Reliability and accuracy of 3D preoperative planning software for glenoid implants in total shoulder arthroplasty

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ABSTRACT

Background: Shoulder arthroplasty is technically demanding and can be associated with failures due to implant loosening, especially in the presence of posterior glenoid bone loss. Novel preoperative planning has been employed more frequently in an attempt to improve implant positioning, however, there is little data comparing the effectiveness of various systems for shoulder arthroplasty. Our goal was to assess the reliability and validity of preoperative planning software systems for measurements and implant selection.

Methods: A retrospective analysis was done of 80 patients who underwent total shoulder arthroplasty. Preoperative computed tomography studies were used to create a preoperative plan using 3 software systems: independent preoperative plan software (IPPS) and 2 automated manufacturer preoperative simulation (AMPS I and II). We collected preoperative native and implant version and inclination and implant size from each software. Simulated plans of each patient were compared to one another.

Results: The mean age of our population was 61 years old (±12), 51.3% females and 48.8% males. The mean native version measured by IPPS was −9.1° ± 11.3°, by AMPS I was −11.7° ± 8° and by AMPS II software was −11° ± 13.4°. The mean native inclination for IPPS was 4.7° ± 6.8°, for AMPS I was 10.4° ± 5.9° and for AMPS II software was 7.76° ± 7.2°. The mean implant version for IPPS was −4.8° ± 6.5°, for AMPS I was −6.73° ± 2.6° and for AMPS II software was −5.4° ± 5°. The mean implant inclination suggested by IPPS was 2.04° ± 4.4°, by AMPS I was 3.5° ± 3.2°, and by AMPS II software was 7.04° ± 7.2°. Five of 14 comparisons resulted in statistically significant differences. Our results demonstrated strong positive correlations (r > 0.7) between AMPS I and AMPS II for Native Version and Implant Inclination. When implant diameter/size was compared between IPPS and AMPS II, AMPS I and AMPS II, we found a matching rate of 66.7% and 100%, respectively.

Conclusion: Our results support the use of either independent or commercially available preoperative simulation software to reliably measure pathology and accurately guide intra-
Total shoulder arthroplasty (TSA) has demonstrated excellent long-term clinical outcomes for the treatment of severe osteoarthritis (OA). TSA provides reduction of shoulder pain, additionally, anatomic resurfacing allows for functional restoration of the rotator cuff and deltoid.2,19,25,26 Patients with intact rotator cuff function, an anatomic TSA is often considered optimal implant selection to maintain the direction of forces generated by rotator cuff muscles and deltoid contractions. This maintains the primary functionality of these muscles. In reverse shoulder arthroplasty (RSA), the center of rotation is medialized which does not rely on rotator cuff muscles as much and recruits deltoid for earlier abduction at the expense of external rotation. This changes the muscles primary functions.18 Severe OA is frequently associated with progressive posterior humeral head subluxation and posterior glenoid bone loss.5,7,8,19,22,26 Unfortunately, increased glenoid retroversion and/or bone loss has been associated with sub-optimal outcomes TSA.6,24

The main challenge with anatomical TSA is implant positioning (version and inclination), which significantly affects glenoid implant component survival over time.5,16 Therefore, it is considered desirable to correct glenoid retroversion and inclination prior to placement of a glenoid component for total shoulder arthroplasty.19 In order to achieve optimal surgical results, careful preoperative planning is required.8 A surgeon’s determination of how to correct for pathologic glenoid version is influenced by a combination of surgical experience, judgment and preoperative imaging studies. For example, the surgeon may choose to correct by reaming the “high side” or by correcting for extreme bone loss via a graft or an augmented component.5

The use of simulation software to understand the biomechanics of implant positioning with respect to glenoid vault and version has been recently reported in the literature. Furthermore, preoperative planning with three-dimensional (3D) computed tomography (CT) imaging clearly provides advantages in accurately assessing: glenoid retroversion, guidance of surgical technique, implant selection, optimization of implant positioning,6,20 bone graft sizing and positioning, central post/screw and peripheral screw positioning, and screw length.26 To fully realize the best-fit glenoid implant for each specific patient, a computerized preoperative planning software making use of 3D CT-based models of the glenoid with properly sized implants would be used.13 The use of the visual information provided by software simulations at the time of surgery significantly improves the ability of experienced shoulder arthroplasty surgeons to reproduce final implant position.10 The literature has shown that accuracy of implant placing improves with 3D CT imaging preoperative planning especially with implant templating and patient specific instrumentation.5,19 It has been noted in the literature that the most influential factor for accuracy of implant placement is the 3D CT preoperative planning.5,10 Both in bone models and actual surgical procedures, surgeons demonstrated improved glenoid orientation with the use of preoperative planning software to guide implantation of the glenoid component.1,14,25 Iannotti et al10 showed an increase in the ability to place the glenoid component within 5° of desired inclination and 10° of desired version with 3D templating and computer planning, compared to standard techniques in a randomized controlled trial.26 Additionally, Berhouet et al1 demonstrated that when using preoperative planning software to visualize the entire scapula, the surgeons were able to place the glenoid component within 0.3° and 0.1° of desired version and tilt respectively, with less glenoid vault perforations.

No universal guidelines are available to define normal thresholds for glenoid version. However, glenoid retroversion greater than 5° may compromise the stability of the shoulder.7 The purpose of this study was to compare 3 available preoperative planning software programs to determine the accuracy and variability of measurements and implant selection for the glenoid side in TSA.

Materials and methods
A retrospective review was performed to include 80 patients with preoperative CT scans indicated for total shoulder arthroplasty performed by a single fellowship-trained shoulder surgeon. CT studies of each patient were uploaded to create an anatomic TSA preoperative plan using 3 different shoulder arthroplasty software systems. All CT studies followed specific protocol (120 kV, 140 mAs, 0.6-mm collimation, 512 × 512 matrix, no gantry tilt, and 50-cm field of view) to allow for uploading into specific software which required fine cuts and the entire scapula to be included. Images were reconstructed with use of a semismooth algorithm, B40, at 0.75-mm increments in the axial plane as minimum requirements in order to be eligible for planning.13 OrthoVis (Custom Orthopaedic Solutions Inc., Cleveland, OH, USA) which is a validated independent preoperative planning simulation software (IPPS, Fig. 1) was compared to available plans for 2 automated manufacturer preoperative simulations (AMPS) plans: Arthrex Virtual Implant Positioning (Arthrex Inc., Naples, FL, USA; AMPS I, Fig. 2) and Tor nier Blueprint 3D Planning (Wright Medical Inc., Memphis, TN, USA; AMPS II, Fig. 3). A review of hospital electronic medical records was performed to identify procedure type, manufacturer, and glenoid size implanted.

For IPPS, the surgeon defines the plane of the scapula and glenoid with 3 points, one placed at the inferior angle of the scapula body, a second at the scapula trigonum, and the third in the center of the glenoid fossa. A line drawn from the center of the glenoid fossa to the scapula trigonum is in the center of the glenoid vault. A plane that best represented the

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overall version and inclination of the glenoid fossa was defined by placing 3 points on the glenoid articular surface; these points were approximated to the superior glenoid, the anterior inferior glenoid, and the posterior inferior glenoid, in the area of greatest bone loss to provide the most accurate reflection of glenoid plane. The measured retroversion angle is calculated as the angle between the plane of the scapula and plane of the glenoid and using the glenoid vault model. Information provided by this software program includes native version and inclination, as well as, type, size, version, inclination, and roll of the implant.

For AMPS I, 3D preoperative plan was devised based upon standard set forth algorithm by manufacturer reviewed by engineers using the CT scan protocol, which was sent to the surgeon for revision/approval. The plan contained information on the native anatomy (version and inclination), implant version and inclination, type, size and roll of the implant, and selected and confirmed by the surgeon.

For AMPS II, CT scans were uploaded by the surgeon in order to design a preoperative plan. The software measured, in degrees, native version and inclination. The surgeon can select implant type, size, radius, version, inclination, and
amount of medialization to determine the percentage of back seating. We had no access to the algorithms in both automated manufacturer systems used to determine the planes of the scapula and glenoid. In addition, both manufacturers have the option of ordering patient-specific instrumentation if needed based on the preoperative plan.

IPPS is an independent and well-validated software program. All simulated anatomic and implant measurements were performed manually by a senior surgeon with extensive planning experience, therefore, this was considered the gold standard based on surgeon defined measurements. Preoperatively, 3D virtual planning software provided an automated plan of bony pathology and proposed implant size and positioning. The senior surgeon then reviewed the automated plan, making appropriate edits and fine-tuning implant size, selection, and positioning. Intraoperatively, the surgeon reviewed but was not bound by these preoperative plans. The final selection was always based on the surgeon’s expertise and intraoperative assessments when gaging bone quality, soft tissue balancing, patient specific anatomy, and optimal recreation of glenohumeral biomechanics.

**Statistical analysis**

Statistical analyses included demographics of patient population studied and paired sample t test to compare the means version and inclination of pathologic glenoid and glenoid implant. Accuracy was determined for a perfect match and within ± one size. Mean difference was determined by calculating difference between measurements on a case by case basis which was then averaged. In addition, descriptive statistics were employed to assess accuracy of glenoid implant size prediction. Pearson’s correlation coefficients (r values) were used to measure the strength of the correlation between the IPPS and AMPS I and II for version and inclination measurements obtained with planning systems (Fig. 4). A P value ≤.05 was considered statistically significant and SPSS Software (IBM Corp. Released 2016; IBM SPSS Statistics for Macintosh, Version 24.0. Armonk, NY, USA) was used for all statistical analysis.

**Results**

The mean age of our population was 61 years old (±12), 51.25% females and 48.75% males. The mean native version measured by IPPS was −9.1° ± 11.3°, by AMPS I was −11.7° ± 8°, and by AMPS II software was −11° ± 13.4°. The mean native inclination reported by IPPS was 4.7° ± 6.8°, by AMPS I was 10.4° ± 5.9° and by AMPS II software was 7.76° ± 7.2°. The mean implant version measured by IPPS was −4.8° ± 6.5°, by AMPS I was −6.73° ± 2.6° and by AMPS II software was −5.4° ± 5°. The mean implant inclination by IPPS was 2.04° ± 4.4°, by AMPS I was 3.5° ± 3.2° and by AMPS II software was 7.04° ± 7.2° (Table 1).

The average differences and correlations for each test among the software systems are summarized in Tables 2 and 3. The assessments were reliable for native version and inclination for AMPS II and native version for AMPS I when compared to IPPS (Table 2), however, there was a significant difference in measured glenoid inclination for AMPS I when compared to IPPS (P = .039). There was a strong positive correlation between IPPS and AMPS I for implant version (r ≥ 0.7) and a moderate positive correlation for implant inclination (r ≥ 0.6; Fig. 5). There was no strong agreement between AMPS II and IPPS for glenoid implant version and inclination when comparing the preoperative planning software systems. The lowest average difference was found to be between the IPPS and AMPS I for Implant Inclination (0.062° ± 3.10°; P = .937) and the highest average difference was between AMPS I and AMPS II for Implant Inclination (5.562° ± 5.15°; P ≤ .001).

With regards to accuracy of software to predict actual intraoperative implant size selected, AMPS I and AMPS II had a prediction rate of 100% and 67% for perfect match rate, respectively. AMPS II showed 88% matching rate within one size above or below (Fig. 4).

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**Fig. 3** – Tornier Blueprint 3D planning software (AMPS II, Automated Manufacturer Preoperative software).

**Fig. 4** – (a) Reliability assessment of native version and inclination, planned implant version and inclination, between AMPS I and II compared to IPPS, (b) Accuracy assessment of planned glenoid size using AMPS I and II compared to actual implants used. *IPPS, Independent Preoperative Planning Software; AMPS I and II, Automated Manufacturer Preoperative Software I and II.*
retroversion. However, the optimal degree to which glenoid version should be corrected is still under debate. Some authors recommend glenoid positioning to be adjusted to the patient’s premorbid version, while others advocate for orientation perpendicular to the scapular plane.\(^{27}\) Glenoid component retroversion greater than 10° has been attributed to increased micromotion at the bone-to-cement interface.\(^{27}\) Glenoid retroversion of 15° has been associated with increased contact pressure and an increased risk of glenoid loosening. Therefore, careful preoperative planning is essential for accurate preparation and execution of the optimal surgical plan.\(^{1,6,8,10,23}\)

Our cohort represents a target population that aligns with the current literature regarding age and gender and our results demonstrated no statistically significant difference among all 3 software systems in regards to glenoid native version.\(^{3}\) Since we utilized the same CT scan data inputted into the 3 different systems, these results were expected. Although when we looked at glenoid native inclination, we found variations between the software systems. This finding likely indicates a difference in measurement parameters, landmarks, or implant parameters between the software programs. Chalmers et al.\(^{2}\) found when there was a correction of 2D CT slice axis into the plane of the scapula, this decreased variations in measured glenoid retroversion (mean, 2.5°) and inclination (mean, 21°). In 48% of cases, the change in version was >5° and in 94% of cases, the change in inclination was >5°. Variability between subjects was slightly lower in the corrected measurements in comparison to uncorrected measurements for almost all variables, possibly because of the creation of a homogeneous reference plane. These results support correction of 2D CT slice axis into the plane of the scapula for accurate measurement of version and inclination. Automated software measurements more closely mirrored corrected glenoid version and inclination given the use of 3D imaging. This supports the use of any of the 3D preoperative planning softwares available as they all correct for the plane of the scapula and provide more accurate measurements.

Apart from understanding the patient’s native anatomy, the suggested implant positioning made by each software program is another important piece of information considered by a surgeon when planning a shoulder arthroplasty. No statistically significant difference was found among all 3 software systems considering the final glenoid implant version and inclination.\(^{38}\) This similarity between systems addresses an important intraoperative issue. Surgeons can now trial various implant positions preoperatively and be confident in the accuracy of the software which is substantial in the determination of the ideal position for the implant.\(^{15}\) This is especially important as researchers have demonstrated that the

Table 1 – Mean glenoid measurements for all 3 software systems.

<table>
<thead>
<tr>
<th></th>
<th>Average native version</th>
<th>Average native inclination</th>
<th>Average implant version</th>
<th>Average implant inclination</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPPS</td>
<td>-9.1° ± 11.3°</td>
<td>4.7° ± 6.8°</td>
<td>-4.8° ± 6.5°</td>
<td>2.04° ± 4.4°</td>
</tr>
<tr>
<td>AMPS I</td>
<td>-11.7° ± 8°</td>
<td>10.4° ± 5.9°</td>
<td>-6.73° ± 2.6°</td>
<td>3.5° ± 3.2°</td>
</tr>
<tr>
<td>AMPS II</td>
<td>-11° ± 13.4°</td>
<td>7.76° ± 7.2°</td>
<td>-5.4° ± 5°</td>
<td>7.04° ± 7.2°</td>
</tr>
</tbody>
</table>

IPPS, Independent Preoperative Planning Software; AMPS I, II, Automated Manufacturer Preoperative Software I and II.

Table 2 – Reliability assessment of automated systems simulation compared to IPPS based on paired samples t tests.

<table>
<thead>
<tr>
<th></th>
<th>Mean difference (degrees)</th>
<th>Pearson correlation (r)*</th>
<th>P value(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPPS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AMPS I</td>
<td>0.9°</td>
<td>0.8</td>
<td>.467</td>
</tr>
<tr>
<td>AMPS II</td>
<td>0.5°</td>
<td>0.5</td>
<td>.682</td>
</tr>
<tr>
<td>AMPS I</td>
<td>3.1°</td>
<td>0.6</td>
<td>.039</td>
</tr>
<tr>
<td>AMPS II</td>
<td>1.6°</td>
<td>0.3</td>
<td>.134</td>
</tr>
</tbody>
</table>

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* r: Pearson correlation. Strong positive correlation ≥ 0.7. Moderate positive ≥ 0.5.
1 P value: significant at the .05 level and below (2-tailed).

Table 3 – Pearson correlations of glenoid position (version and inclination, in degrees) between systems obtained with IPPS, AMPS I, and AMPS II preoperative planning software systems.

<table>
<thead>
<tr>
<th></th>
<th>Mean difference (degrees)</th>
<th>Pearson correlation (r)*</th>
<th>P value(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPPS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AMPS I</td>
<td>0.1°</td>
<td>0.7</td>
<td>.811</td>
</tr>
<tr>
<td>AMPS II</td>
<td>0.2°</td>
<td>0.3</td>
<td>.777</td>
</tr>
<tr>
<td>AMPS I</td>
<td>0.7°</td>
<td>0.6</td>
<td>.258</td>
</tr>
<tr>
<td>AMPS II</td>
<td>3.5°</td>
<td>0.4</td>
<td>≤.001</td>
</tr>
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Discussion

Shoulder arthroplasty is a surgical option to treat end stage osteoarthritis with excellent long-term clinical outcomes. To achieve optimal results for TSA it is important to identify and quantify preoperative posterior glenoid retroversion and bone loss. By doing so, the surgeon is able to effectively reestablish the biomechanics of the shoulder and correct glenoid

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rate of failure or poor outcomes in patients with severe glenoid wear, that was uncorrected at the time of total shoulder replacement for osteoarthritis, was increased (more than 2.5 times) compared with the rate for patients in whom glenoid wear was corrected.11,12,17

When we analyzed implant inclination our results showed a statistically significant difference only between IPPS and AMPS II. IPPS and AMPS II showed a weak positive correlation as opposed to the 2 automated systems that showed no significant difference (P > .05) and a moderate positive correlation. Each program uses implant size/diameter based on their manufacturer references and their specific implant designs which accounts for some of the variations in implant measurements. Surgeons can put these results in context when using the plans for optimal implant placement the superior-inferior plane.

Besides the similarity among software systems, the accuracy of the plan is of great value. We found the implant selected by the surgeon intraoperatively matched 100% and almost 70% between implant size suggested by AMPS I and AMPS II respectively (Fig. 6). We used these measurements to assess the accuracy of each software’s preoperative plan when compared to a blinded surgeon’s intraoperative decision-making. Intraoperatively, there is likely to be more trialing of various implant sizes that could be avoided with the use of adequate preoperative plans and mapping of deformities through version and inclination measurements. Inadequate understanding of deformities and pathology may lead to less than ideal implants and positioning to correct pathology or may take more time to assess and select these appropriate implants. Narrowing down or optimizing the surgeon’s implant selection using preoperative simulation software has

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Fig. 5 – Strong positive correlations between IPPS and AMPS I, for native glenoid and glenoid implant version. 'IPPS, Independent Preoperative Planning Software; AMPS I and II, Automated Manufacturer Preoperative Software I and II.

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Fig. 6 – For accuracy of implant size prediction, AMPS I showed a perfect match in 100% of the cases*. AMPS II showed a perfect match in 67% of the cases and 88% within one size up or down**.

*AMPS I, Automated Manufacturer Preoperative Software I, 4 cases included.
**AMPS II, Automated Manufacturer Preoperative Software II, 9 cases included.
potential to reduce hospital costs by decreasing the number of instrument trays, decreasing sterilization costs, using less hospital resources (instrument tables, laps), and decreasing OR time which ultimately may affect patient outcomes.

The strengths of this study include using an independent surgeon directed software system and comparing glenoid measurements to 2 automated manufacturer’s preoperative planning systems. Although novel comparison to independent software systems was a strength, osteophytes and quality of the CT scan are variables that affect automated software reading when the planes of the scapula and the glenoid are yet to be defined and may explain some of the variances observed. Additionally, even though we had all our patients scanned under the same protocol (same hospital), all of the CT scans selected were able to be used by one software or another without errors but may have not met criteria for all the software systems. This may not be true for all surgical cases and at times imaging quality can be a limitation. Although we could not directly account for these variations, by comparing a large cohort of cases, these variations were minimized and accounted for in our statistical analyses. Furthermore, the preoperative planning simulations of each system were blinded to the surgeon so that none of the previous results affected the surgeon’s judgment in managing the different systems. Since we did a retrospective analysis the use of simulation didn’t influence the surgeon’s choice regarding the actual implant selected.

Conclusion

Our results support the use of either independent or commercially available preoperative simulation software. These software’s reliably measure pathology and accurately guide intraoperative implant selection. Notwithstanding, some manufacturer’s software (AMPS II) provide more critical data which enhances precision in implant placement and correction of pathologic bone loss. These outcomes demonstrated reliability and accuracy for preoperative planning simulation, assisting surgeons in selecting proper implant size and positioning.

Disclaimer

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REFERENCES


