between the floor of the fossa and the glenoid was measured using the angle tool in OsiriX (Fig. 4); 90° was subtracted from this measurement to obtain inclination values. A total of 10 equally spaced measurements were obtained by each reviewer from anterior to posterior starting 3 mm from the anterior glenoid rim to 3 mm from the posterior rim.

Analysis

Descriptive statistics were obtained for all demographic data. Intraclass correlation coefficients were calculated to assess inter-rater reliability for version and inclination measurements performed by two independent raters. After confirming reliability, the average of the two raters' measurements was taken for each of the ten intervals along the glenoid across all 30 patients. The manual OsiriX measurements were compared to both the VIP and the Blueprint measurements by calculating the overall mean for each across all 30 patients, and a paired t-test was performed.

Root mean square error (RMSE) and both maximum and minimum differences between VIP and Blueprint, Osirix and VIP, and Osirix and Blueprint were calculated to evaluate the predictive reliability of the software programs.

A heat map was generated by dividing the glenoid face into four quadrants grouping the superior, upper middle, lower middle, and inferior interval measurements for version and similar anterior, middle anterior, middle posterior, and posterior interval measures for inclination (Fig. 5) using the 10 initial interval measurements.

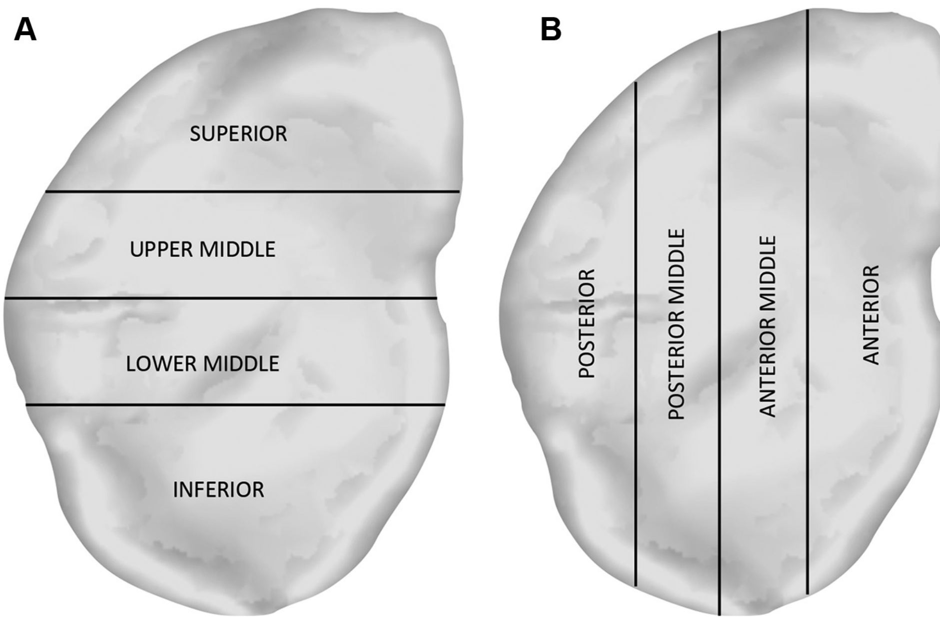

Figure 5 The glenoid face divided into four quadrants grouping the superior, upper middle, lower middle, and inferior measurements for version (**A**) and similar anterior, middle anterior, middle posterior, and posterior measures for inclination (**B**). The quadrants with measurements closest to the VIP and to the Blueprint measurement were identified to determine the region of the glenoid VIP and Blueprint obtained their measurements from.

The quadrant with the greatest number of measurements closest to the VIP and to the Blueprint measurement was identified to determine the region of the glenoid VIP and Blueprint obtained their measurements.

For each patient, the interval (1-10) which was closest to the VIP and to the Blueprint measurement was identified and recorded for both version and inclination and the median interval was calculated.

Statistical analysis was performed using SPSS (version 27.0; IBM Corp., Armonk, NY, USA).

Results

The mean patient age was 70.4 ± 6.5 (range: 55.9 to 86.8 years), with 19 (63%) male and 11 (37%) female. Eighteen (60%) underwent RSA, and 12 (40%) underwent TSA. Twenty (67%) were right shoulders, and 10 (33%) were left shoulders.

Intraclass correlation coefficients calculated for the two independent raters for both version and inclination measurements across all 30 shoulders averaged 0.921 for version and 0.917 for inclination, where >0.90 indicates excellent reliability. Inclination

Table I
Summary of interclass correlation coefficient calculated for two independent raters for 10 equidistant version and inclination measurements along the glenoid among 30 CTs.

Measurement interval	Version	Inclination
1	0.683	0.825
2	0.842	0.886
3	0.780	0.843
4	0.885	0.803
5	0.898	0.907
6	0.911	0.888
7	0.919	0.855
8	0.896	0.894
9	0.817	0.896
10	0.790	0.824
Average	0.921	0.917

CT, computed tomography.
1 is superior and 10 is inferior for version measurements; 1 is anterior and 10 is posterior for inclination measurements. Interpretation: <0.5: poor reliability; 0.5 to 0.75: moderate reliability; 0.75 to 0.9: good reliability; >0.90: excellent reliability.

Table II
Summary of mean version measurements across 30 patients using OsiriX, VIP, and Blueprint.

Patient	Osirix	VIP	Blueprint
1	−5.91	−2.5	−10
2	−13.37	−5.7	−8
3	−3.71	−2.6	−9
4	−23.23	−18	−24
5	−12.87	−20.3	−22
6	−10.38	−9.3	−15
7	−7.63	−4.1	−4
8	−7.54	−0.3	−3
9	0.58	−3.5	−1
10	−4.71	−0.8	−1
11	−23.61	−34.8	−36
12	−6.22	−5.8	−7
13	−4.73	−3.1	−3
14	−4.39	−5.4	−6
15	−18.32	−13	−18
16	−5.93	−6.8	−8
17	−14.58	−15.50	−18
18	−26.25	−24.9	−24
19	−20.84	−24.9	−24
20	−34.78	−31.5	−39
21	−22.23	−18.9	−28
22	−5.68	−9.1	−8
23	−18.68	−22.9	−24
24	−28.84	−27.7	−30
25	−20.20	−15.7	−20
26	−5.40	2.1	1
27	−13.29	−8.1	−16
28	−7.02	−1.1	−7
29	−16.07	−11.9	−22
30	−16.51	−19.7	−18
Average	−13.41	−12.19	−15.07

Negative values indicate retroversion, while positive values indicate anteversion.

Table III
Summary of mean inclination measurements across 30 patients using OsiriX, VIP, and Blueprint.

Patient	Osirix	VIP	Blueprint
1	5.06	9.1	6
2	8.95	10.2	9
3	−2.83	2.9	0
4	−6.75	−3	−5
5	5.96	6	5
6	17.74	21.7	20
7	3.56	7.2	3
8	0.60	11.1	4
9	5.77	8.4	4
10	5.34	9	6
11	−6.82	11.6	12
12	14.01	16.1	24
13	9.36	4.3	9
14	11.77	13.1	15
15	7.12	15	6
16	6.88	9.2	7
17	7.09	7.9	7
18	0.74	2.5	3
19	12.22	2.5	3
20	1.59	0.5	1
21	0.35	13.6	8
22	5.97	3.6	5
23	5.63	11.6	7
24	6.72	4.2	6
25	3.82	2.8	3
26	1.72	5.3	1
27	8.23	20	1
28	12.03	18.3	21
29	5.87	8.5	12
30	8.35	15.9	10
Average	5.54	8.97	7.10

Negative values indicate retroversion, while positive values indicate anteversion.

measurements were consistent across all 10 measurement points, while version was most consistent in the central measurements. See Table I for complete inter-rater reliability data.

Cumulative measurements

Among the 30 preoperative CTs, mean glenoid version manually recorded using OsiriX by combining data across all 10 measurements was 13.5° retroversion (range = 0.6 anteversion to 34.8 retroversion), compared with 15.1° retroversion (range = 1 anteversion to 39 retroversion) recorded by Blueprint (P = .516) and 12.2° retroversion (range = 2.1 anteversion to 34.8 retroversion) by VIP (P = .621). Mean inclination manually recorded using OsiriX was 5.5° (range = -6.8 to 17.4), compared with 7.1° (range = −5 to 24; P = .314) and 9.0° (range = −3.0 to 21.7; P = .024) recorded by Blueprint and VIP, respectively. The only statistically significant difference found between manual measurements and the two software systems was inclination measured by VIP. Version measurements for all 3 measurements were within 5° in 14 of 30 (47%) patients. Inclination measurements were within 5° in 19 of 30 (63%) patients. See Tables II and III for a summary of data across all 30 patients.

Variance between systems

RMSE for version between Osirix and VIP was 4.65° (min = 0.4°, max = 11.2°), for Osirix and Blueprint was 4.44° (min = 0.0°, max = 12.4°), and for VIP and Blueprint was 4.45° (min = 0.1°, max = 10.1°). RMSE for inclination between Osirix and VIP was 6.43° (min = 0.0°, max = 18.4°), for Osirix and Blueprint was 5.25° (min = 0.1°, max = 18.8°), and for VIP and Blueprint was 5.13° (min = 0.2°, max = 19.0°). Figure 6 displays the distribution of differences for the 30 individual cases.

Heat map analysis showed VIP measurements most frequently aligned with the inferior quadrant of the glenoid (n = 13), while Blueprint aligned with the superior quadrant of the glenoid (n = 13) for version. Inclination measurements aligned with the posterior quadrant of the glenoid for both VIP (n = 19) and Blueprint (n = 15). Complete data are illustrated for both VIP and Blueprint measurement locations in Figure 7.

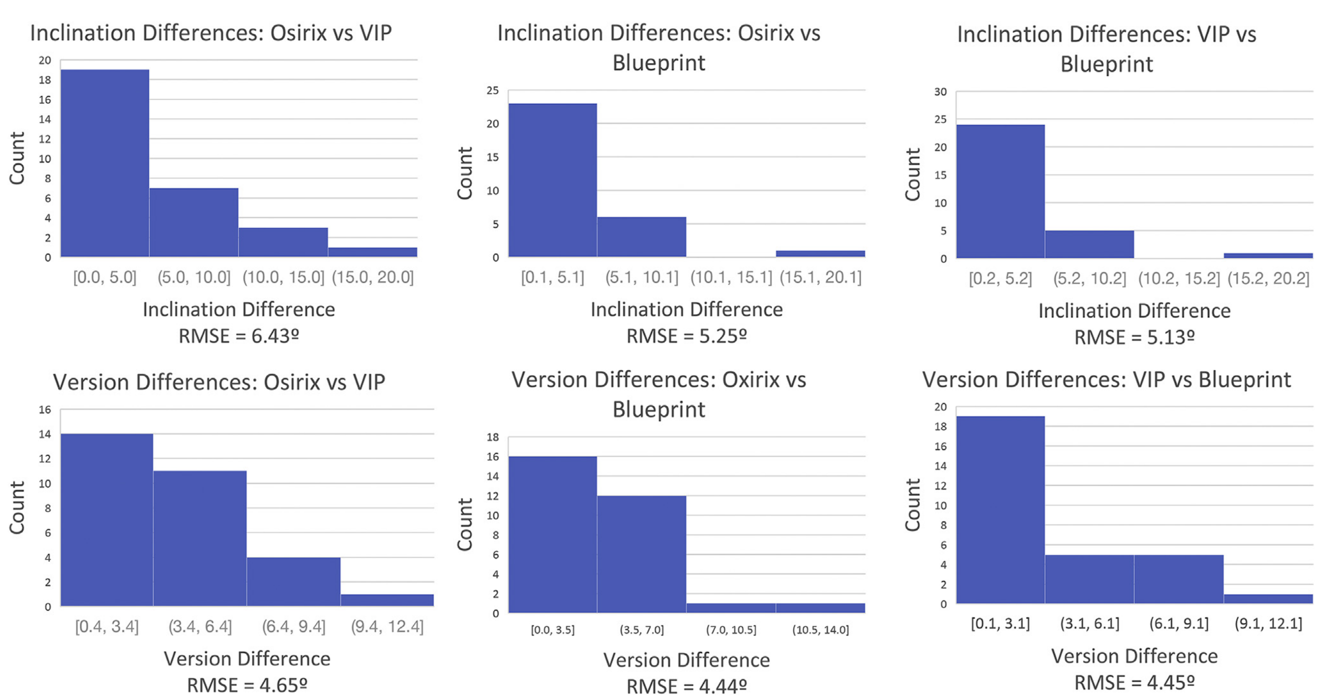

Figure 6 Histograms comparing the range of differences in both version and inclination measurements between the manual OsiriX measurements, VIP, and Blueprint. The majority were within the root mean square error (*RMSE*) values for each comparison with few outliers.

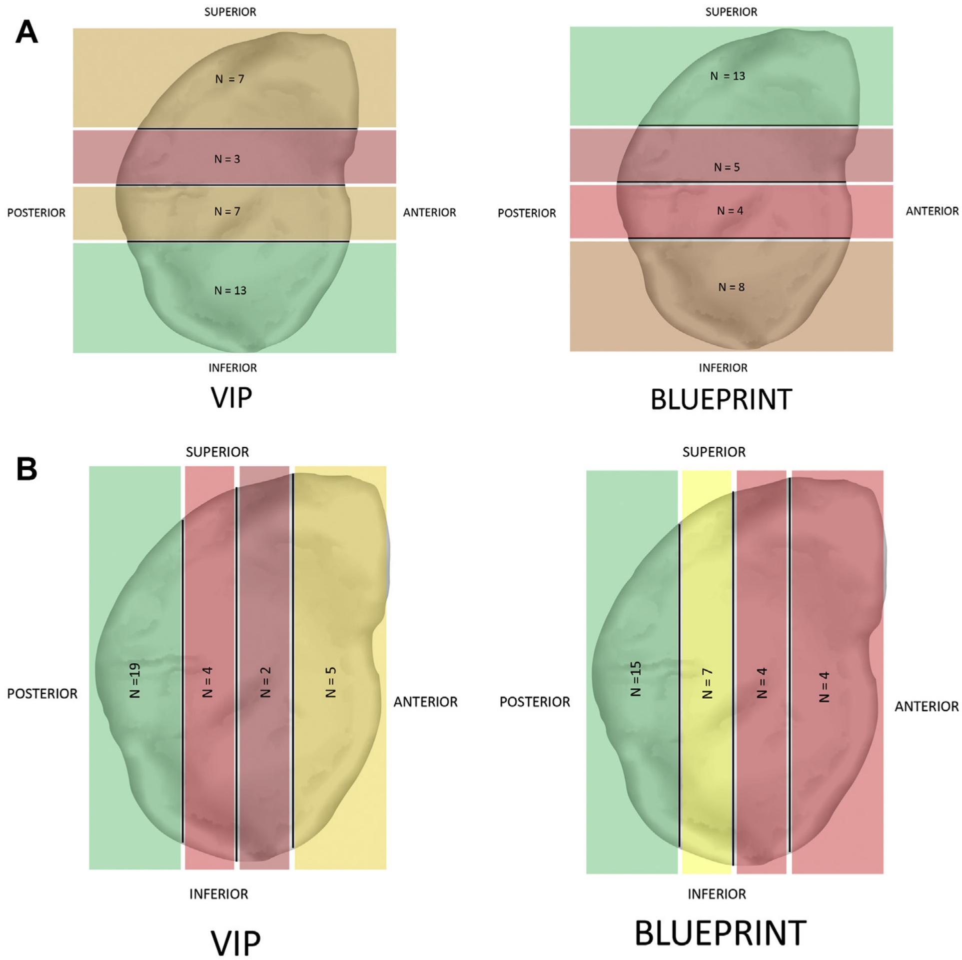

Figure 7 Heat map illustrating the density of manual measurements which VIP and Blueprint corresponded to for the 30 shoulders for both glenoid version (**A**) and glenoid inclination (**B**). VIP favored the inferior quadrant, while Blueprint favored the superior quadrant for version. Both VIP and Blueprint favored the posterior quadrant for inclination.

The median location for which VIP version measurements corresponded with manual measurements was at interval 7 compared to that of Blueprint which was at interval 4 (Fig. 8, *A*). For inclination, the median location for both VIP and Blueprint was interval 8 (Fig. 8, *B*).

Discussion

The findings of the current study do not support our hypothesis that both Blueprint and VIP systems would correlate with the manual measurements obtained from the central aspect of the glenoid. Glenoid version measurements favored the inferior region of the glenoid for VIP software with median version at interval 7, while Blueprint measurements favored the superior region with median version at interval 4. Inclination measurements were more consistent across both software programs' measurements, favoring the posterior quadrant both at interval 8. These findings not only demonstrate variability in the region of the glenoid in which measurements are obtained but also in the glenoid version and inclination measurement outputs by the two systems studied and manually obtained measurements.

The secondary finding of this study is that in this cohort of 30 patients, there is variability in the average output of the software systems for version and inclination compared with the combined data of the 10 glenoid measurements. Reported retroversion appears to increase as the amount of data input increases. The approach based on the center of the glenoid, as used by VIP, resulted in the lowest amount of retroversion. Retroversion increased with the use of 10 locations used and even further with a best-fit circle technique as used in Blueprint. Both VIP and Blueprint tend to measure increased inclination compared to manual measurements. Version and inclination measurements between the three methods were within 5° in 47% and 63% of patients, respectively, which is similar to the findings from Denard et al, who found a less than 5° difference between VIP and Blueprint in 69.8% for version and 54.0% for inclination.[2] Another similar study looked at the differences between four commercially available software planning systems and compared these to manual surgeon measurements for version, inclination, and posterior subluxation. They found that the software programs measured increased inclination and increased retroversion compared to manual measurements and that manual measurements between surgeons had less variability than between software programs.[3] The variability in the averages of this cohort taken as a whole are quite small, with the RMSE ranging from 4.44° to 4.65° for version and 5.13° to 6.43° for inclination. This represents a difference of a few degrees and is likely an acceptable clinical variability range with regards to implant positioning. Though most measurement differences fall within this range, the individual differences of a few of the patients as displayed in Figure 6 are significant which could have considerable implications for preoperative planning, patient-specific instrumentation, and final implant positioning.

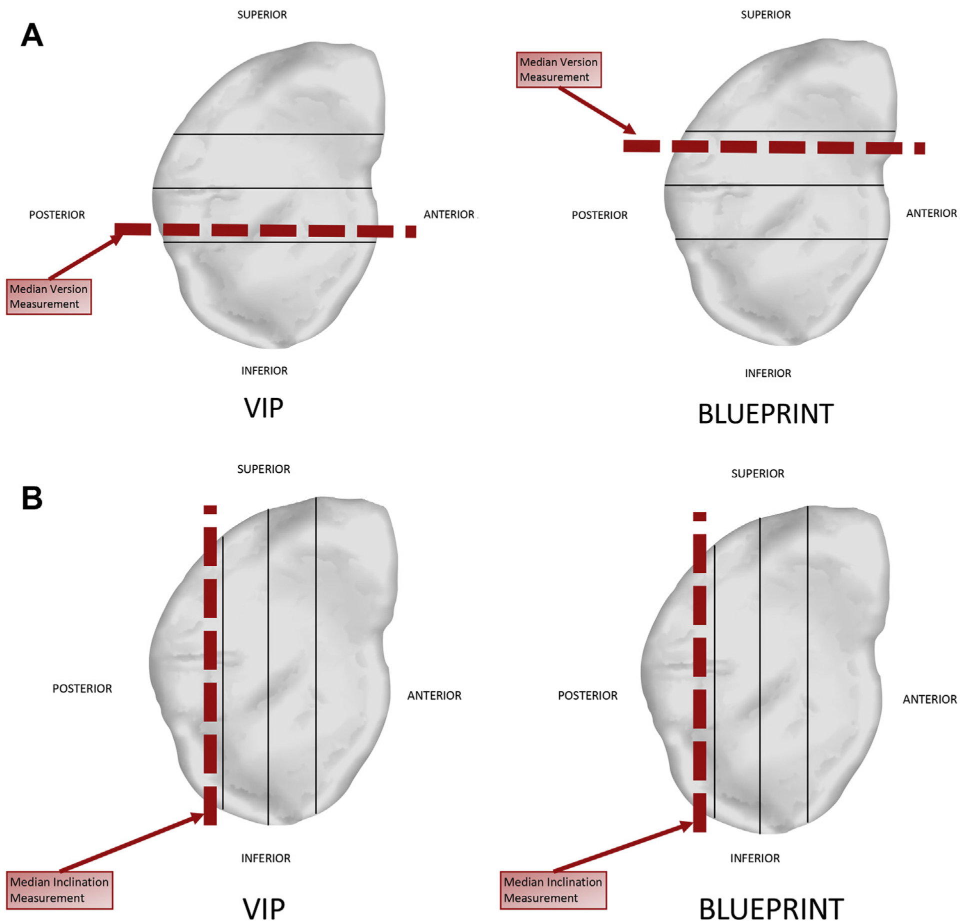

Figure 8 Dotted red line represents the median location for which software measurements corresponded with manual measurements. Version median (**A**) was at interval 7 for VIP compared to interval 4 for Blueprint. Inclination median (**B**) was at interval 8 for both VIP and Blueprint.

With regards to manual measurement accuracy, intraclass correlation coefficients were highest in the center of the glenoid with respect to anterior-posterior positioning on reformatted 3D CT scans for version. Version measurements taken at interval 5, which is the center of the glenoid, closely matched the overall version average across all 10 measurements. Inclination measurement accuracy was fairly consistent throughout the glenoid from superior to inferior, with the measurements taken at interval 4 closely matching the average across all intervals; however, the measurements taken at intervals 4-9 are all within 1 degree of each other and the average which is consistent with VIP and Blueprint favoring the posterior quadrant. These findings indicate version should be measured as close to the center of the glenoid on reformatted 3D CT imaging as possible and inclination should be measured at the center to posterior half. Our findings are similar to those of other studies which found both high intrarater and inter-rater reliability[1,3,19]; however, Reid et al found that when comparing 2D to 3D CT scans, 3D scans were more likely to return a more retroverted measurement.[19]

The recent emergence of 3D PPS and more widespread use of patient-specific instrumentation manufactured based on individual CT scans has been shown to improve recognition of complex glenoid deformity and thus improve implant placement and accuracy.[8,9,12,13,22,25,26] Conversely, Hartzler et al[6] demonstrated a possible cognitive bias when using PPS and less agreement with the initial preoperative plan with increased complexity of deformity, especially retroversion, and with increased surgeon experience. While advances in CT imaging software have been developed to assist with the accuracy and efficiency of preoperative shoulder arthroplasty planning, there exists a paucity of literature that examines the discrepancy between such 3D automated systems in relation to the region along the glenoid where version and inclination are measured. While both VIP and Blueprint are accepted as reliable preoperative imaging modalities, the methods used to obtain version and inclination measurements are distinct. The current study's findings suggest that the two approaches do not assess glenoid version and inclination along the same region of the glenoid. This may be attributed to the differences in establishment of the scapular plane (Friedman's line versus average scapular plane) and glenoid plane (center point versus best-fit sphere).

There are limitations to the current study. The relatively small patient cohort may have limited our glenoid regional analysis for software program measurements. Additionally, we only compared the manual measurements to two software programs, and thus, these findings are not applicable to all shoulder arthroplasty systems and their associated PPS programs.

The variance in the region of glenoid inclination and version measurements between the two imaging modalities has substantial implications for the future use of advanced preoperative 3D planning software in the setting of shoulder arthroplasty. While prior literature supports the accuracy of such software modalities, the current study suggests that the region where anatomic glenoid measurements are taken may not be consistent between the two. Understanding these differences is important when interpreting clinical findings as well as during preoperative planning.

Conclusion

PPS systems for shoulder arthroplasty vary in the region of the glenoid for which version and inclination are measured, which may affect the absolute values generated. Location of version measurement was different among the two commercial software programs, with VIP corresponding the closest to the most inferior region of the glenoid while Blueprint the most superior. Further research should assist in determining the version and inclination variations among commercial planning software.

Disclaimers:

Funding: No funding was disclosed by the authors.
Conflicts of interest: Dr. Romeo is a consultant and receives royalties and speaker fees from Arthrex, Inc. Dr. Provencher receives royalties and is a consultant for Arthrex, Inc., is a consultant for JRF, and receives royalties from Elsevier, Inc. The other authors, their immediate families, and any research foundation with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

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