J Shoulder Elbow Surg (2021) 30, 787–794

JOURNAL OF SHOULDER AND ELBOW SURGERY

www.elsevier.com/locate/ymse

# Surgeon acceptance of an initial 3D glenoid preoperative plan: rates and risk factors

**Robert U. Hartzler, MD, MS[a,*], Patrick J. Denard, MD[b,c], Justin W. Griffin, MD[d,e], Brian C. Werner, MD[f], Anthony A. Romeo, MD[g]**

[a]*TSAOG Orthopaedics and BRIO, San Antonio, TX, USA*
[b]*Southern Oregon Orthopedics, Medford, OR, USA*
[c]*Department of Orthopaedics and Rehabilitation, Oregon Health & Science University, Portland, OR, USA*
[d]*Jordan-Young Institute, Virginia Beach, VA, USA*
[e]*Eastern Virginia Medical School, Norfolk, VA, USA*
[f]*Department of Orthopaedic Surgery, University of Virginia, Charlottesville, VA, USA*
[g]*Musculoskeletal Institute, Dupage Medical Group, Downers Grove, IL, USA*

**Background:** Although the effect of 3-dimensional (3D) planning for total shoulder arthroplasty (TSA) on component positioning and patient outcomes has been increasingly studied, the effect of 3D planning on surgeon decision making has not been well studied.
**Methods:** A retrospective review was performed of a database containing TSA cases for which the glenoid component was planned with a commercially available 3D computed tomography software program (Virtual Implant Positioning; Arthrex, Inc.) from 2016 to 2019. A total of 6483 cases planned by 417 surgeons were included. The glenoid version ($V_{tech}$) and inclination ($I_{tech}$) of the Virtual Implant Positioning technician plan as well as the surgeon's final plan for version ($V_{surg}$) and inclination ($I_{surg}$) were extracted. When the version and/or inclination of the surgeon plan matched that of the technician, that variable was defined as ''accepted.'' The rates of acceptance of $V_{tech}$ and $I_{tech}$ were calculated and analyzed for association with implant type, native version and inclination, and running case count. A subgroup analysis of high-volume users (n > 30 cases) was analyzed to determine if any of the variables independently was associated with surgeon acceptance.
**Results:** There was a very high rate of matching of version (66%), inclination (72%), or both (55%) and a low rate (18%) where neither parameter of the glenoid plan matched that of the technician. In univariate analysis, as the case count and retroversion increased the rate of accepting of version dropped noticeably (70%-50% and 47%, respectively [ $P < .0001$]). The rate of accepting the plan for inclination did not vary much as case count changed. In the multivariate analysis, 23 of 56 high-volume surgeons had at least 1 independent factor associated with accepting the technician-planned glenoid version, and 5 surgeons had 2 independent factors. In the multivariate analysis of matching glenoid inclination, 27 of 56 high-volume surgeons had at least 1 independent factor associated with accepting the technician-planned glenoid version, and 9 surgeons had 2 or more independent factors.
**Conclusions:** In a large database of TSAs with 3D-planned glenoids, there were high rates of cases with surgeon agreement with an initial plan provided by an industry technician: 66% in version, 72% in inclination, 55% for both version and inclination. Surgeon acceptance of the initial plan decreased as pathoanatomy increased and case count increased. Shoulder surgeons should be aware that an initial 3D preoperative plan provided by industry represents a potential source of cognitive bias in shoulder arthroplasty planning.

Institutional review board approval was not required for this basic science study.

*Reprint requests: Robert U. Hartzler, MD, MS, TSAOG Orthopaedics and BRIO, 150 E Sonterra Blvd, Suite 300, San Antonio, TX 78232, USA.
E-mail address: rhartzler@tsaog.com (R.U. Hartzler).


https://doi.org/10.1016/j.jse.2020.06.032

**Level of evidence:** Basic Science Study; Validation of Computer Modeling/Surgical Planning System


**Keywords:** Total shoulder arthroplasty; three-dimensional planning; CT scan; glenoid version; glenoid inclination; reverse shoulder arthroplasty

Preoperative planning in total shoulder arthroplasty (TSA) continues to evolve, and 3-dimensional (3D) virtual planning based on advanced imaging studies has been demonstrated to provide certain benefits, most notable of which is more accurate placement of the glenoid component.[5] Numerous commercial systems for implant-specific 3D planning and patient-specific instrumentation (PSI) exist currently, many having technical differences of which surgeons should be aware.[2,8,9]

Significant variability in how surgeons use these tools in TSA preoperative planning is expected, particularly for more challenging cases such as glenoid bone loss or deformity, because a variety of implants and operative techniques can be used to address these pathologies. However, little published information exists about how surgeons use 3D planning in different clinical scenarios.[3]

Therefore, the purpose of this study was to investigate the characteristics of the surgeon-planned version and inclination of the glenoid component and their relationships to the provided surgical plan generated by a nonsurgeon technician and various other factors that might influence surgeon planning in a large database of 3D-planned shoulder arthroplasty cases. The hypothesis of the study was that a high rate of matching (acceptance) of the initial plan by surgeons would be seen and that surgeons would be more likely to accept the plan with increasing experience using the program and more normal glenoid anatomy.

## Materials and methods

A retrospective review was performed of a database containing TSA cases (including both anatomic and reverse shoulders) for which the glenoid component was planned with a commercially available 3D computed tomography (CT) software program (Virtual Implant Positioning [VIP]; Arthrex, Inc., Naples, FL, USA). The database was queried from March 28, 2016 (time of US Food and Drug Administration [FDA] approval), through January 22, 2019 (study initiation). Cases with incomplete information or those submitted as "plan only" (no 3D guide ordered) were excluded by the statistical software used in the analysis (SAS Q5 9.2; SAS Institute Inc., Cary, NC, USA). Thus, all cases included in the analysis had the ability to use a reusable, patient-specific glenoid targeting device with 5 contact points, 2 on the anterior glenoid and 3 posteriorly, calibrated by either a 3D-printed bone model or a calibrating device to place a guide pin used for instrumentation of the glenoid.[8]

For this 3D planning software, a CT submitted for 3D planning with the VIP system must meet certain FDA requirements (Supplementary Appendix S1) and is screened and processed by a VIP Operations team technician trained in the use of the software. The team comprises 11 employees (Arthrex, Inc.) trained in the segmentation, thresholding, and implant positioning of the Arthrex anatomic (aTSA) and reverse total shoulder arthroplasty (rTSA) components in the VIP system. Each member of the team receives a product-specific training and onboarding process that includes an introduction to case planning, independent case planning with supervision, independent case planning with peer-review, and continuing education. Technicians are trained by a senior planner on anatomy, VIP software, FDA standards/requirements, implant options, selection and positioning by a senior planner. Once a technician shows proficiency, independent planning continues through with supervision until he or she achieves consistency in case planning (satisfactory intra- and interobserver reliability). All cases, regardless of the experience of the technician, are peer-reviewed before being sent to surgeons for final approval. Continuing education for the VIP Operations team occurs on a bimonthly basis and includes anatomy, implant, peer-reviewed literature, and complex case reviews.

Technician processing includes separation of the humerus and scapula, creation of the 3D virtual model of the scapula, measurement of 3D native glenoid version and inclination angles in whole number degrees (°) based on anatomic landmarks, and creation of a preliminary surgical plan that must meet certain FDA guidelines for implant version and inclination (Table I) while attempting to achieve certain technical goals that are considered reliable rules of thumb (Table I) for placement of either an all-polyethylene glenoid in an aTSA or rTSA baseplate. The version ($V_{tech}$) and inclination ($I_{tech}$) of the technician plan for each case were extracted from the database.

The surgeon then must finalize the VIP plan before final creation of the glenoid targeting device. Thus, the surgeon can either accept the technician's plan or modify the plan. The surgeon has the ability to modify the implant type and the initial plan for glenoid version ($V_{surg}$) and inclination ($I_{surg}$) to select parameters that are outside of the FDA limits placed on the technician's plan. The surgeon also has the ability to rotate and translate the component in 3D space (6 degrees of freedom); however, those additional parameters were not included in the current study.

When the version and/or inclination of the surgeon plan matched that of the technician, that variable was defined as "matched" or "accepted" for that case (eg, $V_{surg} = V_{tech}$). Because of the workflow as outlined above, it is assumed that the surgeon consciously or unconsciously is affected by the initial technician plan. The rates of "acceptance" of $V_{tech}$ and $I_{tech}$ were calculated and analyzed for association with implant type, native version and inclination, and running case count. A subgroup analysis of high-volume VIP users, chosen as those with greater than or equal to 30 planned cases,[11] was performed with a multivariate analysis to determine if any of the variables

**Table I** TSA planning parameters used by VIP technician

| | FDA limitation | Expert "rules of thumb" |
|---|---|---|
| aTSA | Version: 0° to −10° (retroverted) | Complete backside seating |
| | Inclination: −5° to 5° | Center peg or keel in the vault center |
| | | Minimize reaming (preserve subchondral bone) |
| | | Minimize keel or peg vault perforation |
| | | Rotation to match the native glenoid |
| rTSA | Version: −10° to 10° | Size of the baseplate matches the native glenoid (Univers rTSA baseplate) |
| | Inclination: −10° to 0° | Inferior part of the baseplate aligns with the inferior rim of the glenoid |
| | | Avoid medialization >5 mm, indicate bone graft needed if a deficient area |
| | | Minimize central peg vault perforation |
| | | Rotation to match the native glenoid |

*TSA*, total shoulder arthroplasty; *VIP*, Virtual Implant Positioning; *aTSA*, anatomic total shoulder arthroplasty; *rTSA* reverse total shoulder arthroplasty; *FDA*, US Food and Drug Administration.

independently was associated with (anonymized) surgeon acceptance of $V_{tech}$ and $I_{tech}$.

## Statistical methods

A professional statistician carried out the statistical analysis using SAS 9.4 (SAS Institute Inc.). Surgeon version and inclination ($V_{surg}$ and $I_{surg}$) frequency and percent as well as the acceptance rate ($V_{surg} = V_{tech}$ and $I_{surg} = I_{tech}$) were calculated. Factors analyzed for association with technician plan acceptance were the following categorical variables: implant type (aTSA vs. rTSA), native glenoid version (>0°, 0 to <−5°, −5° to <−10°, −10° to <−15°, −15° to <−20°, −20° to <−25°, and −25° or less [anteversion > 0°, retroversion < 0°]), native glenoid inclination (<0°, 0° to ≤5°, 5° to ≤15°, greater than 15° [superior inclination = positive, inferior inclination = negative]), and running case count (0-24, 25-49, 50-99, 100+). Running case count was a surgeon-specific running total variable different from a surgeon's total volume in the data set. For example, running case count <25 means the 25 earliest VIP cases for a surgeon.

In a univariate analysis, a $\chi^2$ test (Fisher's exact for sparse data) was used to investigate for differences in surgeon acceptance for the above variables. Running case count and native glenoid version/inclination were also analyzed as continuous variables using a univariate logistic regression analysis to determine odds radios for acceptance for the high-volume surgeon subgroup analysis. Finally, a multivariate analysis was conducted for the high-volume surgeon subgroup. Statistical significance was set at $P < .05$.

## Results

During the 34-month period studied, 9685 cases were submitted to the planning system. Cases with incomplete information for the variables of interest (N = 2411) or that were submitted as "plan only" (no 3D guide ordered, N = 791) were excluded. Thus, 6483 cases planned by 417 surgeons were included in the overall analysis. Fifty-six surgeons and their 4314 planned cases (67%) were included in the high-volume group.

The frequencies of surgeon-chosen glenoid version and inclination are shown in Fig. 1. There were a remarkably large number of cases with surgeon version ($V_{surg}$) at −10° (30% of cases) and surgeon inclination ($I_{surg}$) at 0° and 5° (43% and 27% of cases, respectively). These values represent the endpoints of version and inclination allowed by the technician (Table I).

Table II shows the frequency of surgeon matching or accepting (eg, $V_{surg} = V_{tech}$) the individual parameters of the technician plan. There was a very high rate of matching of version and inclination and a low rate where neither parameter of the glenoid plan matched that of the technician.

Table III shows the univariate analyses for the entire data set (N = 6483 cases and 417 surgeons) with some notable factors associated with surgeons accepting the technician plan. First, the rate of accepting of version dropped noticeably from 70% to 50% ($P < .0001$) as the case count increased from the 0-24 to the 100+ range. Although statistically significant, the rate of accepting the plan for inclination did not seem to vary much as case count changed (74%-68%, $P < .0001$). Similarly, aTSA had only a slightly higher but still statistically significant rate of plan acceptance vs. rTSA (68% vs. 65%, $P = .018$). The rate of surgeon acceptance decreased significantly as native retroversion ($P < .0001$) and inclination ($P < .0001$) increased.

In the high-volume group of 56 surgeons, 2.3 cases on average per month were planned during the study period (range, 0.9-12.4 cases/mo). The rate of aTSA plans vs. rTSA plans varied widely amongst this group of surgeons: one surgeon only planned aTSA cases (N = 53, 100%), whereas another planned 92% of 39 cases as rTSA. In all, 51% of cases were planned as aTSA and 49% were planned as rTSA in this group.

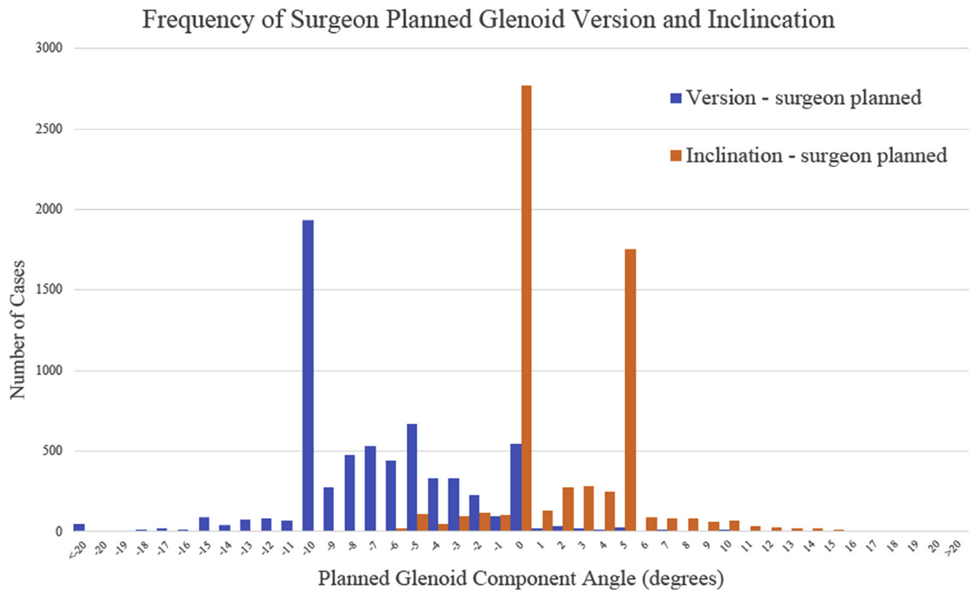


**Figure 1** In a large database of 3D-planned total shoulder arthroplasties, a high number of cases were planned by surgeons at certain parameters of glenoid version (−10°) and inclination (0° and 5°).

**Table II** Frequency of matching between surgeon and VIP technician version and inclination for 6483 (all surgeons) and 4314 (high-volume surgeons) cases 3D planned with VIP (Arthrex, Inc.)

| | N (%) All surgeons | N (%) High-volume surgeons |
|---|---|---|
| Version matched | 4286 (66) | 2703 (63) |
| Inclination matched | 4647 (72) | 2957 (69) |
| Both matched | 3585 (55) | 2167 (50) |
| Neither matched | 1135 (18) | 821 (19) |

*VIP*, Virtual Implant Positioning.

Table II shows a similar rate of matching the technician version and inclination for the high-volume group in comparison with the whole data set. Fourteen surgeons represented the highest rate (75th percentile) of neither $V_{surg}$ nor $I_{surg}$ matching the technicians plan (“non-accepters”). Even in this group, there was only an overall 40% rate (509 of 1272 cases) of neither surgeon version nor inclination matching the tech plan (individual surgeon range, 33%-70%).

In the multivariate analysis of matching glenoid version, 23 of 56 high-volume surgeons had at least 1 independent factor associated with accepting the technician-planned glenoid version, and 5 surgeons had 2 independent factors (Table IV). Interestingly, for each variable, the odds ratio (OR) was greater than 1 (positively associated with matching) for some surgeons and less than 1 (negatively associated with matching) for other surgeons. For example, of the 6 surgeons where implant type (rTSA vs. aTSA) was associated with accepting version, 3 were more likely to accept for rTSA (range OR, 1.75-41.76) and 3 were less likely to accept for rTSA (range OR, 0.13-0.2). For the 11 surgeons where running case count was associated with accepting version, 6 had a positive effect (range OR, 1.01-1.07), meaning that they were more likely to accept version as case count increased. For the remaining 5 surgeons, running case count had a negative effect (range OR, 0.93-0.98), meaning that they were less likely to accept version as case count increased. Most surgeons (10 of 11) were more likely to accept the technician-planned glenoid version as the native version grew positive (less retroverted).

In the multivariate analysis of matching glenoid inclination, 27 of 56 high-volume surgeons had at least 1 independent factor associated with accepting the technician-planned glenoid version, 7 surgeons had 2 independent factors, and 2 had 3 independent factors (Table V). For 8 surgeons, as native inclination decreased (became more normal), matching was more likely. Similar to the analysis for version, running case count and implant type (rTSA) had both positive and negative association with matching of technician-planned glenoid inclination that depended on the individual surgeon (Table V).

## Discussion

The current knowledge of 3D planning in shoulder arthroplasty has sought to answer questions pertaining to the uses and effects of this set of tools *on the patient*. In this study, the authors hoped to investigate the effects of the 3D

**Table III** Univariate analysis of factors associated with matching between surgeon and technician glenoid version and inclination in VIP-planned cases

| | Total | Matched version | $\chi^2$ | | Total | Matched inclination | $\chi^2$ |
|---|---|---|---|---|---|---|---|
| | N | n (%) | *P* value | | N | n (%) | *P* value |
| Running case count | | | | Running case count | | | |
| 0-24 | 3481 | 2438 (70) | <.0001 | 0-24 | 3481 | 2566 (74) | <.0001 |
| 25-49 | 1228 | 810 (66) | | 25-49 | 1228 | 831 (68) | |
| 50-99 | 1006 | 656 (65) | | 50-99 | 1006 | 684 (68) | |
| 100+ | 768 | 382 (50) | | 100+ | 768 | 566 (74) | |
| Implant type | | | | Implant type | | | |
| Anatomic | 3255 | 2197 (68) | .018 | Anatomic | 3255 | 2361 (73) | .125 |
| Reverse | 3228 | 2089 (65) | | Reverse | 3228 | 2286 (71) | |
| Native glenoid version (°) | | | | Native glenoid inclination (°) | | | |
| >0 | 764 | 538 (70) | <.0001 | | | | |
| 0 to < −5 | 1349 | 969 (72) | | <0 | 544 | 403 (74) | <.0001 |
| −5 to <−10 | 1465 | 1052 (72) | | 0 to ≤5 | 1241 | 960 (77) | |
| −10 to <−15 | 1122 | 729 (65) | | 5 to ≤15 | 3672 | 2607 (71) | |
| −15 to <−20 | 788 | 492 (62) | | >15 | 1026 | 677 (66) | |
| −20 to <−25 | 463 | 254 (55) | | | | | |
| ≤−25 | 532 | 252 (47) | | | | | |

*VIP*, Virtual Implant Positioning.

**Table IV** Multivariate analysis of factors associated with matching of surgeon and technician glenoid version for high-volume surgeons

| Surgeon | Number of cases | Native version | | Running case count | | rTSA | |
|---|---|---|---|---|---|---|---|
| | | OR [95% CI] | *P* value | OR [95% CI] | *P* value | OR [95% CI] | *P* value |
| 22 | 42 | 0.94 [0.86-1.04] | .220 | 1.07 [1.01-1.14] | **.030** | 1.24 [0.27-5.66] | .790 |
| 32 | 37 | 1.05 [0.96-1.14] | .310 | 1.00 [0.93-1.08] | .960 | 0.14 [0.02-0.94] | **.040** |
| 34 | 49 | 0.93 [0.86-0.99] | **.030** | 1.02 [0.97-1.06] | .530 | 1.38 [0.37-5.16] | .630 |
| 38 | 85 | 1.04 [0.99-1.09] | .100 | 0.98 [0.96-1.00] | **.040** | 0.82 [0.25-2.68] | .750 |
| 97 | 89 | 1.14 [1.06-1.22] | **.001** | 1.01 [0.98-1.03] | .640 | 2.36 [0.41-13.54] | .330 |
| 120 | 101 | 1.04 [0.99-1.09] | .110 | 1.04 [1.01-1.06] | **.001** | 1.00 [0.26-3.87] | 1.000 |
| 134 | 46 | 1.05 [0.97-1.15] | .220 | 1.07 [1.01-1.14] | **.030** | 0.40 [0.09-1.81] | .230 |
| 140 | 42 | 1.13 [1.02-1.25] | **.020** | 1.04 [0.97-1.11] | .260 | 0.23 [0.04-1.16] | .070 |
| 146 | 35 | 0.97 [0.88-1.06] | .510 | 1.07 [0.98-1.18] | .140 | 6.19 [1.02-37.75] | .050 |
| 157 | 93 | 1.05 [1.00-1.10] | .080 | 0.97 [0.95-0.99] | **.010** | 0.53 [0.17-1.66] | .270 |
| 199 | 70 | 1.10 [1.01-1.19] | **.030** | 1.00 [0.97-1.02] | .850 | 0.85 [0.29-2.53] | .770 |
| 200 | 167 | 1.02 [0.97-1.08] | .400 | 1.02 [1.00-1.03] | **.010** | 0.34 [0.11-1.06] | .060 |
| 208 | 65 | 1.09 [1.02-1.17] | **.020** | 1.02 [0.99-1.05] | .180 | 0.20 [0.06-0.72] | **.010** |
| 221 | 167 | 1.05 [1.02-1.08] | **.003** | 1.00 [0.99-1.01] | .850 | 0.55 [0.23-1.29] | .170 |
| 249 | 60 | 1.03 [0.98-1.09] | .200 | 1.00 [0.97-1.03] | .970 | 0.13 [0.04-0.42] | **.001** |
| 293 | 42 | 1.06 [0.99-1.13] | .090 | 0.93 [0.88-1.00] | **.040** | 3.62 [0.81-16.09] | .090 |
| 306 | 96 | 1.07 [1.02-1.12] | **.008** | 0.98 [0.96-1.00] | **.020** | 0.85 [0.24-3.03] | .800 |
| 337 | 73 | 1.12 [1.05-1.20] | **.001** | 0.97 [0.94-1.00] | .050 | 1.33 [0.33-5.42] | .690 |
| 367 | 224 | 0.97 [0.91-1.04] | .380 | 1.01 [1.00-1.02] | **.001** | 0.42 [0.17-1.03] | .060 |
| 371 | 422 | 1.08 [1.04-1.11] | **<.0001** | 1.00 [1.00-1.00] | .980 | 1.75 [1.08-2.84] | **.020** |
| 375 | 58 | 0.97 [0.91-1.03] | .350 | 1.05 [1.01-1.09] | **.020** | 0.83 [0.24-2.86] | .770 |
| 385 | 60 | 1.07 [1.01-1.14] | **.020** | 1.02 [0.98-1.05] | .320 | 2.98 [0.51-17.36] | .220 |
| 387 | 59 | 1.19 [1.06-1.33] | **.003** | 1.03 [0.98-1.08] | .210 | 41.76 [4.64-375.68] | **.001** |

Bold font indicates statistical significance ($P < .05$).
*OR*, odds ratio; *CI*, confidence interval; *rTSA*, reverse total shoulder arthroplasty.

**Table V** Multivariate analysis of factors associated with matching of surgeon and technician glenoid inclination for high-volume surgeons

| Surgeon | Number of cases | Native inclination | | Running case count | | rTSA | |
|---|---|---|---|---|---|---|---|
| | | OR [95% CI] | *P* value | OR [95% CI] | *P* value | OR [95% CI] | *P* value |
| 22 | 42 | 0.92 [0.74-1.13] | .430 | 1.00 [0.91-1.11] | .960 | 157.35 [9.45-2619.23] | **<.0001** |
| 30 | 79 | 1.02 [0.94-1.11] | .640 | 1.03 [1.01-1.06] | **.009** | 0.30 [0.11-0.86] | **.025** |
| 31 | 158 | 1.01 [0.95-1.06] | .790 | 1.01 [1.01-1.02] | **.001** | 2.26 [0.95-5.37] | .064 |
| 32 | 37 | 0.81 [0.65-1.01] | .060 | 0.90 [0.78-1.04] | .150 | 0.03 [0.00-0.91] | **.044** |
| 34 | 49 | 0.98 [0.89-1.07] | .630 | 0.90 [0.84-0.97] | **.004** | 0.02 [0.00-0.24] | **.002** |
| 38 | 85 | 1.00 [0.93-1.08] | 1.000 | 0.97 [0.95-0.99] | **.007** | 0.42 [0.13-1.42] | .160 |
| 74 | 44 | 0.91 [0.79-1.04] | .170 | 1.01 [0.96-1.07] | .590 | 0.16 [0.04-0.73] | **.020** |
| 92 | 92 | 0.86 [0.78-0.95] | **.002** | 0.98 [0.96-0.99] | **.010** | 1.17 [0.43-3.18] | .750 |
| 97 | 89 | 0.86 [0.76-0.98] | **.020** | 1.00 [0.97-1.02] | .950 | 0.05 [0.01-0.19] | **<.0001** |
| 119 | 57 | 0.80 [0.62-1.03] | .080 | 1.15 [1.02-1.29] | **.020** | 1.87 [0.14-25.13] | .640 |
| 120 | 101 | 1.00 [0.92-1.10] | .930 | 1.02 [1.00-1.04] | **.030** | 0.18 [0.06-0.57] | **.003** |
| 123 | 55 | 0.79 [0.68-0.92] | **.002** | 1.03 [0.99-1.08] | .160 | 0.34 [0.07-1.55] | .160 |
| 134 | 46 | 0.94 [0.83-1.06] | .280 | 1.04 [0.99-1.10] | .130 | 0.22 [0.05-0.880] | **.030** |
| 140 | 42 | 0.50 [0.27-0.94] | **.030** | 1.09 [0.91-1.29] | .350 | 0.00 [0.00-0.21] | **.010** |
| 157 | 93 | 0.90 [0.82-0.99] | **.030** | 0.95 [0.92-0.97] | **.0001** | 0.15 [0.05-0.48] | **.002** |
| 198 | 154 | 0.99 [0.95-1.05] | .840 | 1.03 [1.02-1.04] | **.0007** | 1.49 [0.66-3.38] | .340 |
| 199 | 70 | 0.88 [0.77-1.01] | .070 | 1.00 [0.98-1.03] | .870 | 6.03 [1.42-25.68] | **.020** |
| 200 | 167 | 0.90 [0.82-0.97] | **.010** | 1.02 [1.01-1.04] | **.001** | 0.11 [0.03-0.34] | **.0002** |
| 249 | 60 | 1.00 [0.92-1.09] | .980 | 0.99 [0.96-1.02] | .530 | 0.10 [0.03-0.36] | **.0004** |
| 293 | 42 | 0.86 [0.76-0.97] | **.020** | 1.02 [0.97-1.08] | .440 | 1.24 [0.29-5.27] | .780 |
| 321 | 115 | 0.98 [0.92-1.04] | .450 | 1.01 [1.00-1.02] | **.040** | 0.62 [0.29-1.33] | .220 |
| 329 | 80 | 0.92 [0.85-1.00] | **.040** | 1.04 [1.01-1.06] | **.003** | 1.84 [0.66-5.17] | .250 |
| 371 | 422 | 1.01 [0.97-1.05] | .570 | 1.00 [1.00-1.00] | .890 | 12.90 [7.82-21.29] | **<.0001** |
| 375 | 58 | 1.02 [0.92-1.12] | .740 | 1.04 [1.00-1.08] | .080 | 10.95 [2.69-44.57] | **.001** |
| 387 | 59 | 0.98 [0.89-1.08] | .660 | 1.08 [1.03-1.12] | **.001** | 1.57 [0.33-7.49] | .570 |
| 389 | 58 | 0.98 [0.89-1.07] | .620 | 0.98 [0.95-1.01] | .180 | 3.81 [1.06-13.65] | **.040** |
| 397 | 73 | 0.94 [0.87-1.01] | .070 | 0.99 [0.96-1.01] | .220 | 3.58 [1.11-11.55] | **.030** |

Bold font indicates statistical significance ($P < .05$).
*OR*, odds ratio; *CI*, confidence interval; *rTSA*, reverse total shoulder arthroplasty.

planning process *on the surgeon*. It seems important that the majority of surgical plans in the study, even by high-volume surgeons, match the plan created by an industry technician. In fact, very few plans did not match the provided plan in at least 1 parameter.

The most natural assumption, and it should be recognized as an assumption, is that this high rate of concordance is due to the fact that the surgeon accepts the presented plan with very little change made in most cases. If true, this phenomenon is likely due to 1 or more cognitive biases to which the human mind is susceptible.[4] These possible sources of cognitive error include *authority bias*, the tendency to unquestioningly accept information provided by authority figures (eg, an industry "expert") and *social loafing*, the tendency for poorer effort in group vs. individual projects.

Likely, these potential effects of the planning process on the surgeon are dependent somewhat on the personality of the surgeon. For example, for the entire data set, the tendency for $V_{surg} = V_{tech}$ decreased as the case count increased; in other words, surgeons tended to modify the plan for version as their experience with the system grew. However, approximately half of the high-volume surgeons affected by case count had greater acceptance of the plan as their experience grew.

An additional potential source of bias introduced by an initial plan is called the *anchoring effect* and pertains to the well-described phenomenon that the human mind creates different estimates based on different starting points.[10] Thus, even if the surgeon does not simply "accept" the presented initial plan, the final plan is likely affected by the presence of the offered starting point. One example of this could be failure of the surgeon to switch to a reverse prosthesis for severe deformity if the initial surgical plan was created for aTSA. Another example is that the surgeon corrects too much version resulting in severe bone loss because the initial plan called for a high degree of correction. The effect of the anchoring phenomenon on surgeon 3D planning should be a topic for future study.

Perhaps the "acceptance" phenomenon found in the current study should not be worrisome to the orthopedic community. It may be that for the majority of cases a 3D plan produced by a non-surgeon technician (or artificial intelligence) with only the information provided by the CT and the rules and limits placed imposed by the planning system would not be significantly different from an completely independent surgeon plan that included the surgeon's experience, clinical knowledge of the patient, and other sources of patient imaging (plain x-rays, magnetic resonance imaging, etc.). This would seem to be very likely for cases in which the anatomy tends to be more normal, as this had a clear effect in the study on plan acceptance.

Conversely, the total knee arthroplasty literature that pertains to PSI contains several studies that raise caution about the utility of an initial surgical plan provided by industry. Pietsch et al[7] noted a high rate of changes—up to 68% modified for component size, position, or rotation, made by the surgeon to the technician's initial preoperative plan. Okada et al[6] evaluated changes made to an initial industry-provided surgical plan and noted a 91% rate of cases needing correction and a mean of 3.3 corrections per case. Cucchi et al[1] discouraged "blind acceptance" of a manufacturer's PSI preoperative total knee arthroplasty plan, also noting a poor rates of agreement between this and the surgeon's preoperative plan. These studies were small, single-center analyses, which might explain the lower rates of plan acceptance than what was observed in the current study.

Whether good or bad, the initial plan acceptance phenomenon should be recognized both by orthopedic device industry and surgeons and should be a topic for further investigation. For industry, it is important to acknowledge that in surgical planning an initial plan might bias the surgeon. Therefore, it is important that the plan be a sound one with certain safety checks, particularly as the potential of surgical plans generated by artificial intelligence becomes a reality. Surgeons also might prefer a planning package with no initial plan offered to try to reduce bias. Although recognition of potential sources of cognitive bias does not automatically eliminate their effect,[4] surgeons should try to recognize the tendency to accept what is presented with an uncritical eye and cognitive laziness particularly when exacerbated by fatigue.[4] Particularly for difficult cases, surgeons should be aware of the potential anchor bias effect of an initial surgical plan.

## Limitations

The current study contains and, in fact, highlights the primary limitation of retrospective research studies: the presence of unidentified confounding variables. If not for the very large numbers of cases being planned by the technicians at the FDA lower limit of glenoid version and FDA upper limits of inclination, the effect of the initial surgical plan on the final surgical plan might not have been detected. Now that the effect has been detected, and likely exists for all the available commercial 3D planning systems, an attempt should certainly be made to account for it in subsequent retrospective studies.

For example, the authors' original intention was to study the effect of surgeon tendency for correction of glenoid version toward 0° vs. leaving this in a retroverted position for B-type glenoids or high native retroversion. Similarly, large database studies might attempt to retrospectively find the effects of correcting inclination in TSA. However, if the initial surgical plan creates bias (ie, an unidentified confounding variable), these types of studies might be investigating more the effect of the initial plan than the surgeon's plan. Therefore, prospective, well-controlled studies on these questions are in order.

Although a formal power analysis was not performed, the study would not seem to lack power given that thousands of surgical cases were analyzed. In fact, it may be that some statistically significant trends were discovered that are not clinically meaningful (eg, higher rate of version acceptance for aTSA). It is difficult to speculate on the clinical significance of other positive statistical results. For example, the odds of acceptance for an individual surgeon being 2% decreased cumulatively for each additional case might seem insignificant but could have a large effect with a large number of cases. Finally, clinical outcomes were not correlated with implant position in this study. Further study is needed in this area.

## Conclusions

In a large database of TSAs with 3D-planned glenoids, there were very high rates of cases with surgeon agreement with an initial plan provided by an industry technician: 66% in version, 72% in inclination, 55% for both version and inclination. Surgeon acceptance of the initial plan decreased as pathoanatomy increased (native version and inclination further away from 0°) and case count increased. Shoulder surgeons should be aware that an initial 3D preoperative plan provided by industry represents a potential source of cognitive bias in shoulder arthroplasty planning.

## Disclaimer

Arthrex, Inc. provided the data and funding for the study, primarily in funding the statistical analysis.

Robert U. Hartzler reports publishing royalties from Wolters Kluwer Health and is a paid consultant for Stryker.

Patrick Denard reports that from Arthrex, Inc. he receives royalties, research support, and is a paid consultant and that from Wolters Kluwer Health he receives publishing royalties.

Justin Griffin reports that from Arthrex, Inc. he receives royalties and is a paid consultant and that from Springer he receives publishing royalties.

Brian Werner reports that he receives research support from Biomet, lntegra LifeScience, and Arthrex, Inc. and that he is a paid consultant for Arthrex, Inc.

Anthony Romeo reports that from Arthrex, Inc. he receives royalties, research support, and is a paid consultant; from Saunders/Mosby-Elsevier and SLAC Inc. he receives publishing royalties and financial or material support; from MNA and MLB he receives other financial or material support; and from Paragen Technologies research support and stock or stock options.

## Supplementary Data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jse.2020.06.032.

## References


1. Cucchi D, Menon A, Compagnoni R, Ferrua P, Fossati C, Randelli P. Significant differences between manufacturer and surgeon in the accuracy of final component size prediction with CT-based patient-specific instrumentation for total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 2018;26:3317-24. https://doi.org/10.1007/s00167-018-4876-8
2. Denard PJ, Provencher MT, Lädermann A, Romeo AA, Parsons BO, Dines JS. Version and inclination obtained with 3-dimensional planning in total shoulder arthroplasty: do different programs produce the same results? JSES Open Access 2018;2:200-4. https://doi.org/10.1016/j.jses.2018.06.003
3. Greene A, Cheung E, Polakovic S, Hamilton M, Jones R, Youderian A, et al. Inter-surgeon variability in using 3D planning software for reverse total shoulder arthroplasty: an analysis of 360 cases. Orthop Proc 2019;101-B:64.
4. Howard J. Cognitive errors and diagnostic mistakes. Cham, Switzerland: Springer; 2019.
5. Iannotti JP, Walker K, Rodriguez E, Patterson TE, Jun BJ, Ricchetti ET. Accuracy of 3-dimensional planning, implant templating, and patient-specific instrumentation in anatomic total shoulder arthroplasty. J Bone Joint Surg Am 2019;101:446-57. https://doi.org/10.2106/JBJS.17.01614
6. Okada Y, Teramoto A, Suzuki T, Kii Y, Watanabe K, Yamashita T. Preoperative corrections are required for planning of patient-specific instrumentation in total knee arthroplasty. Knee 2017;24:1492-7. https://doi.org/10.1016/j.knee.2017.09.008
7. Pietsch M, Djahani O, Hochegger M, Plattner F, Hofmann S. Patient-specific total knee arthroplasty: the importance of planning by the surgeon. Knee Surg Sports Traumatol Arthrosc 2013;21:2220-6. https://doi.org/10.1007/s00167-013-2624-7
8. Rodríguez JA, Entezari V, Iannotti JP, Ricchetti ET. Pre-operative planning for reverse shoulder replacement: the surgical benefits and their clinical translation. Ann Jt 2019;4:4. https://doi.org/10.21037/aoj.2018.12.09
9. Shah SS, Sahota S, Denard PJ, Provencher MT, Parsons BO, Hartzler RU, et al. Variability in total shoulder arthroplasty planning software compared to a control CT-derived 3D printed scapula. Shoulder Elbow 2019. https://doi.org/10.1177/1758573219888821
10. Tversky A, Kahneman D. Judgment under uncertainty: heuristics and biases. Science 1974;185:1124-31.
11. Weinheimer KT, Smuin DM, Dhawan A. Patient outcomes as a function of shoulder surgeon volume: a systematic review. Arthroscopy 2017;33:1273-81. https://doi.org/10.1016/j.arthro.2017.03.005