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Short-term clinical and radiologic outcomes of reverse total shoulder arthroplasty with navigation system in the Asian population: a retrospective comparative study

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A R T I C L E I N F O

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Level of evidence: Level III; Retrospective Cohort Comparison; Treatment Study

Background: In reverse total arthroplasty (rTSA), glenoid component positioning is a critical factor for outcomes especially in Asian populations with smaller glenoids. The purpose of this study was to compare the clinical and radiologic outcomes of rTSA with and without the navigation system with a minimum follow-up of 2 years in the Asian population.

Methods: This was a retrospective comparative study of 33 rTSAs with the navigation system (NAV group) and 40 conventional rTSAs (CON group). Radiologic measurements regarding the position of the glenoid component, glenoid vault perforation by the central cage, and scapular notching, as well as clinical outcomes including range of motion, functional scores, and complications were compared. Number, length, and angulation of screws were assessed.

Results: The mean age was 73.9 ± 5.9 years with a mean follow-up of 30.1 ± 6.4 months. The NAV group more frequently utilized augmented baseplate ($P < .001$), showed less superior inclination ($P = .030$) and had lower incidence of glenoid vault perforation ($P = .040$). The length of superior ($P = .001$) and inferior screws ($P = .045$) was longer in the NAV group. In the NAV group compared to the CON group, more inferior orientation of superior screws ($P < .001$), more anterior orientation for inferior screws ($P = .031$), and anterior screws ($P = .003$) were observed. The NAV group showed significantly less penetration into the suprascapular fossa by a superior screw ($P = .007$). Final range of motion, functional scores, and complications showed no significant differences between the 2 groups.

Conclusion: In the short-term follow-up, the use of a navigation system in rTSA showed no significant difference in clinical outcomes and complications compared to conventional implantation. However, it enabled a lower superior inclination and a reduced glenoid vault perforation by the central cage, simultaneously allowing for the insertion of longer peripheral screws in a safer direction compared to conventional implantation.

The glenoid component positioning is known to be one of the key factors influencing longevity and outcomes of reverse total arthroplasty (rTSA).[2] Although precise standards for optimal glenoid component position in rTSA remain debatable, several factors have been reported to reduce scapular notching, instability, and implant failure.[5,11,24,42] These include factors related to the position of the glenoid baseplate, such as reaming depth, superior inclination,[24,42] retroversion,[18] and inferior overhang,[11,24] as well as those related to fixation, including screw length and the position of the central peg.[5,25]

This retrospective chart review study involving human participants was in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The Human Investigation Committee of Samsung Medical Center (SMC no. 2023-12-100) approved the study. Consent for participate was waived because of retrospective study design and no additional harm to the patients. Consent for publish was waived because of retrospective study design and no additional harm to the patients.

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While thorough preoperative planning is crucial for appropriate insertion of baseplate, executing the procedure according to the preoperative plan can also be technically challenging.[41] Particularly in Asian populations with small glenoid morphology,[3] the limited surgical field and bone stock further compound the difficulty in glenoid procedure.[16] Therefore, the navigation system including preoperative planning software and intraoperative navigation monitoring has been establishing itself as an effect tool in reducing deviation from the planned baseplate position. A recent meta-analysis by Velasquez et al revealed that the navigation system improved the accuracy of baseplate positioning.[45] Moreover, it has been reported that the ability of the navigation to provide real-time feedback allows for the visualization of the glenoid vault position, aiding in the determination of the baseplate insertion site and maximizing screw length.[44,45]

Nevertheless, studies on the clinical outcomes of rTSA with the navigation system are limited in number. To our knowledge, there are only few studies that compare the clinical and radiologic outcomes, as well as complications, of rTSA with and without the navigation system in Asian population. Thus, this study aims to compare clinical and radiologic outcomes of rTSA with and without the navigation system in an Asian population with a minimum follow-up of 2 years. We hypothesized that the use of the navigation system in rTSA would not compromise clinical outcomes but would lead to differences in radiologic outcomes in terms of glenoid component and peripheral screw positioning compared with conventional rTSA in the short-term follow-up.

Methods

This retrospective study was performed after institutional review board approval (SMC no. 2023-12-100). Since this study did not impose additional harm on patients and given its retrospective design analyzing electronic medical records and imaging tests, the requirement for informed consent was waived. The study assessed 95 patients who underwent primary rTSA between September 2019 and December 2021, who were included. The inclusion criteria were patients with a preoperative diagnosis of irreparable rotator cuff tear, cuff tear arthropathy, or glenohumeral osteoarthritis. The exclusion criteria included a preoperative diagnosis of avascular necrosis, fracture, rheumatoid arthritis, or those who had less than 2-year postoperative follow-up.

Baseline characteristics, including age at the time of surgery, sex, follow-up duration, involvement of dominant arm, height, body mass index, and diabetes mellitus, were collected from the electronic medical record.

Preoperative planning

The goals for glenoid component placement included (1) positioning the central cage within the glenoid vault,[30] (2) achieving an inclination of 0°,[11,33] (2) setting the version between 5° of retroversion and 5° of anteversion,[18] (4) ensuring a minimum of 3.5 mm of inferior overhang,[6] and (5) considering the use of a small baseplate based on native glenoid size.[20]

Patients included in the study underwent rTSA using a single implant system (Equinoxe; Exactech Inc., Gainesville, FL, USA). After October 2020, the use of a navigation system (ExactechGPS; Exactech Inc., Gainesville, FL, USA) became available. Planning for conventional rTSA involved preoperative radiographs and 3-dimensional computed tomography (3D-CT) scans without specific preoperative planning software. If the glenoid height exceeded that of the standard baseplate, a small baseplate was planned for use.[20] Subsequently, the superoinferior position of the glenoid baseplate to achieve the target inferior overhang was determined. The reaming depth to achieve the target inclination using the supraspinatus fossa line as a reference,[42] along with the Friedman's axis for target retroversion,[9] was planned. Particularly, in cases where it was estimated that the scapular neck length (SNL) would be 9 mm or less due to the required reaming to achieve the target inclination, consideration was given to the use of a metal-augmented baseplate.[31] In contrast, navigation rTSA planning utilized the planning software (Exactech Blue Ortho, Grenoble, France) based on 3D-CT scans. Therefore, the same target position was determined using 3D simulation.

Surgical technique

All surgeries were conducted by a single senior surgeon (JCY) using a beach chair position and deltopectoral approach. The long head of biceps tendon was transected, followed by detachment, and tagging of the subscapularis tendon with nonabsorbable suture. The humeral head was dislocated and resected at a retroversion of 20°.

In the conventional (CON) group, the superoinferior position of the center pin within the glenoid was manually measured intraoperatively following preoperative planning to achieve the target inferior overhang. If a metal-augmented baseplate was chosen after preoperative planning, it was inserted after minimal reaming perpendicular to the native glenoid face. For standard baseplates, the reaming depth determined through preoperative planning was manually measured intraoperatively to decide the extent of reaming, and eccentric high-side reaming to correct the inclination was conducted.[32] Drilling for the peripheral variable-angle compression screws was performed toward the coracoid base and the scapular body at the superior and inferior screw holes,[13] respectively, followed by insertion. Subsequently, anterior screw was inserted.

In the navigated (NAV) group, a coracoid tracker was affixed to the coracoid process, followed by the registration of anatomical landmarks using a hand-held tracker. Subsequent steps of glenoid reaming, center pin insertion, and baseplate insertion were performed in accordance with the preoperative planning, guided by real-time feedback. This was made possible since the navigation system visualizes the position of the center pin and the reaming depth in real time to meet the baseplate position determined by the 3D preoperative planning software. For screw placement, the longest possible trajectories within the glenoid vault were identified and utilized at the superior, inferior, and anterior positions, with real-time verification. In both groups, an additional posterior screw was inserted if at least 2 screws failed to achieve firm fixation.

Finally, the glenosphere was inserted, the humeral stem was positioned at a 20° retroversion, and the subscapularis tendon was reattached to the lesser tuberosity.

Radiologic evaluation

Plain radiographs, including glenohumeral anteroposterior and axillary lateral views were used to measure the native glenoid inclination (β-angle)[27] preoperatively, and the inclination and the inferior overhang of the glenoid component postoperatively.[20] Scapular notching was evaluated 2 years postoperatively using the Nerot-Sirveaux classification.[37] In cases where an acromial stress fracture was suspected, an additional CT scan was performed and the appearance was classified as described by Levy et al.[23]

The height, width, and retroversion of the native glenoid were measured using preoperative 3D-CT scans.[9] Postoperative 3D-CT scans were also acquired 2 months postsurgery for all patients to assess early failures,[46] the retroversion of the glenoid component, and perforation of the glenoid vault by the baseplate central

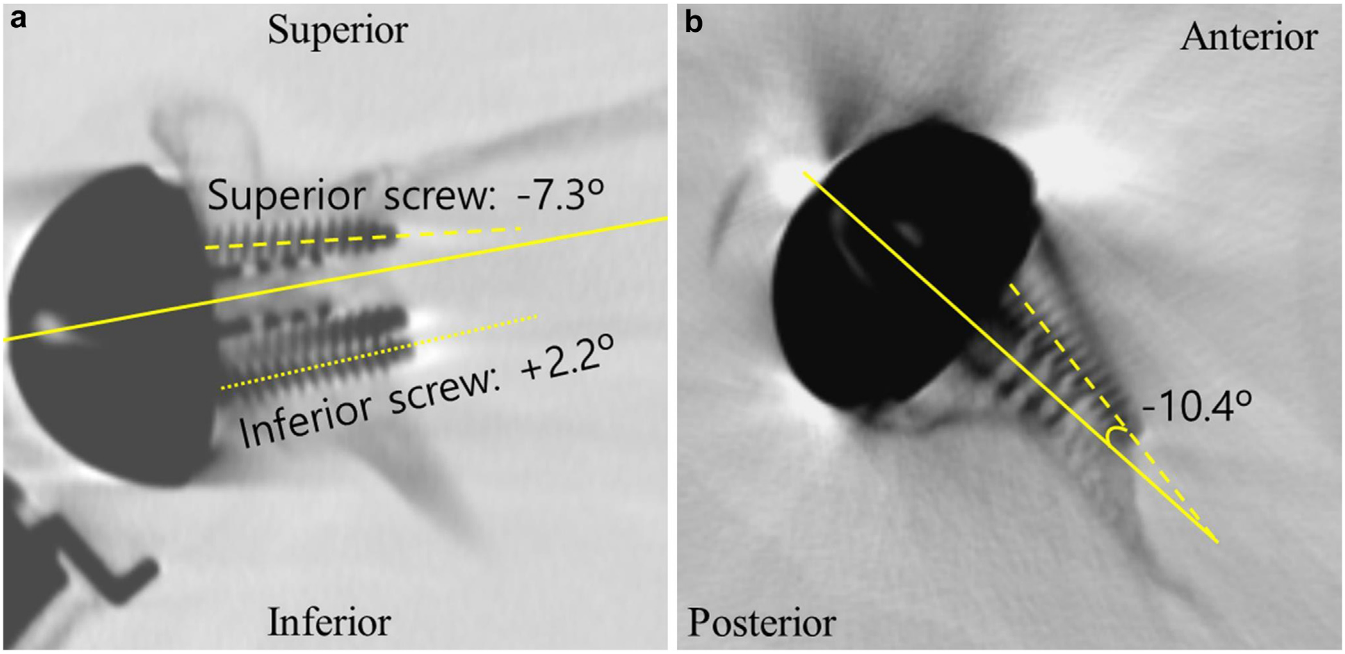

Figure 1 Measurement of screw orientation in 2-month postoperative CT. (**a**) The superoinferior orientation of screws (), based on the central cage axis (), was measured in the oblique coronal view. Note that positive values indicate a superior direction, while negative values indicate an inferior direction compared to the central cage axis. (**b**) The anteroposterior orientation of screw (), based on the central cage line (), was measured in the axial view. Note that positive values indicate an anterior direction, while negative values indicate a posterior direction compared to the central cage axis. *CT*, computed tomography.

cage.[20,29] Orientations of each screws were assessed in the oblique coronal (Fig. 1, *a*) and axial planes (Fig. 1, *b*), measuring the angle between the cage axis and the screw axis.[29] To reduce inconsistencies in measurements, the oblique coronal, oblique sagittal and axial planes in postoperative 3D-CT scans were reconstructed using the same criteria for all patients: the most medial point on the scapular spine border, the inferior angle of the scapular body, and the center of the baseplate central cage.[47] Additionally, the evaluation included whether the superior screw penetrated into the suprascapular fossa (Fig. 2).

All radiologic evaluations were independently and blindly performed by 2 shoulder-trained orthopedic surgeons (JSK, JHP), and inter-rater reliability were established.

Clinical evaluation

All patients were evaluated a day before surgery. Postoperative evaluations were conducted at 2, 6, and 12 months and annually on an outpatient basis. Active range of motion (ROM) including forward elevation, external rotation (ER) at side, internal rotation (IR) (behind-the-back, T1 to 12 scoring 1 to 12; L1 to 5 scoring 13 to 17; and buttock scoring 18), and abduction were assessed. Functional scores including a visual analog scale for pain and function, the American Shoulder and Elbow Surgeons,[28] and Constant scores[7] were evaluated by a shoulder-specialized physiotherapist (SML).

Statistical analysis

R studio (version1.3.959, build 554; Posit, Boston, MA, USA) was used for all statistical analysis. Comparison of the mean values between the groups was performed using the unpaired *t*-test or Mann-Whitney U test for continuous variables. Categorical data were compared using the chi-squared or Fisher's exact test. Preoperative to postoperative changes in the same group were analyzed using paired *t*-test or Wilcoxon's signed-rank test. The interobserver reliability was calculated by evaluating intraclass correlation coefficients for numerical data and Cohen's kappa (κ) coefficient for categorical data, and was interpreted as follows: <0.40, poor; 0.40 to 0.59, fair; 0.60 to 0.74, good; and >0.74, excellent.[4] The power analysis was conducted using G*Power version 3.1.9.4 (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany). The threshold for statistical significance was defined as $\alpha < 0.05$ for a 2-sided test, and the power for each statistical analysis was calculated given the sample size.

Results

Of the initial 91 patients assessed, a total of 71 patients were evaluated in this study after excluding the exclusion criteria (proximal humerus fracture, n = 1; rheumatoid arthritis, n = 3, and follow-up less than 2 years, n = 18). The final cohort contained 33 patients in the NAV group and 40 patients in the CON group with follow-up rate 82.5% (33 of 40) and 78.4% (40of 51), respectively (Fig. 3). Demographics and surgical characteristics are demonstrated in Table I. Mean age was 73.9 ± 5.9 years, mean follow-up was 30.1 ± 6.4 months (range, 23.8-48.5), and there were no differences in demographics between the groups. The augmented baseplates were more frequently used in the NAV group (87.9% vs. 20.0%, $P < .001$). The operating time was significantly longer in the NAV group than the CON group (98.0 ± 15.6 minutes vs. 86.3 ± 15.2 minutes, $P = .002$).

At the baseline, there were no significant differences in radiologic measurements between the groups. However, postoperatively it was observed that the superior inclination of the glenoid component was significantly lower in the NAV group (3.4 ± 4.0° vs. 6.5 ± 6.7°, $P = .030$). Additionally, the incidence of glenoid vault perforation by central cage was significantly lower in the NAV group (12.1% vs. 32.5%, $P = .040$) (Table II). The interobserver reliabilities for all radiologic measurements were graded as excellent. Power using the data of the comparison for the superior inclination

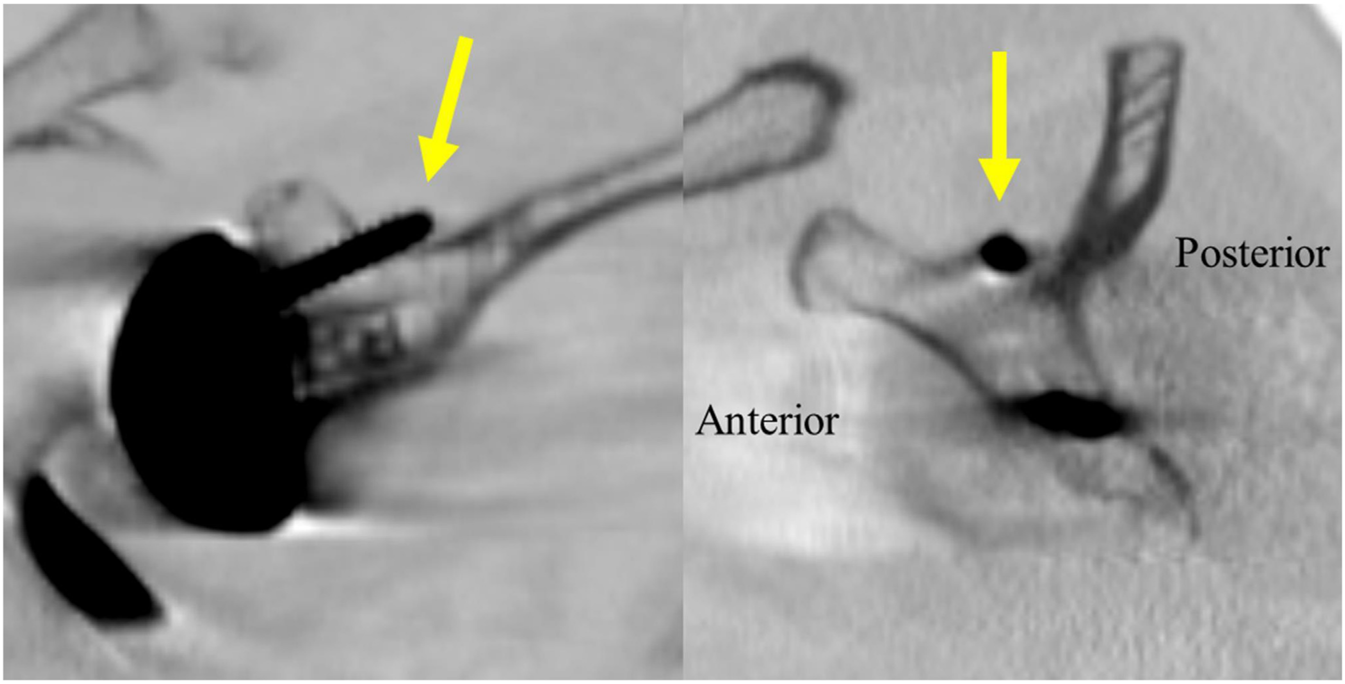

Figure 2 Penetration of superior screw into the suprascapular fossa in the oblique coronal and oblique sagittal CT view, two months postoperatively. (→) indicates the penetration of superior screw into the suprascapular fossa. *CT*, computed tomography.

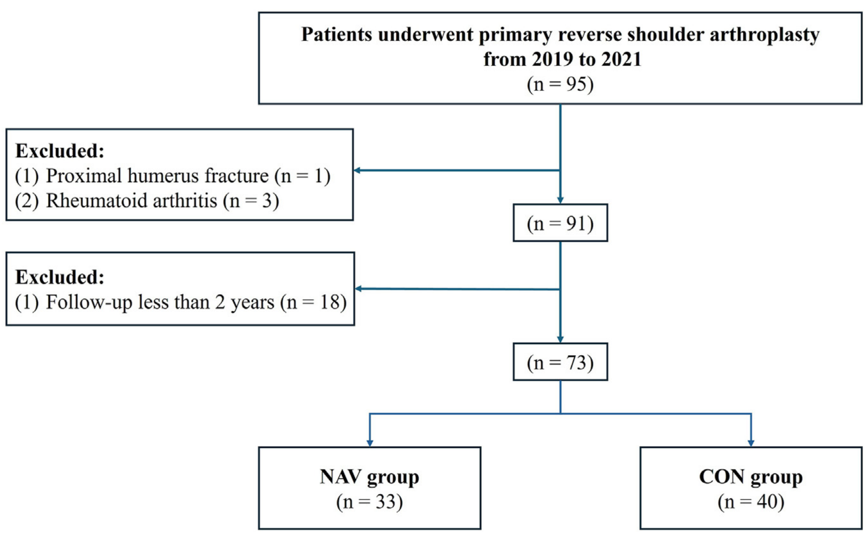

Figure 3 A flowchart of patient selection. *NAV*, navigation reverse total arthroplasty; *CON*, conventional reverse total arthroplasty.

and the incidence of glenoid vault perforation were 0.67 and 0.96, respectively.

There was no significant difference in the number of used screws between the groups. However, the NAV group utilized significantly longer superior (29.4 ± 4.7 mm vs. 25.7 ± 4.0 mm, $P = .001$) and inferior (27.6 ± 5.4 mm vs. 25.0 ± 4.1 mm, $P = .045$) screws. In the analysis of screw orientation of the NAV group compared to the CON group in the coronal and axial planes (Table III), superior screws showed more inferior orientation (−2.5 ± 5.1° vs. 3.7 ± 5.7°, $P < .001$) (Fig. 4, *a*), inferior screws showed more anterior orientation (−1.3 ± 4.9° vs. −4.3 ± 6.2°, $P = .031$) (Fig. 4, *b*), and anterior screws showed more anterior orientation (−4.5 ± 7.1° vs. −9.8 ± 6.1°, $P = .003$) (Fig. 4, *c*). Finally, the rate of superior screw penetration into the suprascapular fossa was significantly lower in the NAV group (3.2% vs. 27.5%, $P = .007$). The interobserver reliability was good to excellent for screw angulation and excellent for suprascapular fossa penetration. The calculated powers were 0.95 and 0.68 for screw length; 0.99, 0.70, and 0.93 for screw orientation; and 0.99 for superior screw penetration into the suprascapular fossa.

The ROM and patient-reported outcomes improved significantly in both groups except for ER and IR, with no significant differences between the groups preoperatively and postoperatively (all $P > .05$) (Table IV). The improvements of ROM and patient-reported outcomes also showed no differences between the groups (all $P > .05$). There were no significant differences between the NAV and CON

Table I
Patient demographics and surgical characteristics.*

Variables	Overall	NAV	CON	P value
Number of shoulders	73	33	40	
Sex, M:F	16:57	7:26	9:31	.895
Mean age, y	73.9 ± 5.9	74.0 ± 7.2	73.8 ± 4.8	.887
Diagnosis, IMRCT: CTA: GHOA	26 : 29 : 18	12 : 14 : 7	14 : 15 : 11	.815
Follow-up, mo	30.1 ± 6.4	29.6 ± 7.3	30.4 ± 5.5	.297
Involvement of dominant arm	52 (71.2)	25 (75.8)	27 (67.5)	.438
Mean height, cm	153.6 ± 8.3	153.4 ± 9.7	153.7 ± 7.2	.715
Mean BMI, kg/m^2	25.6 ± 3.6	25.6 ± 4.0	25.5 ± 3.2	.829
DM	14 (19.2)	7 (21.2)	7 (17.5)	.688
Baseplate, standard: small	21 : 52	11 : 22	10 : 30	.434
Augment baseplate used	37 (50.7)	29 (87.9)	8 (20)	<.001†
None: Sup: Post: Postsup	36 : 27: 8 : 2	4 : 24: 4 : 1	32 : 3: 4 : 1	
Size of the glenosphere 36 mm: 38 mm	66 : 7	29 : 4	37 : 3	.694
Subscapularis repair	56 (76.7)	26 (78.8)	30 (75.0)	.703
Operating time, min	91.6 ± 16.4	98.0 ± 15.6	86.3 ± 15.2	.002†

NAV, navigation rTSA group; *CON*, conventional rTSA group; *IMRCT*, irreparable massive rotator cuff; *CTA*, cuff tear arthropathy; *GHOA*, glenohumeral osteoarthritis; *BMI*, body mass index; *DM*, diabetes mellitus; *Sup*, superior; *Post*, posterior; *Postsup*, posterosuperior.
*Data are presented as mean ± standard deviation or number (percentage).
†Statistically significant ($P < .05$).

Table II
Comparison for preoperative and postoperative radiologic measurements.*

Variables	NAV	CON	P value
Preoperative			
Mean glenoid height, mm	32.8 ± 3.4	33.5 ± 3.8	.712
Mean glenoid width, mm	25.9 ± 2.9	25.4 ± 3.1	.344
Mean native β-angle, °	9.0 ± 5.4	8.6 ± 5.2	.705
Mean native retroversion, °	3.6 ± 5.39	6.6 ± 14.5	.346
Postoperative			
Mean postoperative inclination, °	3.4 ± 4.0	6.5 ± 6.7	.030†
Mean postoperative retroversion, °	1.4 ± 4.3	1.5 ± 4.8	.835
Mean inferior overhang, mm	5.6 ± 1.3	5.5 ± 2.1	.400
Glenoid vault perforation	4 (12.1)	13 (32.5)	.040†
Scapular notching	3 (9.1)	8 (20.0)	.195
Acromial fracture	1 (3.0)	2 (5.0)	1.000

NAV, navigation rTSA group; *CON*, conventional rTSA group; *rTSA*, reverse total shoulder arthroplasty.
*Data are presented as mean ± standard deviation or number (percentage).
†Statistically significant ($P < .05$).

Table III
Comparison for baseplate screw length, orientation, and supraspinatus fossa penetration by a superior screw.*

Variables	NAV	CON	P value
Mean number of screws	3.2 ± 0.4	3.2 ± 0.4	.435
Mean length of the screw, mm			
Superior screw	29.4 ± 4.7	25.7 ± 4.0	.001†
Inferior screw	27.6 ± 5.4	25.0 ± 4.1	.045†
Anterior screw	27.9 ± 5.1	26.0 ± 5.4	.153
Mean angulation of the superior screw, °			
Coronal plane‡	−2.5 ± 5.1	3.7 ± 5.7	<.001†
Axial plane§	1.7 ± 4.8	3.3 ± 5.6	.253
Mean angulation of the inferior screw, °			
Coronal plane‡	2.7 ± 5.8	0.3 ± 7.1	.138
Axial plane§	−1.3 ± 4.9	−4.3 ± 6.2	.031†
Mean angulation of the anterior screw, °			
Coronal plane‡	4.5 ± 4.2	4.2 ± 4.7	.844
Axial plane§	−4.5 ± 7.1	−9.8 ± 6.1	.003†
Supraspinatus fossa penetration	1 (3.2)	11 (27.5)	.007†

NAV, navigation rTSA group; *CON*, conventional rTSA group; *SD*, standard deviation; *rTSA*, reverse total shoulder arthroplasty.
*Data are presented as mean ± standard deviation or number (percentage).
†Statistically significant ($P < .05$).
‡Positive values indicate a superior direction, while negative values indicate an inferior direction compared to the central cage axis.
§Positive values indicate an anterior direction, while negative values indicate a posterior direction compared to the central cage axis.

group in terms of dislocation, which occurred in 1 patient in each group (3.0% vs. 2.5%, $P = 1.000$), or in acromial stress fracture (3.0% vs. 5.0%, $P = 1.000$). Glenoid component loosening and periprosthetic infection were not observed in either group. There were no complications associated with navigation such as coracoid fracture or system failure.

Discussion

In this study, it was found that the use of the navigation system in rTSA can reduce the superior inclination of the glenoid component and decrease glenoid vault perforation. Additionally, it was observed that longer screws for glenoid baseplate fixation could be inserted with fewer perforations into the suprascapular fossa with intraoperative navigation.

Superior inclination of the glenoid component has been reported to be a major cause of scapular notching, instability, and reduction in ROM after rTSA.[11,36,42] In this study, a significantly lower glenoid component inclination was observed in the NAV group compared to the CON group as Gaj et al reported.[10] This appears to be attributable to the increased use of augmented baseplates for the correction of superior inclination, which aligns with the findings of a systematic review by Velasquez et al,[45] which reported that 74.34% of pooled cases in the NAV group used augmented baseplates, compared to only 32.22% in the CON group. This phenomenon stems more from a deeper understanding of glenoid deformity through 3D planning software than from the navigation system itself.[35] However, the routine use of augmented baseplates without appropriate reaming of the glenoid should be avoided, as it can lead to excessive lateralization on the glenoid side, potentially causing overstuffing,[26] acromial stress fracture,[21] or a reduction in ROM.[39] Therefore, in deformity correction using augmented baseplates, the navigation system plays a crucial role in achieving the planned baseplate positioning and reaming depth. Simultaneously, in patients with limited bone stock, such as Asians or those with glenoid bone defects, the absence of real-time feedback during eccentric high-side reaming can lead to excessive medialization,[21] potentially causing scapular notching and limited impingement-free adduction.[1,33] In particular, Fortun et al[8] reported that the SNL for Caucasians and African-Americans was 10.8 ± 3.3 and 10.0 ± 3.2 mm, respectively, whereas Arashiro et al[1] reported that the SNL for Asians was 8.2 ± 1.9 mm. Therefore, in

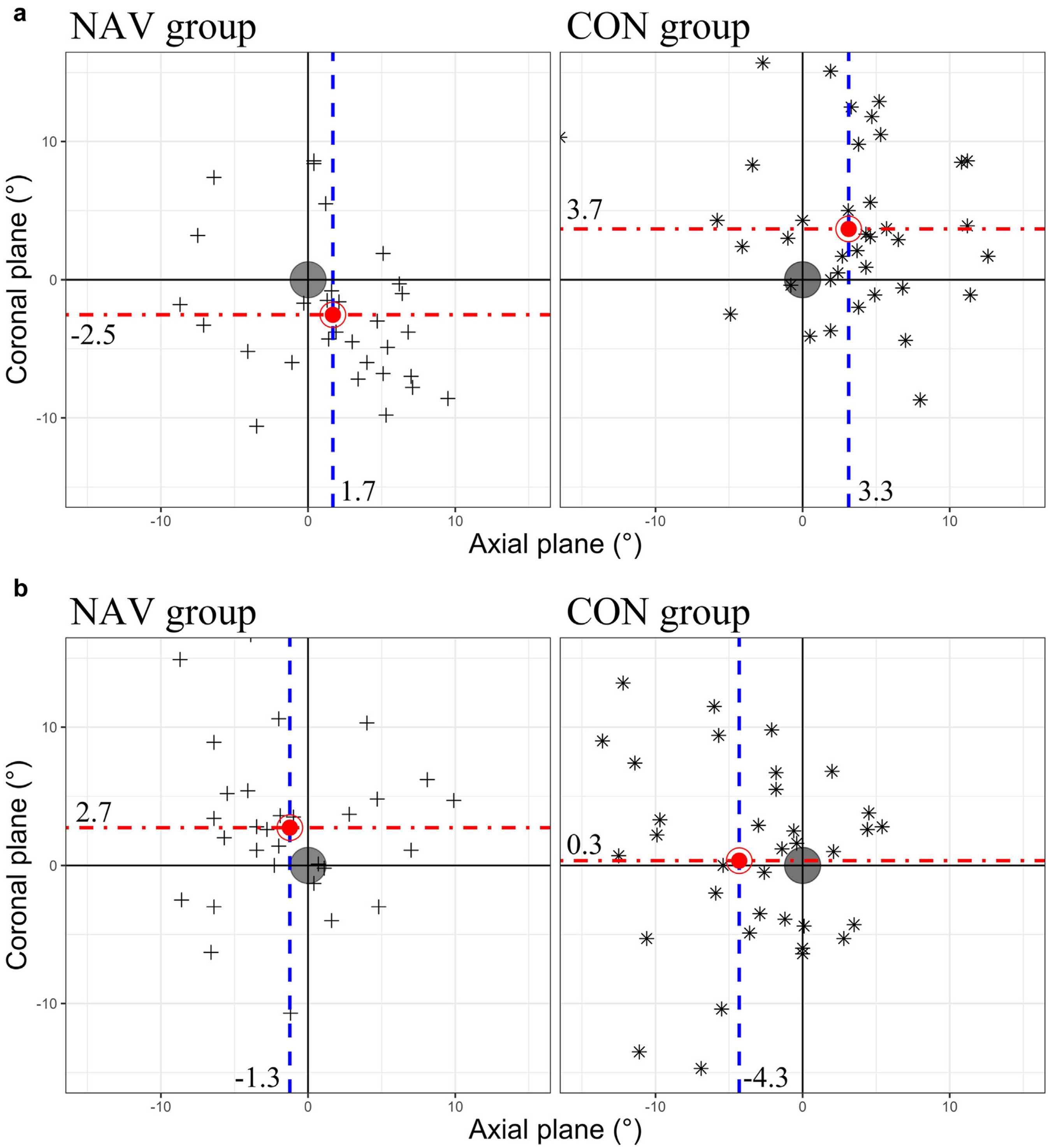

Figure 4 Scatter plots of screw orientation for the NAV group (*left*) and CON group (*right*). The (●) indicates the center of each screw hole, and the (◉) represents the mean orientation of the screw for each group. Positive values indicate superior direction in the coronal plane, anterior direction in the axial plane, respectively. (**a**) Superior screw. (**b**) Inferior screw. (**c**) Anterior screw. *NAV*, navigation reverse total shoulder arthroplasty; *CON*, conventional reverse total shoulder arthroplasty.

Asians, correction of superior inclination solely through inferior reaming must be cautious. In this study, while there was no significant difference in scapular notching between 2 groups, incidence rate of the scapular notching was more than double in the CON group despite almost identical inferior overhang. Therefore, the navigation system can be an effective tool for surgeons, capable of improving superior inclination while preventing excessive medialization or lateralization in patients with a small glenoid morphology.[1,24]

Unlike baseplate fixation with a central screw,[43] there are concerns in central cage type baseplate fixation that perforation of the glenoid vault by the cage may weaken the initial fixation[5] and

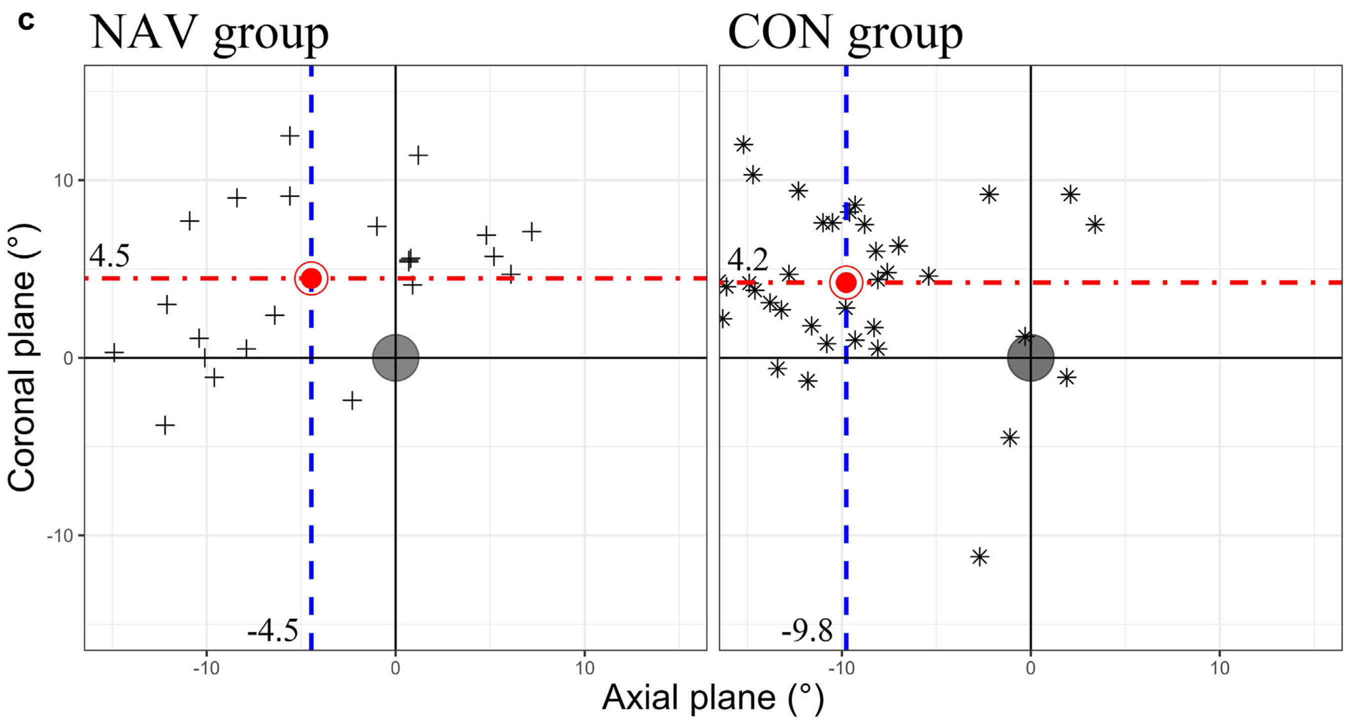

Figure 4 (*continued*).

potentially lead to glenoid component loosening.[22,40] Jeong et al[15] reported that the optimal insertion site for placing a central cage within the glenoid vault in the Asian population is located 2-mm inferior and posterior to the intersection point of the vertical and horizontal axes of the glenoid. However, inserting a guide pin accurately into the posteroinferior area of the glenoid is challenging, especially in the Asian population with smaller glenoid sizes and narrow surgical fields.[16] In this study, the effectiveness of the navigation system in positioning the cage within the vault was demonstrated by the significant difference in the rates of glenoid vault perforation between the groups. While glenoid component failure did not occur in both groups, it can be expected that a firmer fixation of baseplate can be achieved through the navigation system.

Length and numbers of baseplate peripheral screws have been reported to be the key elements in ensuring secure fixation of the baseplate.[25,34] Especially in patients with limited bone stock, it is important to insert the minimal number of screws while maximizing their length to preserve bone stock.[25,34,38] However, an important consideration is the potential for complications arising from inserting screws along a problematic trajectory. Several studies have reported instances of suprascapular nerve injury due to the penetration of the superior screw into the suprascapular fossa,[17] and Jang et al have demonstrated that 12% of superior screws had a high risk of iatrogenic suprascapular neuropathy.[14] In this study, it was observed that the NAV group had significantly fewer instances of superior screw penetration into the suprascapular fossa, while also utilizing longer superior and inferior screws, which have been reported as the most crucial screws in reducing micromotion.[25] These results are consistent with studies that indicate the use of a navigation system enables the insertion of longer peripheral screws.[19,44] Conversely, the screw orientation observed in this study exhibited differences compared to the findings reported by Nashikkar et al,[29] which were measured using the same reference and method in coronal and axial planes. Among their results,[29] the observation that the superior screws exhibited more inferior angulation when using navigation was consistent with our study. However, their findings that the anterior and inferior screws demonstrated more posterior angulation were contradicted by the results of our study. These discrepancies may be interpreted as an advantage of the navigation, reflecting the need to accommodate interethnic variations in scapular bone anatomy[3] and individual differences in deformity[5] to achieve optimal screw purchase. Therefore, the results of this study suggest that in the Asian population, achieving reduced screw misplacement and longer screw purchase may require different screw orientations than those previously reported, and the navigation system in rTSA can effectively facilitate this.

This study failed to identify significant differences in ROM, patient-reported outcomes, and complications between the groups. These results are comparable with those of other studies that compared clinical outcomes between groups using navigation and those not using it after a similar follow-up period.[10,12] In contrast, a study by Youderian et al,[48] involving a larger cohort, reported that the use of navigation led to higher IR and ER after 2-year follow-up. However, the ROM data in the study by Youderian et al[48] only include comparisons of final outcomes, lacking data on intergroup differences during the preoperative period. Therefore, the impact of navigation on clinical outcomes appears to warrant further investigation through prospective randomized studies. In most short-term follow-up studies, similar to our study, there were no significant differences observed between the groups in terms of complications such as scapular notching,[12,48] acromial stress fracture,[12,48] glenoid loosening,[48] and dislocation.[10,12] Furthermore, there were no instances of fracture caused by the coracoid tracker used during navigation rTSA in our study. Therefore, in the short-term follow-up, navigation rTSA can be considered comparable to conventional rTSA in terms of clinical outcomes and complications. However, a 2-year follow-up is relatively short to detect differences in clinical outcomes, especially considering the very low incidence rate of complications. Therefore, to generalize the effects of a navigation system on ROM, clinical outcomes, and complications

Table IV
Comparison for range of motion and patient-reported outcomes at preoperative and final follow-up*

Variables	NAV	CON	P value†
Mean active FE, °			
Preoperative	95.8 ± 49.5	110.5 ± 43.4	.236
Final	128.6 ± 17.2	135.3 ± 15.2	.088
P value‡	<.001§	.001§	
Mean active ER, °			
Preoperative	30.2 ± 21.7	34.1 ± 22.1	.443
Final	32.6 ± 14.5	30.6 ± 17.7	.634
P value‡	.680	.312	
Mean active IR score			
Preoperative	13.9 ± 4.6	12.4 ± 4.8	.148
Final	12.5 ± 3.7	13.2 ± 3.1	.470
P value‡	.300	.578	
Mean active ABD, °			
Preoperative	97.2 ± 47.7	104.7 ± 43.3	.574
Final	124.8 ± 20.0	131.1 ± 23.7	.117
P value‡	.036§	<.001§	
Mean PVAS			
Preoperative	5.3 ± 1.6	4.7 ± 1.2	.195
Final	2.3 ± 1.3	2.1 ± 1.2	.392
P value‡	<.001§	<.001§	
Mean FVAS			
Preoperative	3.9 ± 1.9	4.2 ± 1.8	.522
Final	6.6 ± 1.6	7.0 ± 1.3	.443
P value‡	<.001§	<.001§	
Mean ASES score			
Preoperative	37.7 ± 12.7	42.4 ± 12.6	.064
Final	59.5 ± 13.7	62.5 ± 11.0	.347
P value‡	<.001§	<.001§	
Mean Constant score			
Preoperative	32.3 ± 16.4	38.1 ± 15.9	.136
Final	48.5 ± 11.3	50.6 ± 7.7	.386
P value‡	<.001§	<.001§	

NAV, navigation rTSA group; *CON*, conventional rTSA group; *FE*, forward elevation; *ER*, external rotation; *IR*, internal rotation; *ABD*, abduction; *PVAS*, visual analog scale for pain; *FVAS*, visual analog scale for functional; *ASES*, American Shoulder and Elbow Surgeons; *rTSA*, reverse total shoulder arthroplasty.
*Data are presented as mean ± standard deviation or number (percentage).
†Comparison between the two groups.
‡Comparison of preoperative and postoperative values in the same group.
§Statistically significant ($P < .05$).

after rTSA, further research utilizing prospective design with a larger sample size and a longer follow-up duration.

A strength of this study is that comparative analysis of the effects of using the navigation system in rTSA performed by a single surgeon, examining radiologic and clinical outcomes as well as complications. However, this study also has several limitations. Firstly, as this study was retrospective nonrandomized in design, and that may introduce potential selection and measurement biases. However, there were no preoperative differences between the 2 groups, and measurements were conducted blindly using the same method to minimize these biases. Secondly, although screw orientation was measured using standardized CT reconstruction method, it was not measured with precise 3D software, which could result in measurement error. Thirdly, the follow-up period was relatively short to analyze late complications, thus limiting our analysis to only early complications. Fourthly, the number of patients enrolled may be small to discern significant differences in clinical outcomes. Fifthly, the lack of long-term studies on lateralization and fixation stability due to metal-augmented baseplates precludes understanding the impact of increased use of augmented baseplates associated with navigation usage. Lastly, because preoperative planning in the CON group did not utilize planning software, it is challenging to discern whether the outcomes in our study were influenced by planning software or intraoperative navigation. However, Gaj et al[10] reported significant differences between preoperatively planned and postoperative superior inclination only in the group that did not use intraoperative navigation, despite both groups being planned with the same planning software. Therefore, it can be inferred that the results of this study were primarily influenced by the intraoperative navigation, which visualizes the plan in real time rather than the preoperative planning software.

Conclusion

In the short-term follow-up, the use of a navigation system in rTSA showed no significant difference in clinical outcomes and complications compared to conventional implantation. However, it enabled a lower superior inclination and a reduced glenoid vault perforation by the central cage, simultaneously allowing for the insertion of longer peripheral screws in a safer direction compared to conventional implantation.

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Data availability

The data that support the findings for this study are available to other researchers from the corresponding author upon reasonable request.

References

1. Arashiro Y, Izaki T, Miyake S, Shibata T, Yoshimura I, Yamamoto T. Influence of scapular neck length on the extent of impingement-free adduction after reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2022;31:185-91. https://doi.org/10.1016/j.jse.2021.07.005.
2. Bacle G, Nové-Josserand L, Garaud P, Walch G. Long-term outcomes of reverse total shoulder arthroplasty: a follow-up of a previous study. J Bone Joint Surg Am 2017;99:454-61. https://doi.org/10.2106/jbjs.16.00223.
3. Cabezas AF, Krebes K, Hussey MM, Santoni BG, Kim HS, Frankle MA, et al. Morphologic variability of the shoulder between the populations of North American and East Asian. Clin Orthop Surg 2016;8:280-7. https://doi.org/10.4055/cios.2016.8.3.280.
4. Cicchetti DV, Sparrow SA. Developing criteria for establishing interrater reliability of specific items: applications to assessment of adaptive behavior. Am J Ment Defic 1981;86:127-37.
5. Codsi MJ, Iannotti JP. The effect of screw position on the initial fixation of a reverse total shoulder prosthesis in a glenoid with a cavitary bone defect. J Shoulder Elbow Surg 2008;17:479-86. https://doi.org/10.1016/j.jse.2007.09.002.
6. Collotte P, Bercik M, Vieira TD, Walch G. Long-term reverse total shoulder arthroplasty outcomes: the effect of the inferior shifting of glenoid component fixation. Clin Orthop Surg 2021;13:505-12. https://doi.org/10.4055/cios20245.
7. Constant CR, Gerber C, Emery RJ, Søjbjerg JO, Gohlke F, Boileau P. A review of the Constant score: modifications and guidelines for its use. J Shoulder Elbow Surg 2008;17:355-61. https://doi.org/10.1016/j.jse.2007.06.022.
8. Fortun CM, Streit JJ, Horton SA, Muh SJ, Gillespie RJ, Gobezie R. Scapular neck length and implications for reverse total shoulder arthroplasty: an anatomic study of 442 cadaveric specimens. Int J Shoulder Surg 2015;9:38-42. https://doi.org/10.4103/0973-6042.154754.
9. Friedman RJ, Hawthorne KB, Genez BM. The use of computerized tomography in the measurement of glenoid version. J Bone Joint Surg Am 1992;74:1032-7.
10. Gaj E, Pagnotta SM, Berlinberg EJ, Patel HH, Picconi O, Redler A, et al. Intraoperative navigation system use increases accuracy of glenoid component inclination but not functional outcomes in reverse total shoulder arthroplasty: a prospective comparative study. Arch Orthop Trauma Surg 2024;144:91-102. https://doi.org/10.1007/s00402-023-05038-y.
11. Gutiérrez S, Walker M, Willis M, Pupello DR, Frankle MA. Effects of tilt and glenosphere eccentricity on baseplate/bone interface forces in a computational model, validated by a mechanical model, of reverse shoulder arthroplasty. J Shoulder Elbow Surg 2011;20:732-9. https://doi.org/10.1016/j.jse.2010.10.035.

12. Holzgrefe RE, Hao KA, Panther EJ, Schoch BS, Roche CP, King JJ, et al. Early clinical outcomes following navigation-assisted baseplate fixation in reverse total shoulder arthroplasty: a matched cohort study. J Shoulder Elbow Surg 2023;32:302-9. https://doi.org/10.1016/j.jse.2022.07.007.
13. Humphrey CS, Kelly JD 2nd, Norris TR. Optimizing glenosphere position and fixation in reverse shoulder arthroplasty, Part Two: the three-column concept. J Shoulder Elbow Surg 2008;17:595-601. https://doi.org/10.1016/j.jse.2008.05.038.
14. Jang YH, Oh SY, Kim SH. Three-dimensional analysis of baseplate screw penetration in reverse total shoulder arthroplasty: risk of iatrogenic suprascapular neuropathy by screw violation. J Shoulder Elbow Surg 2022;31:940-7. https://doi.org/10.1016/j.jse.2021.10.024.
15. Jeong HJ, Jeong MG, Kim SW, Han J, Liu B, Rhee SM, et al. Optimal insertion site of glenoid baseplate in reverse total shoulder arthroplasty: anatomical simulation using three dimensional image processing software. Int Orthop 2021;45:3171-7. https://doi.org/10.1007/s00264-021-05235-7.
16. Ji JH, Jeong JY, Song HS, Ok JH, Yang SJ, Jeon BK, et al. Early clinical results of reverse total shoulder arthroplasty in the Korean population. J Shoulder Elbow Surg 2013;22:1102-7. https://doi.org/10.1016/j.jse.2012.07.019.
17. Kahan JB, Iannotti J, Donohue K. Suprascapular neuropathy from malpositioned baseplate screws in primary reverse shoulder arthroplasty: two case reports. JBJS Case Connect 2020;10:e20.00096. https://doi.org/10.2106/jbjs.Cc.20.00096.
18. Keener JD, Patterson BM, Orvets N, Aleem AW, Chamberlain AM. Optimizing reverse shoulder arthroplasty component position in the setting of advanced arthritis with posterior glenoid erosion: a computer-enhanced range of motion analysis. J Shoulder Elbow Surg 2018;27:339-49. https://doi.org/10.1016/j.jse.2017.09.011.
19. Kida H, Urita A, Momma D, Matsui Y, Endo T, Kawamura D, et al. Implications of navigation system use for glenoid component placement in reverse shoulder arthroplasty. Sci Rep 2022;12:21190. https://doi.org/10.1038/s41598-022-25833-8.
20. Kim JS, Kim SH, Kim SC, Park JH, Kim HG, Lee SM, et al. Effect of using a small baseplate on the radiological and clinical outcomes of reverse total shoulder arthroplasty in Asian patients. Bone Joint J 2023;105-b:1189-95. https://doi.org/10.1302/0301-620x.105b11.Bjj-2023-0450.R1.
21. Kirsch JM, Patel M, Singh A, Lazarus MD, Williams GR, Namdari S. Early clinical and radiographic outcomes of an augmented baseplate in reverse shoulder arthroplasty for glenohumeral arthritis with glenoid deformity. J Shoulder Elbow Surg 2021;30:S123-30. https://doi.org/10.1016/j.jse.2020.12.010.
22. Lädermann A, Schwitzguebel AJ, Edwards TB, Godeneche A, Favard L, Walch G, et al. Glenoid loosening and migration in reverse shoulder arthroplasty. Bone Joint J 2019;101-b:461-9. https://doi.org/10.1302/0301-620x.101b4.Bjj-2018-1275.R1.
23. Levy JC, Anderson C, Samson A. Classification of postoperative acromial fractures following reverse shoulder arthroplasty. J Bone Joint Surg Am 2013;95:e104. https://doi.org/10.2106/jbjs.K.01516.
24. Li X, Knutson Z, Choi D, Lobatto D, Lipman J, Craig EV, et al. Effects of glenosphere positioning on impingement-free internal and external rotation after reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2013;22:807-13. https://doi.org/10.1016/j.jse.2012.07.013.
25. Lung TS, Cruickshank D, Grant HJ, Rainbow MJ, Bryant TJ, Bicknell RT. Factors contributing to glenoid baseplate micromotion in reverse shoulder arthroplasty: a biomechanical study. J Shoulder Elbow Surg 2019;28:648-53. https://doi.org/10.1016/j.jse.2018.09.012.
26. Matsuki K, King JJ, Wright TW, Schoch BS. Outcomes of reverse shoulder arthroplasty in small- and large-stature patients. J Shoulder Elbow Surg 2018;27:808-15. https://doi.org/10.1016/j.jse.2017.11.011.
27. Maurer A, Fucentese SF, Pfirrmann CW, Wirth SH, Djahangiri A, Jost B, et al. Assessment of glenoid inclination on routine clinical radiographs and computed tomography examinations of the shoulder. J Shoulder Elbow Surg 2012;21:1096-103. https://doi.org/10.1016/j.jse.2011.07.010.
28. Michener LA, McClure PW, Sennett BJ. American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form, patient self-report section: reliability, validity, and responsiveness. J Shoulder Elbow Surg 2002;11:587-94. https://doi.org/10.1067/mse.2002.127096.
29. Nashikkar PS, Scholes CJ, Haber MD. Role of intraoperative navigation in the fixation of the glenoid component in reverse total shoulder arthroplasty: a clinical case-control study. J Shoulder Elbow Surg 2019;28:1685-91. https://doi.org/10.1016/j.jse.2019.03.013.
30. Oh JH, Lee S, Rhee SM, Jeong HJ, Yoo JC. Rationale for small glenoid baseplate: position of central cage within glenoid vault (Exactech(®) Equinoxe(®) reverse system). Clin Shoulder Elb 2019;22:24-8. https://doi.org/10.5397/cise.2019.22.1.24.
31. Paisley KC, Kraeutler MJ, Lazarus MD, Ramsey ML, Williams GR, Smith MJ. Relationship of scapular neck length to scapular notching after reverse total shoulder arthroplasty by use of plain radiographs. J Shoulder Elbow Surg 2014;23:882-7. https://doi.org/10.1016/j.jse.2013.09.003.
32. Park JH, Lee JH, Kim DY, Kim HG, Kim JS, Lee SM, et al. Clinical and radiological outcomes with an augmented baseplate for superior glenoid wear in reverse shoulder arthroplasty. Bone Joint J 2024;106-b:268-76. https://doi.org/10.1302/0301-620x.106b3.Bjj-2023-0936.R1.
33. Patel M, Martin JR, Campbell DH, Fernandes RR, Amini MH. Inferior tilt of the glenoid leads to medialization and increases impingement on the scapular neck in reverse shoulder arthroplasty. J Shoulder Elbow Surg 2021;30:1273-81. https://doi.org/10.1016/j.jse.2020.09.023.
34. Roche C, DiGeorgio C, Yegres J, VanDeven J, Stroud N, Flurin PH, et al. Impact of screw length and screw quantity on reverse total shoulder arthroplasty glenoid fixation for 2 different sizes of glenoid baseplates. JSES Open Access 2019;3:296-303. https://doi.org/10.1016/j.jses.2019.08.006.
35. Rosenthal Y, Rettig SA, Virk MS, Zuckerman JD. Impact of preoperative 3-dimensional planning and intraoperative navigation of shoulder arthroplasty on implant selection and operative time: a single surgeon's experience. J Shoulder Elbow Surg 2020;29:2564-70. https://doi.org/10.1016/j.jse.2020.03.041.
36. Simovitch RW, Zumstein MA, Lohri E, Helmy N, Gerber C. Predictors of scapular notching in patients managed with the Delta III reverse total shoulder replacement. J Bone Joint Surg Am 2007;89:588-600. https://doi.org/10.2106/jbjs.F.00226.
37. Sirveaux F, Favard L, Oudet D, Huquet D, Walch G, Molé D. Grammont inverted total shoulder arthroplasty in the treatment of glenohumeral osteoarthritis with massive rupture of the cuff. Results of a multicentre study of 80 shoulders. J Bone Joint Surg Br 2004;86:388-95. https://doi.org/10.1302/0301-620x.86b3.14024.
38. Sprowls GR, Wilson CD, Stewart W, Hammonds KAP, Baruch NH, Ward RA, et al. Intraoperative navigation and preoperative templating software are associated with increased glenoid baseplate screw length and use of augmented baseplates in reverse total shoulder arthroplasty. JSES Int 2021;5:102-8. https://doi.org/10.1016/j.jseint.2020.09.003.
39. Tarallo L, Giorgini A, Micheloni G, Montanari M, Porcellini G, Catani F. Navigation in reverse shoulder arthroplasty: how the lateralization of glenosphere can affect the clinical outcome. Arch Orthop Trauma Surg 2023;143:5649-56. https://doi.org/10.1007/s00402-023-04879-x.
40. Tashiro E, Takeuchi N, Kozono N, Nabeshima A, Teshima E, Nakashima Y. Risk of penetration of the baseplate peg in reverse total shoulder arthroplasty for an Asian population. Int Orthop 2022;46:1063-71. https://doi.org/10.1007/s00264-022-05328-x.
41. Tashjian RZ, Beck L, Stertz I, Chalmers PN. Preoperative three-dimensional computer planning for reverse total shoulder arthroplasty and bone grafting for severe glenoid deformity. Shoulder Elbow 2021;13:492-501. https://doi.org/10.1177/1758573220908903.
42. Tashjian RZ, Martin BI, Ricketts CA, Henninger HB, Granger EK, Chalmers PN. Superior baseplate inclination is associated with instability after reverse total shoulder arthroplasty. Clin Orthop Relat Res 2018;476:1622-9. https://doi.org/10.1097/corr.0000000000000340.
43. Torkan LF, Bryant JT, Bicknell RT, Ploeg HL. Central fixation element type and length affect glenoid baseplate micromotion in reverse shoulder arthroplasty. J Shoulder Elbow Surg 2022;31:1385-92. https://doi.org/10.1016/j.jse.2022.01.120.
44. Velasquez Garcia A, Abdo G. Does computer-assisted navigation improve baseplate screw configuration in reverse shoulder arthroplasty? A systematic review and meta-analysis of comparative studies. J Orthop 2023;36:29-35. https://doi.org/10.1016/j.jor.2022.12.008.
45. Velasquez Garcia A, Abdo G, Sanchez-Sotelo J, Morrey ME. The value of computer-assisted navigation for glenoid baseplate implantation in reverse shoulder arthroplasty: a systematic review and meta-analysis. JBJS Rev 2023;11:e23.00038. https://doi.org/10.2106/jbjs.Rvw.23.00038.
46. Venne G, Pickell M, Ellis RE, Bicknell RT. Reliability of a novel 3-dimensional computed tomography method for reverse shoulder arthroplasty postoperative evaluation. JSES Open Access 2019;3:168-73. https://doi.org/10.1016/j.jses.2019.05.001.
47. Werthel JD, Villard A, Kazum E, Deransart P, Ramirez O. Accuracy of reverse shoulder arthroplasty angle according to the size of the baseplate. J Shoulder Elbow Surg 2022;32:310-7. https://doi.org/10.1016/j.jse.2022.07.006.
48. Youderian AR, Greene AT, Polakovic SV, Davis NZ, Parsons M, Papandrea RF, et al. Two-year clinical outcomes and complication rates in anatomic and reverse shoulder arthroplasty implanted with Exactech GPS intraoperative navigation. J Shoulder Elbow Surg 2023;32:2519-32. https://doi.org/10.1016/j.jse.2023.05.021.