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Assessment of surgeon variability in preoperative planning of reverse total shoulder arthroplasty: a quantitative comparison of 49 cases planned by 9 surgeons

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Background: Preoperative planning software is gaining utility in reverse total shoulder arthroplasty (RTSA), particularly when addressing pathologic glenoid wear. The purpose of this study was to quantify inter- and intrasurgeon variability in preoperative planning a series of RTSA cases to identify differences in how surgeons consider optimal implant placement. This may help identify opportunities to establish consensus when correlating plan differences with clinical data.
Methods: A total of 49 computed tomography scans from actual RTSA cases were planned for RTSA by 9 fellowship-trained shoulder surgeons using the same platform (Exactech GPS, Exactech Inc., Gainesville, FL, USA). Each case was planned a second time 6-12 weeks later. Variability within and between surgeons was measured for implant selection, version correction, inclination correction, and implant face position. Interclass correlation coefficients, and Pearson and Light's kappa coefficient were used for statistical analysis.
Results: There was considerable variation in the frequency of augmented baseplate selection between surgeons and between rounds for the same surgeon. Thresholds for augment use also varied between surgeons. Interclass correlation coefficients for intersurgeon variability ranged from 0.43 for version, 0.42 for inclination, and 0.25 for baseplate type. Pearson coefficients for intrasurgeon variability were 0.34 for version and 0.30 for inclination. Light's kappa coefficient for baseplate type was 0.61.
Conclusions: This study demonstrates substantial variability both between surgeons and between rounds for individual surgeons when planning RTSA. Although average differences between plans were relatively small, there were large differences in specific cases

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suggesting little consensus on optimal planning parameters and opportunities to establish guidelines based on glenoid pathoanatomy. The correlation of preoperative planning with clinical outcomes will help to establish such guidelines.
Level of evidence: Level III; Diagnostic Test Study

Keywords: Reverse total shoulder; preoperative planning; intersurgeon variability; intrasurgeon variability; glenoid retroversion; glenoid inclination; augmented glenoid

Originally indicated for classic cuff tear arthropathy with pseudoparalysis, reverse total shoulder arthroplasty (RTSA) is now routinely used for irreparable rotator cuff tears,[21] cuff-deficient arthritic shoulders,[4,15] inflammatory arthropathy,[7,19] proximal humerus fractures,[8,22] fracture sequelae,[20] and oncologic reconstruction.[3,4] Its prevalence continues to increase, in part due to widening indications, but also because its use in primary osteoarthritis in elderly patients and those with advanced glenoid wear has increased. A recent survey of the American Shoulder and Elbow Surgeons demonstrated that 84% of 176 respondents report performing RSTA more commonly than anatomic total shoulder arthroplasty and 86% agreed that RTSA is more tolerant of residual postoperative retroversion.[18] As such, RTSA is now commonly used to address more advanced glenoid deformity even in the cuff-intact shoulder.[2,23] This is based on mid- and long-term clinical outcomes studies of anatomic total shoulder arthroplasty, which have begun to raise concerns about glenoid implant longevity in cases with increased preoperative retroversion and those with posterior humeral subluxation.[6,11-13,16,17,24]

Some implant companies have introduced augmented glenoid implants to address glenoid deformity, and they have proven a valuable alternative to preserve bone when correcting pathologic glenoid retroversion and inclination. Despite clinical studies demonstrating favorable short- and mid-term results, guidelines for their use have not been established, and their recent introduction allows limited clinical follow-up data on which to formulate evidence-based guidelines.[1,5,9,10,14] Nevertheless, as our understanding of the frequency and impact of glenoid deformity on outcomes of shoulder arthroplasty evolves, their utility is likely to increase as an alternative to corrective reaming and bone grafting.

The use of 3D computed tomography (CT)-based preoperative planning platforms has gained increasing popularity as the importance of addressing glenoid deformity has become more apparent. Most implant companies in widespread use now offer this technology. These systems allow surgeons to virtually select and position the chosen glenoid implant for a given clinical scenario, optimizing parameters such as backside contact, position on the glenoid face, version and inclination correction, peg or screw position in the glenoid vault, and, in some systems, virtual range of motion. Prior studies have suggested that preoperative planning improves a surgeon's ability to achieve the desired reconstruction over conventional free-hand techniques without planning.[7]

To date, there is limited consensus on the parameters of deformity correction, implant configuration, and implant placement that constitute an optimal plan for any given scenario. Surgeons are largely guided by personal preference in the planning process and may differ widely in how they prioritize the importance of specific variables such as version correction, implant backside coverage, and so on. Such differences may ultimately affect the performance of the reconstruction in terms of impingement free range of motion, stability, scapular notching, and short- and long-term implant fixation.

The aim of this study was to quantify inter- and intrasurgeon variability in RTSA baseplate selection. In addition, we sought to quantify differences in version and inclination correction within and between surgeons and average thresholds and ranges for different augment use between surgeons. We hypothesize that multiple surgeons preoperatively planning the same case will present substantial intersurgeon variability between plans. In addition, we hypothesize that individual surgeons preoperatively planning the same case on separate occasions will demonstrate substantial intrasurgeon variability between plans.

Methods

A total of 50 CT scans from real cases submitted for preoperative planning were chosen from a database of actual surgical cases to represent a range of glenoid deformity. All identified patient information was removed from the imaging study. One case was ultimately discarded because of extreme erosion of −35° and consensus among participating surgeons that it was not amenable to RTSA due to severe glenoid bone loss. This left 49 cases each of which was planned by 9 different fellowship-trained shoulder arthroplasty surgeons using the same preoperative planning platform (Exactech GPS; Exactech, Gainesville, FL, USA). Each of these surgeons has participated in the design and development of this platform, thus having extensive experience with its use in both the research and clinical setting. For this system, CT scans are obtained according to a defined protocol, and image formatting and reconstruction are performed by system engineers also using a defined algorithm. Native version and inclination are calculated by the software using the Friedman axis as a reference. This is manually defined at the time of imaging reconstruction by connecting a line from the center of the medial scapular trigonum to the center of the glenoid face. All surgeons receive the same reconstruction and reference axis for planning.

The software allows the surgeon to select one of 4 reverse baseplates: standard; 8° posterior augment; 10° superior augment; and combined posterior superior augment. Implant orientation, face position, and depth can be adjusted in 1 mm and 1° increments. The final version and inclination represent the combination of any correction and that added by the use of an augment. Surgeons were instructed to plan cases according to how they would do so as if performing the actual surgery. No specific guidelines were otherwise provided. Four to six weeks later, surgeons were asked to replan each of the 49 cases again.

Statistical analysis

Interclass correlation coefficients were used to determine intersurgeon variability for continuous data of version and inclination where each round was considered an independent sample. Light's kappa coefficient was used to determine intersurgeon variability for categorical data (baseplate type). Pearson correlation coefficients were used to determine intrasurgeon variability for continuous variables of version and inclination between rounds 1 and 2. Categorical intrasurgeon variability for baseplate type was assessed with Cohen's kappa coefficient. Bland-Altman plots were also used to visually demonstrate intersurgeon and intrasurgeon variability for version and inclination differences between surgeons, with the *Y*-axis demonstrating the difference between rounds 1 and 2 and the *X*-axis demonstrating the average of rounds 1 and 2. Data are presented as mean ± standard deviation.

Results

Cases ranged from 0.9° anteversion to −25° retroversion (average: −11.4° ± 6.1°) and from −14.6° inferior to 15.6° superior inclination (average: 2.6° ± 6.9°).

Intersurgeon variability

Standard baseplates were selected in 21% of cases on average (range: 5%-68%). Average retroversion and inclination for use of a standard baseplate were −5.7° ± 4.9° (range: −2.9° to −8.9°) and 2.0° ± 4.6° superior (range: 0.1° inferior to 4.6° superior). Eight-degree posterior augments were used in an average of 32% (range: 22%-67%). Average retroversion and inclination for this baseplate were −14.3° ± 6.2° (range: −11.3° to −15.5°) and 1.9° ± 3.9° inferior (range: 5° inferior to 2° superior). Ten-degree superior augments were used in 16% of cases on average (range: 3%-32%). Average retroversion and inclination for this baseplate were −9.1° ± 4.9° (range: −5° to −13.6°) and 7.6° ± 3.8° superior (range: 0.6°-15.6° superior). Posterior superior augments were used in 27% of cases on average (range: 2%-67%). Average retroversion and inclination for this baseplate were −15.9° ± 6.8° (range: −11° to −21.6°) and 3.4° ± 6.2° superior (range: 1° inferior to 15.6° superior). Figure 1 demonstrates the graphical variability in augment use between surgeons. Total augment use averaged 79% (range: 32%-95%).

Figure 2 demonstrates the range of version correction for all cases by surgeons. This figure shows that surgeons corrected most cases to a version of 0° with a second small peak around −4° to −5°. A total of 63% of cases were corrected to 0° of version (range: 45%-100%). Surgeon 2, who had the lowest total augment use of 32%, corrected 70% of cases to 0° of version. Surgeon 9, who had the second highest total augment use of 95%, corrected 71% of cases to 0° of version. Surgeon 8, who had the highest augment use at 95%, had the second lowest average correction to −2.8° and the highest number of cases planned for ≥−5° or retroversion.

Table I shows the number of times surgeons chose the same implant for each case's 18 plans (9 surgeons × 2 rounds). Native version and inclination for each number were calculated to determine if variability in implant selection was more common in cases with greater deformity. There were only 2 cases where the same implant was chosen in all 18 plans; however, this did not infer that the same version and inclination were planned. This table demonstrates that similarity in baseplate selection or lack thereof varies across the spectrum of the glenoid deformity and that the degree of preoperative wear does not lead to a

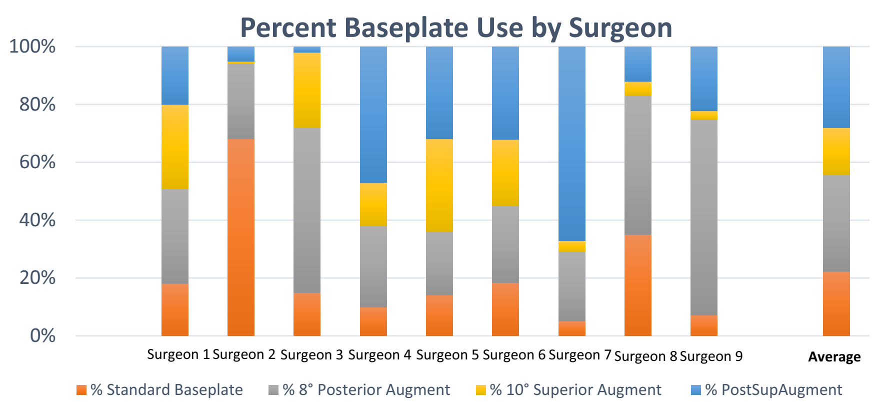

Figure 1 Histogram showing percent baseplate use for each surgeon for each of the standard, 8° posterior augment, 10° superior augment, and combined posterior superior augment.

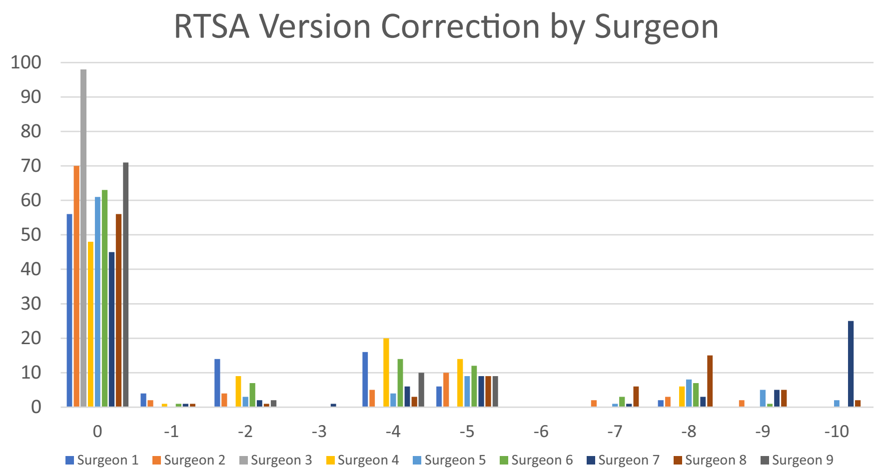

Figure 2 Variability in version correction by surgeons. The *Y*-axis demonstrates the number of cases (maximum 98); the *X*-axis demonstrates the retroversion degree. *RTSA*, reverse total shoulder arthroplasty.

Table I Number of times out of a total of 18 plans that the same baseplate was chosen

Frequency same implant chosen out of possible 18 plans for each case	Number of cases for each frequency	Average version (°)	Average inclination (°)
18	2	−6.4	−4.3
17	1	−19.6	−4.0
16	2	−15.7	−9.8
14	2	−16.5	−8.0
13	6	−17.5	−1.7
12	6	−9.3	2.2
11	4	−12.8	5.1
10	9	−12.2	6.1
9	8	−9.4	5.2
8	3	−5.5	4.8
7	5	−8.1	7.2
6	1	−8.3	3.9

Because 9 surgeons planned each case twice, there are 18 total plans per case. The average native version and inclination are shown as a gauge of baseplate similarity compared with preoperative glenoid deformity. The results indicate that there is little correlation between degree of deformity and variability in baseplate selection between surgeons.

greater degree of variability between surgeons. Table II demonstrates the correlation coefficients for glenoid version, inclination, and baseplate type.

Intrasurgeon variability

Planned version differed between rounds an average of 2.2° ± 2.4° (range: 0°-3.4°), and surgeons planned a different version in 48% of cases (range: 0%-66%). The maximum difference in version between rounds averaged

Table II Interclass correlation coefficients for version, inclination, and baseplate selection indicating intersurgeon variability

Characteristic	Method	Kappa
Baseplate	Light's kappa	0.25
Version	ICC (C,9)	0.43
Inclination	ICC (C,9)	0.42

ICC, interclass correlation coefficient.

8.7° ± 3.1° (range: 0°-16°). Surgeons planned a different inclination in 26% of cases (range: 0%-63%) with an average difference between rounds of 0.8° ± 1.7° (range: 0°-2.6°). The maximum difference in inclination between rounds averaged 4.9° ± 2.4° (range: 0°-10°). A different glenoid baseplate was chosen between rounds in 28% of cases (range: 16%-41%). Figure 3 demonstrates the percent of cases planned differently for version, inclination, and baseplate between rounds for each surgeon. Notably there are fewer instances of differences in inclination than in version correction. Table III demonstrates Pearson correlation coefficients for version and inclination. Figure 4 shows a heatmap of Pearson coefficients for version and inclination by surgeons. These demonstrate little consistency between rounds overall.

Figures 5 and 6 show Bland-Altman plots for version and inclination, respectively. These demonstrate that, on average, the *Y*-axis spread is narrower for inclination differences than for version differences. These plots show a visual account of the substantial variability both with and between surgeons. Only surgeon 3 was internally consistent planning each case to 0° of version and inclination. However, this surgeon chose a different baseplate in 34% of cases to achieve this correction. For many surgeons, these plots also show that variability increases as the average planned version and inclination for both rounds move away from 0°.

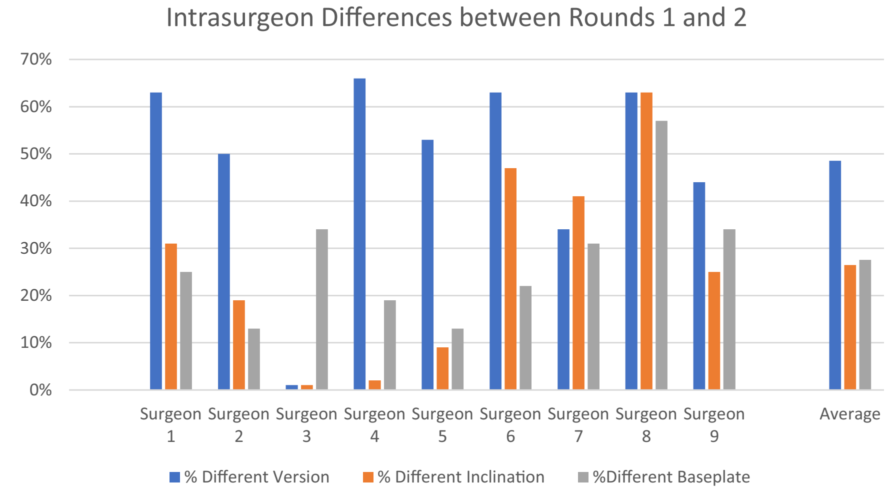

Figure 3 This graph demonstrates the percent of cases where a different version, inclination, or baseplate was planned between rounds 1 and 2 for each surgeon.

Table III Pearson correlation coefficients (version and inclination) and Light's kappa coefficients (baseplate type) indicating intrasurgeon variability

Variable	Estimate	CI lower	CI upper
Baseplate	0.61	0.56	0.67
Version	0.34	0.25	0.42
Inclination	0.3	0.22	0.39

CI, confidence interval.

Intrasurgeon variability for anteroposterior (AP) face placement, superoinferior (SI) face placement, and depth was also analyzed. A different AP position was chosen between rounds on average 40% of the time (range: 28%-59%). A different SI position was chosen in 51% of cases (range: 34%-72%). A different depth was chosen in 38% of cases (range: 16%-59%). When these differences were aggregated for each surgeon, the average total percent of cases with a different face position was 43% (range: 34%-55%). This demonstrates that although some surgeons are more consistent than others, across the board, there remain substantial differences between rounds for all surgeons. The surgeon with the lowest aggregate percentage had the lowest percent difference for SI position but not AP and depth position. Also, surgeon 3, who had no variability between rounds for version and inclination, had the fourth highest aggregate difference for face position and the highest difference for depth. Table IV demonstrates these differences for each surgeon.

Discussion

The main finding of this study was that surgeons differ considerably in what they consider to be an optimal reconstruction and that an individual surgeon's ideal reconstruction for a given case differs over time. Analysis of this planning data not only shows differences in frequency and threshold for implant use but also differences in the degree of correction and range of residual retroversion and inclination after correction. Given that surgeons were not provided specific reconstructive aims other than to plan according to their own specifications of optimal implant placement, the lack of consistency both between and within surgeons suggests several considerations.

First, this variability suggests that specific guidelines on implant placement for the system used in this study have yet to be established. Such guidelines might include parameters that optimize implant fixation, implant orientation, and impingement free range of motion. Such guidelines may only be achieved by long-term standardized clinical outcomes data, radiographic follow-up, continued optimization of virtual planning tools, and perhaps machine learning algorithms that find patterns pointing to better results. Until these aims are achieved, surgeons largely rely on intuition, experience, and what is considered a range of normal anatomy.

Second, this variability may also suggest that there is more than 1 solution that can achieve the goals of reconstruction. In other words, different implant types with different degrees of glenoid preparation can achieve similar ends. It is also likely that small differences in version and inclination correction and position of the implant on the glenoid face may have a minimal impact on clinical outcomes that can be affected by a host of other variables including presenting diagnosis, a history of prior surgery, preoperative pain and function measures, remaining cuff integrity at the time of reconstruction, bone quality, and others.

This contention is supported by the fact that surgeons in this study on average corrected version to $-1.9° \pm 3.7°$

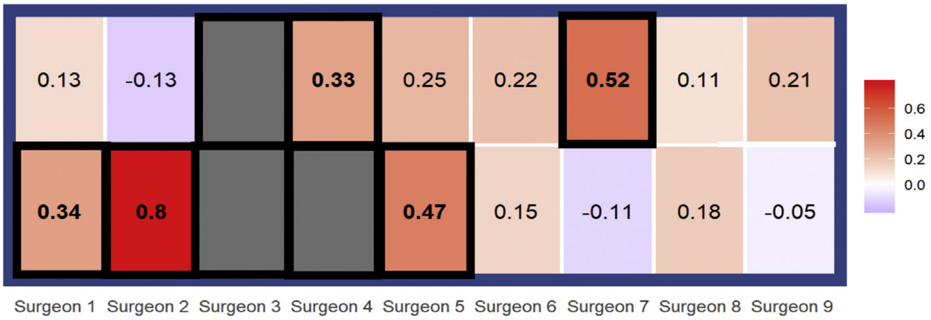

Figure 4 This is a heatmap demonstrating Pearson correlation coefficients for intrasurgeon variability in planned version and inclination. Version correlations are shown on the top row and inclination coefficients are on the bottom row. *Darker colors* indicate higher correlations. The *gray boxes* indicate 100% correlation between rounds.

(range: 0° to −3.5°) but used substantially different baseplate options to achieve this relatively narrow range of corrections. Although the individual case corrections differed substantially between surgeons, the average goal appeared to be achieving close to neutral correction relative to the Friedman axis. Although the maximum difference

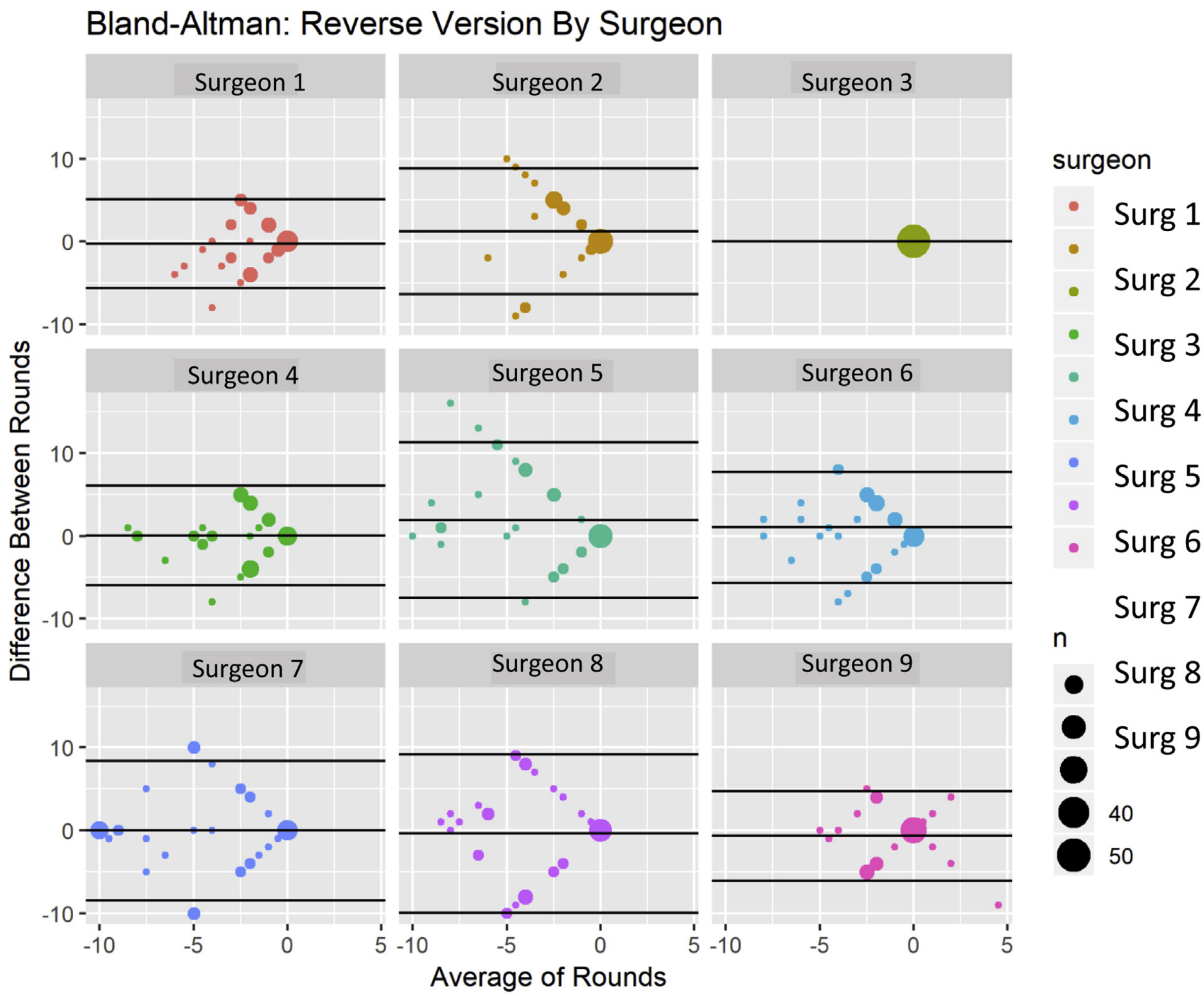

Figure 5 Bland-Altman plots for planned version. The *Y*-axis shows the difference in planned version between rounds 1 and 2, whereas the *X*-axis shows the average version between the 2 rounds. The *horizontal lines* indicate 1.96 × standard deviation. These plots are used to demonstrate the agreement between rounds. Except for surgeon 3, they tend to demonstrate less agreement as planned version moves away from 0°.

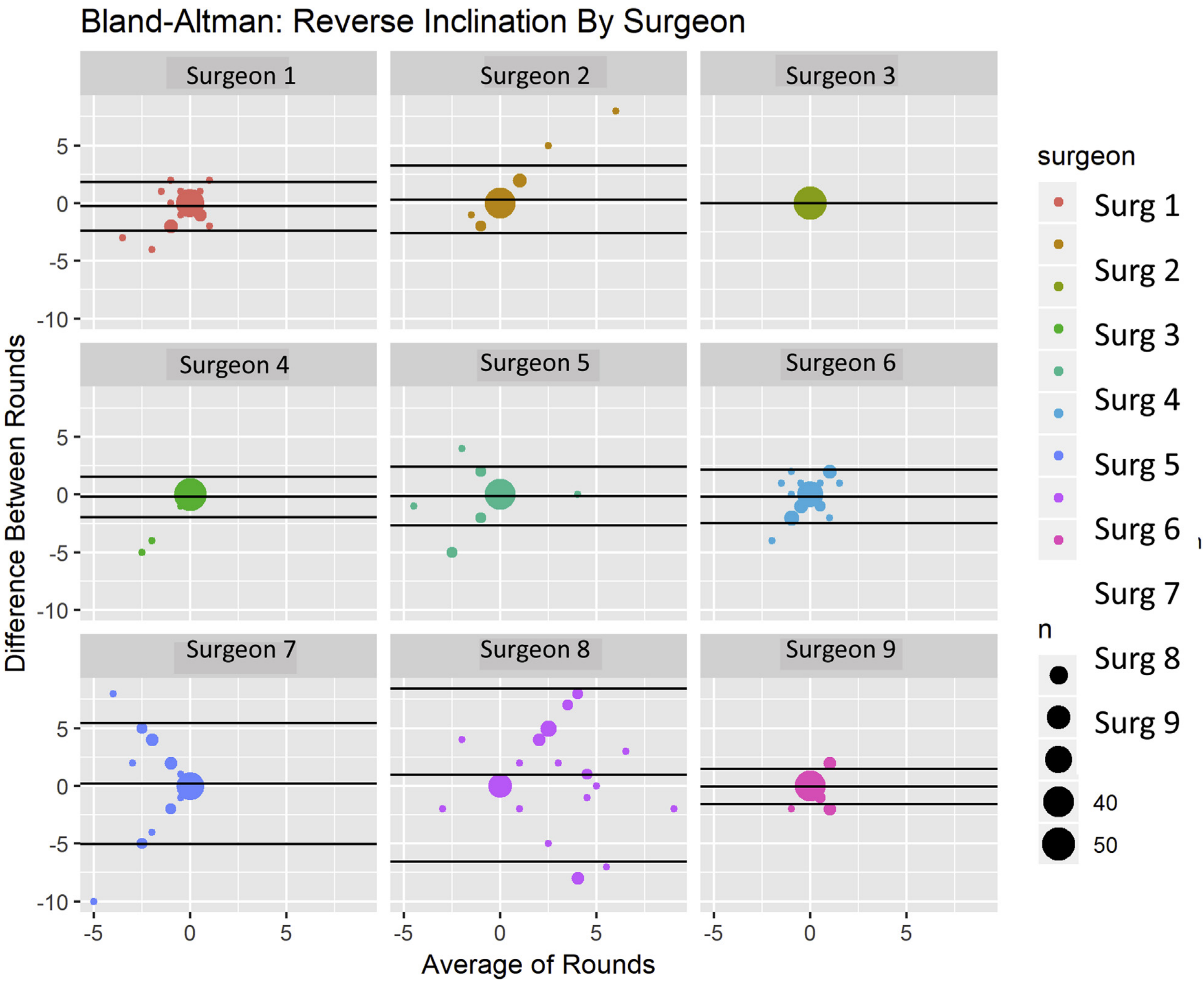

Figure 6 Bland-Altman plots for planned inclination. The *Y*-axis shows the difference in planned version between rounds 1 and 2, whereas the *X*-axis shows the average version between the 2 rounds. The *horizontal lines* indicate 1.96 × standard deviation. These plots show more agreement between rounds for inclination compared with version. They also show less standard deviation overall except for surgeon 8. This would suggest that surgeons are less tolerant of residual baseplate inclination than residual baseplate retroversion.

Table IV Percent of the time each surgeon planned the same AP, SI, and depth position on the glenoid face between rounds 1 and 2

	Surgeon 1	Surgeon 2	Surgeon 3	Surgeon 4	Surgeon 5	Surgeon 6	Surgeon 7	Surgeon 8	Surgeon 9	Average
% Different AP	28	44	38	28	38	41	59	41	47	40
% Different SI	44	59	50	59	41	56	72	34	47	51
% Different depth	50	56	59	16	28	22	34	22	56	38
% Aggregate average	41	53	49	34	36	40	55	32	50	43

AP, anteroposterior; *SI*, superoinferior.

between rounds for one surgeon was 11°, the average difference between rounds was <1° for all 98 cases planned by each surgeon. The same is true for inclination where the maximum difference between rounds was 10° but the average difference was <1°. This relatively narrow range within which surgeons planned this spectrum of cases indicates that although precise guidelines are lacking, surgeons tend to fall within a fairly narrow range in terms of the planned degree of correction. This may indicate that each case has a "safe zone" or "target zone" within which stable fixation and correction of glenoid wear can be achieved using a variety of different constructs.

The large variability in baseplate selection coupled with this relatively narrow range within which cases were corrected may indicate differences in how surgeons prioritize reconstructive goals such as achieving backside coverage, minimizing bone loss through corrective reaming, achieving a fixed degree of correction, and optimizing position of the implant within the glenoid vault. The current iteration of this planning software did not allow us to more quantitatively assess bone removal and backside implant contact though future studies should seek to investigate how these variables influence implant selection and positioning in the hierarchy of parameters surgeons use to plan an ideal reconstruction. Further studies are needed to determine if there are different pathways of achieving the same reconstructive goal or if a narrower definition of an optimal reconstruction is needed to reduce such variation to achieve best practice standards.

The availability of such platforms for many commonly used implant systems suggests that the popularity of preoperative planning will continue to grow. A recent survey of members of the American Shoulder and Elbow Surgeons indicated that 81% of respondents obtain a CT scan in at least half of their cases with 67% doing so in most cases. A total of 46% reported using preoperative planning in a majority of cases with an additional 25% using it in select cases based on complexity. A total of 12% of respondents reported that they are interested but have not yet adopted it into practice.[18] As these systems continue to improve and their use becomes more routine, the information that can be derived from a large library of cases may begin to indicate patterns that a small sample like this cannot achieve.

The limitations of this study include that it is a single implant study using a single reference axis. It is likely, based on differences in baseplate designs and reference axes between systems, that these results cannot necessarily be translated to other systems. Nevertheless, each surgeon in this study had the same reference system applied to each case, so the images were standardized for all surgeons and for each round. The limited number of cases also makes it somewhat difficult to extrapolate any meaningful trends from these data, but we do feel that the sample size used within this study is sufficient to determine intersurgeon and intrasurgeon variability for the sake of demonstrating a lack of consistency.

The strengths of this study include a large number of preoperative plans (total 882) across which to compare differences between and within surgeons. In addition, the spectrum of glenoid pathology allowed us to study whether case complexity increased the variability. This information may be clinically relevant as this technology continues to gain popularity and as its utility improves to include more sophisticated virtual modeling capabilities. The role of machine learning and predictive modeling in correlating implant position with clinical outcomes may also help establish guidelines to more quantitatively determine implant position apart from individual surgeon preference. On the basis of the results of this study, we believe that there may be a target zone within which multiple different plans can achieve the goals of reverse shoulder reconstruction to optimize implant placement for fixation durability, joint stability, and postoperative function. Further research is necessary to confirm this and develop validated planning guidelines.

Conclusions

There is substantial intersurgeon and intrasurgeon variability in baseplate selection and version and inclination correction when preoperatively planning a series of RTSA cases with a spectrum of pathology. Variability does not appear to be a function of the severity of glenoid deformity and existed across the spectrum of morphology. Planned version varied more than inclination, indicating that surgeons have a narrower range of what they consider an acceptable residual inclination. Variability in version and inclination correction can be reduced by adhering to strict rules such as planning all cases to 0° for each. Thresholds for augmented baseplate use varied widely both between and within surgeons between rounds. This may suggest that there are different pathways for achieving correction and optimizing implant placement within a narrow range of values.

Disclaimer

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