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Navigation increases the accuracy of glenoid component implantation in reverse total shoulder arthroplasty in shoulders with severe glenoid wear: a comparative cohort study

Gregory Cunningham, MD[a,b,c,*], Andres Rodriguez Borgonovo, MD[a], Miguel Rivera, MD[a], Rodrigo Brandariz, MD[a]

[a]La Colline Shoulder and Elbow Center, Geneva, Switzerland
[b]Division of Orthopaedics and Trauma Surgery, Department of Surgery, Geneva University Hospitals, Switzerland
[c]Faculty of Medicine, University of Geneva, Geneva, Switzerland

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Background: Indications for reverse total shoulder arthroplasty (rTSA) have increased over the years and seem to yield satisfactory functional results even in patients with severe glenoid wear. New technologies, such as navigation, have gained in popularity intending to increase implantation precision, which is a crucial factor for long-term implant survivorship. However, these technologies remain costly and their widespread use for everyday cases has yet to be determined.
Objectives: This study aimed to compare the accuracy of glenoid component implantation in consecutive series of patients undergoing rTSA with and without navigation, according to the wear patterns of the glenoid.
Study Design & Methods: Two consecutive series of patients operated on by the same shoulder surgeon for rTSA, with and without navigation using the NextAR system (Medacta, Castel San Pietro, Switzerland), were prospectively included in the study. Revision procedures or rTSA requiring glenoid bone graft were not included. Patients' demographics (age, sex, side, and body mass index), preoperative diagnosis, and glenoid wear patterns in both the coronal and axial planes were analyzed and defined as mild and severe. Postoperative implantation accuracy measurements were carried out on postoperative computed tomography scans and consisted of rTSA angle, version, maximal bone purchase of peripheral screws and central peg, and glenosphere eccentricity from the inferior glenoid neck.
Results: 56 shoulders were included, 28 in each group. There were no significant differences in patient demographics, preoperative diagnosis, and wear pattern severity between both groups. In the navigated group, patients with severe bone wear presented a significantly higher accuracy in all analyzed parameters, whereas patients with mild glenoid defects did not show significant differences in the glenoid implantation version and glenosphere position from the inferior glenoid neck.
Conclusion: Navigation significantly improves glenoid implantation accuracy, particularly in patients with severe glenoid wear patterns. While its applicability in standard cases is debatable for experienced shoulder surgeons, it could prove valuable for patients with severe bone defects. Further studies are needed to assess if this will impact clinical and long-term implant survival outcomes.

Indications for reverse total shoulder arthroplasty (rTSA) have been increasing in recent years due to its ability to restore satisfactory and predictable shoulder function, even in cases with severe glenoid bone deformity, making it the procedure of choice for rotator cuff arthropathy and even in some cases of primary arthritis.[18] A major contribution to this expansion is the better understanding of the biomechanics of rTSA and the tridimensional wear patterns and anatomy of the glenoid.[4,9] Also, the rise of new technologies has helped to push the boundaries of what was deemed to be a nonressurfacable glenoid. Preoperative three-dimensional planning, patient-specific guides and instrumentation, and navigation are now widely available and frequently used with the aim to improve accuracy of prosthetic component implantation, especially the glenoid. A recent systematic review and meta-analysis of 633 shoulder

Geneve Canton Ehich committee approved this study (2023-01366).
*Corresponding author: Gregory Cunningham, MD, Shoulder and Elbow Center La, Colline, Geneva, Switzerland.
E-mail address: Gregory.james.cunningham@gmail.com (G. Cunningham).

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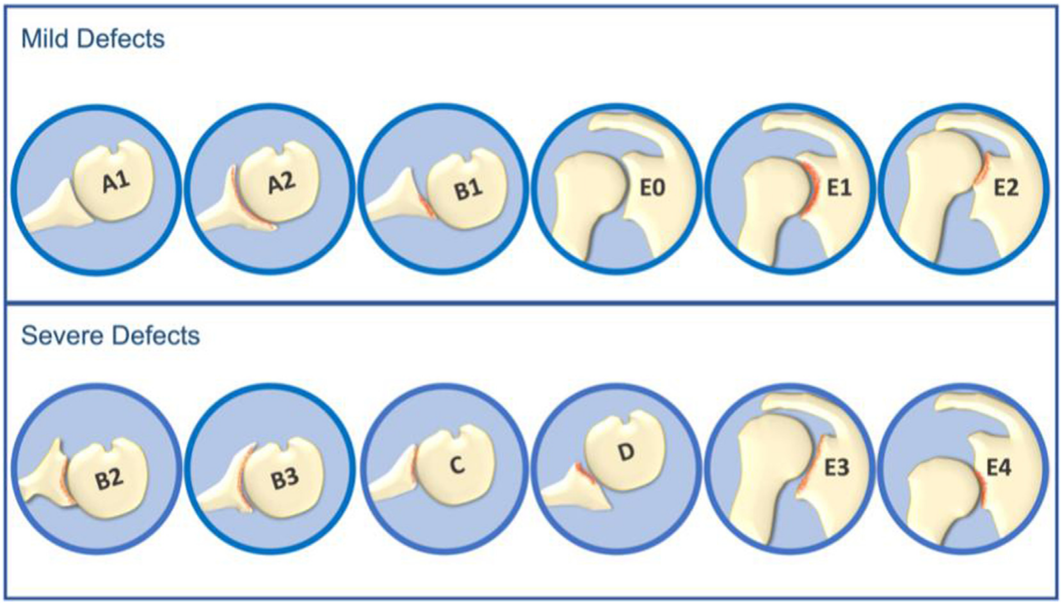

Figure 1 Severity grading of the glenoid bone wear. Glenoid wear severity was classified as mild or severe based on the most advanced wear pattern observed in either the frontal or axial plane. For instance, if the classifications were E0 and B2, the wear was designated as 'severe' due to the presence of B2.

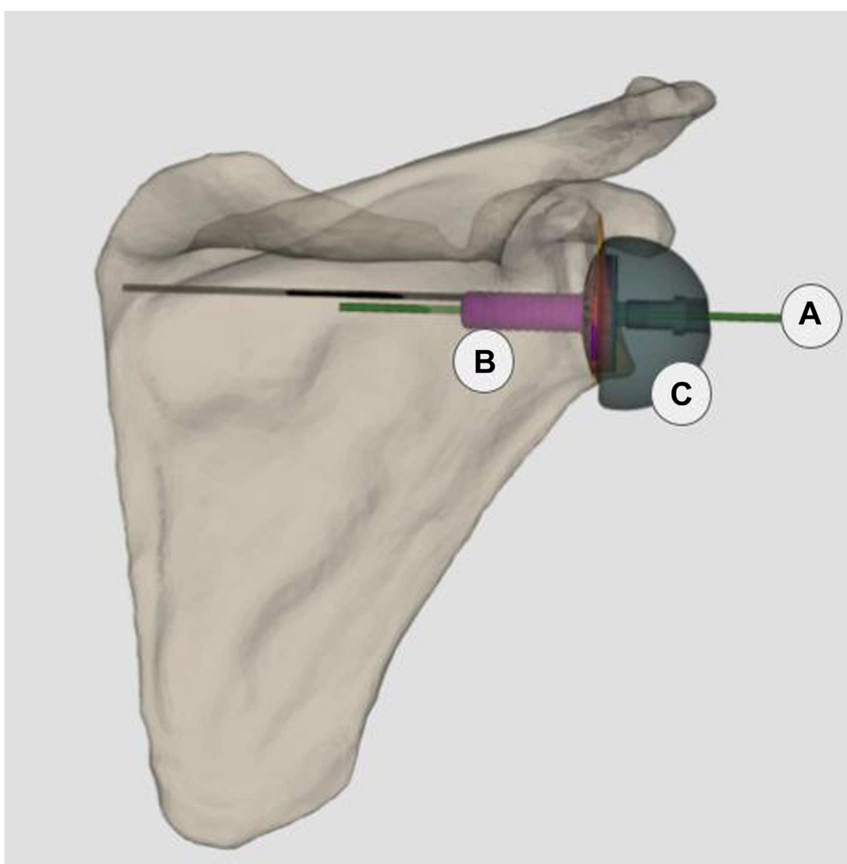

Figure 2 Preoperative planning 3D model. Image obtained from MyShoulder 3D preoperative planning solution software (Medacta, Castel San Pietro, Switzerland). (**A**): Positioning of the central pin. (**B**): Positioning of the glenoid base plate. (**C**): Positioning of the glenosphere.

arthroplasties from 6 comparative trials showed that navigation improved screw purchase length, number of screws per case, and the proportion of cases fixed with two screws.[22] However, its widespread utilization to all common diagnoses or glenoid types is still under debate since these technologies are associated with higher costs, increased operative times, and added

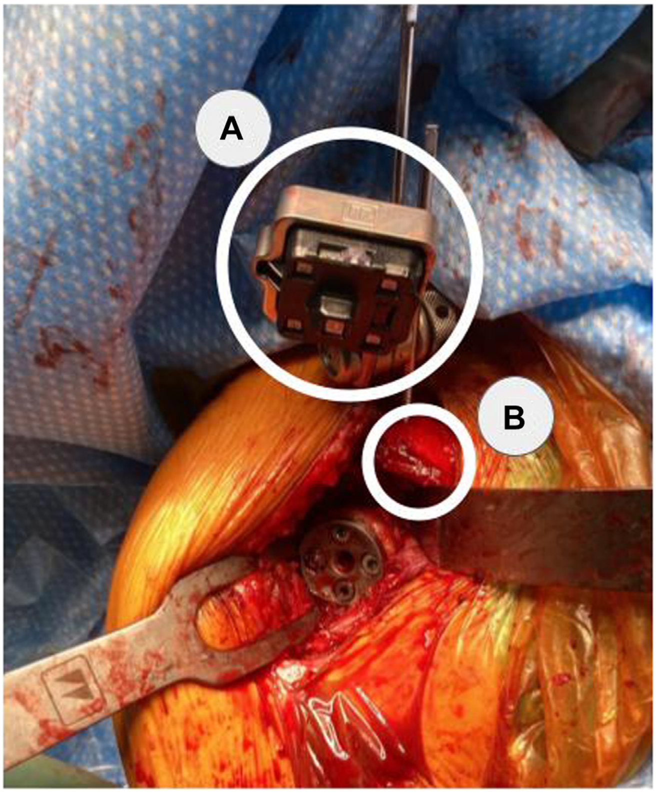

Figure 3 Intraoperative image showing the navigation tracking system (**A**) implanted on the coracoid (**B**).

steps in the surgical workflow.[23] There are to this date no studies comparing the effectiveness of navigation in terms of glenoid implantation accuracy according to the preoperative glenoid type. Therefore, this study aimed to determine whether navigation was more effective for glenoid component positioning in a comparative analysis of 2 consecutive series of patients, according to the severity of glenoid type. We hypothesized that the difference would only be significant in patients with severe wear patterns.

Material and methods

Study design and patient recruitment

This study compared two prospective consecutive series of patients operated for rTSA by a single fellowship-trained shoulder surgeon (G.C,) with over 10 years of experience and 6 years with the implant (Medacta Shoulder System; Medacta, Castel San Pietro, Switzerland). The two groups consisted of patients operated for rTSA with navigation (NAV group) and without navigation (non-NAV group), spanning before and after the introduction of navigation technology and 3D planning software (NextAR; Medacta, Castel San Pietro, Switzerland). Patients with full clinical and imaging indications for rTSA were included. Revision rTSA, cases that required glenoid bone graft, and patients who refused to participate in the study were excluded. All included patients had signed an informed consent for the use of their clinical data for research purposes before data collection. Approval by the local ethical committee was obtained (2023-01366)

Preoperative data collection

Demographic characteristics, such as age, sex, body mass index (BMI), operated side, as well as a primary diagnosis based on preoperative imaging, were recorded. The glenoid wear pattern was classified according to Sirveaux and Favard[20] and Badet and Walch[24] classifications on X-rays and on 0.63 mm slice resolution computed tomography (CT) Scans. The glenoid version was measured according to the medial plane of the scapula (Friedman)[7] and to the tip of the glenoid.[14] The measurements were carried out by two fellowship-trained shoulder surgeons on 3D-corrected slicing (OsiriX; Pixmeo, Bernex, Switzerland).

Glenoid bone defect classification

To facilitate the analysis and the reproducibility of the results, glenoid wear was stratified into mild and severe, combining Sirveaux and Favard[20] and Badet and Walch[24] classifications (Fig. 1). Advanced eccentric wear patterns in both the axial and coronal planes that could alter the glenoid architecture and interfere with intraoperative judgment of baseplate placement or require eccentric reaming for correction were classified as severe

Preoperative planning

Patients included in the NAV group were planned using MyShoulder 3D preoperative planning solution software (Medacta, Castel San Pietro, Switzerland). CT data were manually reconstructed into a 3D model by the company's engineers. The planification was then corrected and validated by the primary surgeon. Patients in the non-NAV group were not planned with 3D software, as it was launched at the same time as the navigation software.

In both groups, the optimal baseplate position aimed for was defined as having at least 90% contact with glenoid bone, aligned with the inferior glenoid border, with the central peg aligned to the rTSA angle in the frontal plane and the tip of the glenoid vault in the axial plane to maximize bone purchase (Fig. 2).[2,4,11,13,16] Optimal screw position was defined to have the maximum bone purchase without violating the scapular spine.

Surgical technique

In both groups, patients were implanted with a semi-inlay Grammont-designed stem with a pegged monobloc baseplate and two to four peripheral screws, according to the size of the baseplate (24.5 mm or 27 mm, respectively). They were operated in the beach-chair position, the joint was approached through a deltopectoral approach, the humeral head was resected, and the glenoid was exposed and prepared in the same fashion.

In the non-NAV group, the baseplate was sized and implanted using the standard central pin guide provided by the industry. The same objectives for optimal implant positioning as described above were aimed for.

In the NAV group, the deltopectoral approach was extended 1 cm proximally to allow access to the upper surface of the coracoid and implant a tracking device with two pins on the coracoid for scapula referencing. After performing surface acquisition, preoperative planning was followed to navigate the baseplate, peripheral screws, and glenosphere implantation (Fig. 3).

In both groups, a standard or lateralized glenosphere with inferior eccentricity in different sizes (36, 39, or 42) was implanted, according to preoperative planning. The humeral component and polyethylene liner were subsequently sized and implanted without navigation in both groups, and the rest of the procedure was executed according to standard practice.

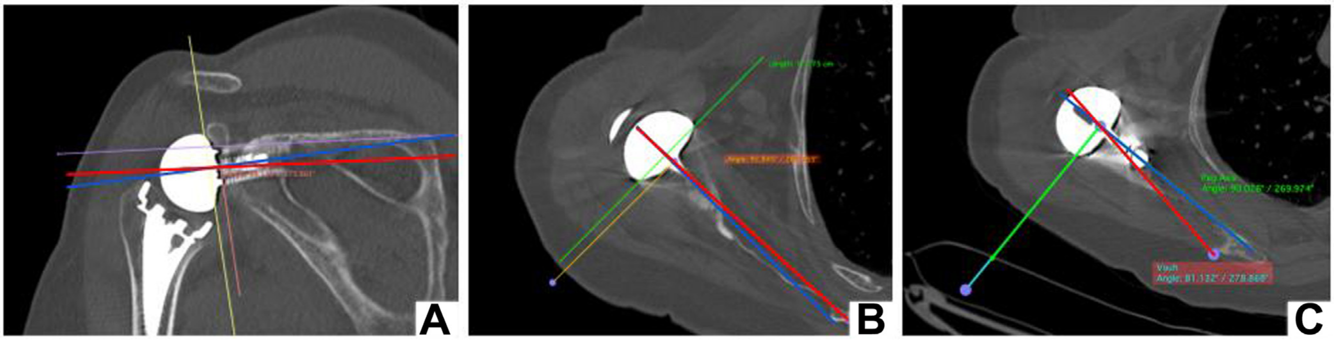

Figure 4 Postoperative computed tomography (CT) scan measurements. (**A**): CT scan coronal slice showing RSA angle measurement (—: RSA line/—: peg's axis). (**B**): CT scan axial view representing the measurement of the Friedman angle (—: Friedman line/—: peg's axis). (**C**): CT scan axial view with the glenoid vault angle measurement (—: vault line/—: peg's axis). *RSA*, reverse total shoulder arthroplasty.

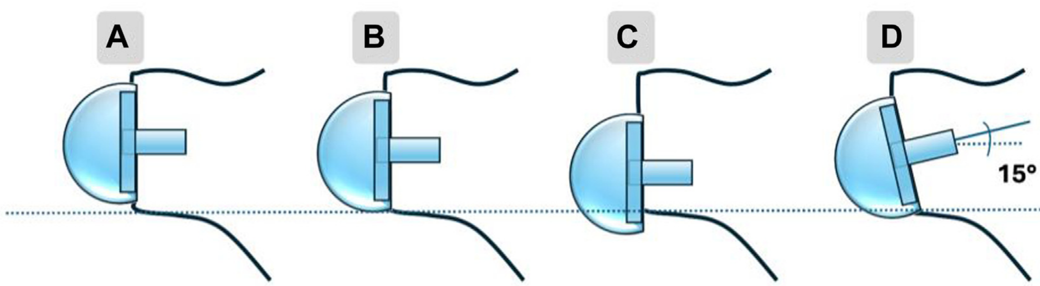

Figure 5 Nyffeler classification for glenosphere positioning. Illustration of the 4 positions of the glenoid component according to Nyffeler: (**A**) glenosphere eccentric superiorly; (**B**) glenosphere aligned with the inferior glenoid border; (**C**) glenosphere extending beyond the inferior glenoid border; (**D**)-glenosphere tilted downward by 15 degrees.

Table I
Patients demographics.

Variable	NavG (n = 28)	CoG (n = 28)	*P* value*
Age (years)	77.5 ± 5.56 (65-89)	75.21 ± 6.25 (60-84)	.15
Gender (n, %)			.91
Male	6 (21)	7 (25)	
Female	22 (79)	21 (75)	
Affected side (n, %)			.48
Right	18 (64)	16 (57)	
Left	10 (36)	12 (43)	
BMI	26.58 ± 4.97 (25.5-28)	27.1 ± 5.24 (25-29)	.7
Preoperative Friedman (degrees)	−5.95 ± 7.61	−3.40 ± 4.55	.152
Preoperative vault (degrees)	−13.29 ± 7.78	11.63 ± 4.65	.365
Preoperative diagnosis			
CTA	10	14	.449
OA	9	4	
MIRCT	8	9	
PTA	1	1	

CTA, Cuff tear arthropathy; *OA*, Osteoarthritis; *MIRCT*, Massive irreparable rotator cuff tear; *PTA*, Post-traumatic arthritis; *BMI*, body mass index; *NavG*, navigation group; *CoG*, control group.

*Paired T-Test analysis, Mann-Whitney U test, and chi-square test were performed according to the sample.

Intraoperative data collection

Operative time, implant sizes, and number screws were recorded.

Postoperative data collection

Postoperative CT scan measurements were performed by two fellowship-trained shoulder surgeons blinded to the groups, using OsiriX software (Pixmeo, Geneva, Switzerland) (Fig. 4). The following parameters were recorded:

- Baseplate version: according to Friedman angle and Glenoid vault.[7,14]
- rTSA angle.[2]
- Peg positioning: Baseplate alignment with the inferior rim.[1]
- Gleonosphere position: according to Nyffeler classification.[16]
- Number, length, and bone purchase rate of peripheral screws.

In addition, rTSA, Friedman, and vault angles measured as 0 to −5 degrees, and glenosphere in the C position, were subcategorized as "objective accomplished (Fig. 5)."

Statistical analysis

Sample size was estimated from the rTSA angle, using the mean difference of 8.75 according to previous studies.[22] To achieve a power (β) of 0.80, the number of patients required for each group was 27. Because of a predicted loss to follow-up, we aimed to include 30 patients in each group. Interobserver reproducibility was analyzed for all the variables showing very high agreement (intraclass correlation coefficient between 0.80 and 0.95).

Preoperative and postoperative variables were compared via paired t-test for independent samples. Continuous variables were presented as means and standard deviations (SDs), whereas categorical variables were presented as absolute and relative frequencies. Statistical analysis was performed using the independent Student t-test with a 95% confidence interval to calculate the differences in version and rTSA angle. Statistical analysis was performed using Stata software (version 16; StataCorp, College Station, TX, USA). $P < .05$ was considered statistically significant.

Table II
Glenoid bone defect classifications.

Glenoid bone defect classifications					P value*
	Counts (n)	% of total	NavG (%)	CoG (%)	
Glenoid type Walch					
A1	21	37.5	17.9	19.6	.353
A2	12	21.4	7.1	14.3	
B1	8	14.3	5.4	8.9	
B2	6	10.7	8.9	1.8	
B3	6	10.7	7.1	3.6	
D	3	5.4	3.6	1.8	
Glenoid type Favard					
E0	11	19.6	8.9	8.9	.665
E1	30	53.6	25	30.4	
E2	3	5.4	1.8	3.6	
E3	11	19.6	12.5	7.1	
E4	1	1.8	1.8	0	
Glenoid defect severity					
Mild	36	64.3	26.8	37.5	.094
Severe	20	35.7	23.2	12.5	

NavG, navigation group; *CoG*, control group.
*Chi-square test was performed.

Results

Patient demographics

Fifty-six consecutive patients were included in this study: 28 in the NAV group (operated between 2022 and 2023) and 28 in the non-NAV group (operated between 2021 and 2022). There were no statistically significant differences regarding age, gender, operated side, BMI, and underlying diagnosis (Table I). Cuff tear arthropathy was the most frequent diagnosis (n = 25), followed by massive irreparable cuff Tear (n = 18), primary arthritis (n = 11), and post-traumatic arthritis (N = 2).

Preoperative radiologic assessment

Both groups did not show significant differences in preoperative Friedman and vault angles ($P = .152$ and $P = .365$) and the glenoid wear pattern. In the axial plane, Walch glenoid type A1 was the most frequent, followed by A2, B1, B2 and B3, and D (37.5%, 21.4%, 14.3%, 10.7%, 10.7%, and 5.4%, respectively). In the frontal plane, Favard type E1 was the most frequent, followed by E0, E3, E2, and E4 (53.6%, 19%, 19%, 5.4% and 1.8%, respectively). When stratifying according to the severity of the glenoid defect (mild or severe), both groups were also comparable ($P = .094$). While 64.3% of the cases were classified as mild defects (15 cases for NAV group and 21 non-NAV group), 35.7% were severe (13 and 7 per group, respectively). (Table II)

Intraoperative measurements

While operative time was longer in the NAV group (72 ± 14 vs. 59.46 ± 10.77 minutes, $P = –.0005$), baseplate size, number of used screws, and glenosphere size did not show differences between the two groups ($P = .737$, .153, 0.064). (Table III)

Table III
Intraoperative measurements.

Variable	NavG (n = 28)	CoG (n = 28)	P value*
Glenosphere size			
36	23	19	.064
39	5	5	
42	0	5	
Operative time (minutes)	72 ± 14 (66-77)	59.46 ± 10.77 (55-63)	.0005
Number of screws			
2	22	24	
3	5	1	.153
4	1	3	
Baseplate size			
24.5	22	23	.737
27	6	5	

NavG, navigation group; *CoG*, control group.
*Paired T-Test analysis, Mann-Whitney U test and chi-square test were performed according to the sample.

Overall radiologic results

Patients in the NAV group presented higher rTSA angle accuracy than those in the non-NAV group (−0.89° ± 3.86 vs. 3.07° ± 8.05; $P = .022$). In addition, baseplate alignment with the inferior glenoid border was significantly more accurate in the NAV group, with a mean difference of 3 mm ($P < .001$). Similarly, glenosphere positioning was significantly more accurate in NAV group, with 89% of the glenospheres extending beyond the inferior border of the glenoid (C position), as opposed to 43% in the non-NAV group ($P < .001$). Finally, the superior and inferior screws of the NAV group had a significantly better bone purchase than the non-NAV group ($P < .001$ and $P = .014$). (Table IV)

Accuracy correlation with body mass index

BMI correlation analysis showed no significant correlation with the postoperative rTSA, Friedmann, vault angles, and glenosphere positioning (Pearson's correlation test: 0.014; 0.14; 0.101; −0.129, respectively). Moreover, the subgroup of patients with BMI > 30 also showed no significant association with inaccuracies in the fulfilment of the objectives of inclination, version, and position of the glenosphere (chi-square test: rTSA angle $P = .78$; Friedmann $P = .84$; vault $P = .198$; glenosphere position $P = .288$).

Accuracy in glenoids with mild deformity

In patients with mild glenoid deformities, there were significant differences in favor of the NAV group in rTSA angle ($P = .044$), central peg positioning ($P = .009$), and superior screw bone purchase ($P < .001$). However, the "C" glenosphere position did not

Table IV
Overall radiologic results.

Variable	NavG (n = 28)	CoG (n = 28)	P value*
rTSA angle (degrees)	−0.89 ± 3.86	3.067 ± 8.05	.022
Glenoid version Friedman (degrees)	−4.57 ± 76.63	−0.36 ± 5.93	.014
Glenoid version vault (degrees)	−9.78 ± 6.59	−6.13 ± 6.79	.042
Central pin and peg positioning (mm)	15.25 ± 1.73	18.30 ± 3.32	<.001
Sup_Screw length (mm)	29.85 ± 4.21	26.63 ± 2.98	.001
Sup_Screw length of perforation (mm)	2.85 ± 2.39	7.33 ± 5.97	<.001
Sup screw bone purchase (mm)	27 ± 4.85	19.3 ± 6.87	<.001
Inf_Screw length (mm)	33.28 ± 4.25	32.53 ± 3.44	.46
Inf_Screw length of perforation (mm)	2.14 ± 0.75	4.36 ± 4.54	.013
Inf screw bone purchase (mm)	31.1 ± 4.13	28.2 ± 4.76	.014
Glenosphere position			
A	0	2	<.001
B	3	14	
C	25	12	

NavG, navigation group; *CoG*, control group; *rTSA*, reverse total shoulder arthroplasty.
*Paired T-Test analysis, Mann-Whitney U test and chi-square test were performed according to the sample.

show differences between the NAV group and non-NAV group (13 and 9 cases, respectively), nor did the glenoid version measured by the Friedman and the Vault method (P = .078 and P = .188, respectively) or the inferior screw bone purchase (P = .162). (Table V)

Accuracy in glenoids with severe deformity

All variables showed statistically significant increased accuracy in the NAV group. Version according to Friedman's angle was −3.61 ± 7.13 degrees in the NAV group and 2.29 ± 4.79 degrees in the non-NAV group (P = .04). Version according to the glenoid vault was −8.69 ± 6.18 degrees in the NAV group and −2.71 ± 7.13 degrees in the non-NAV group (P = .046). (Table VI) Patients in the NAV group had a positive association with the fulfillment of the objectives of inclination, version, and position of the glenosphere in all analyzed variables except for the glenoid vault, which did not show a significant association. (Table VII)

Discussion

The main finding of this study was that navigation improves rTSA glenoid component implantation, especially in patients with severe bony defects. Technologies that aim to improve rTSA implantation precision are the state of the art in shoulder arthroplasty. These can range from 3D-printed patient-specific guides to patient-specific implants and navigation or robotic-assisted surgery.[21] However, these technologies are costly, and their clinical implication and long-term efficiency are thus highly scrutinized and yet to be demonstrated. Whether it could be argued that it may be of some assistance to surgeons starting their practice or with low patient volumes, this study shows that in the hands of experienced high-volume surgeons, there may be little advantage of navigation in cases with mild bony deformity but still a significant difference in glenoid implantation precision in cases with severe bony deformity.

A cadaveric study with the same navigation system was recently carried out by Rojas et al, comparing pre- and postoperative 3D CT scan reconstructions to calculate the deviation between planned and postoperative inclination, retroversion, entry point, depth, and rotation of the glenoid component placement. The deviations recorded were in cases of angulation less than 2 degrees and in cases of distances less than 2 mm.[19] Although in our study we did not aim to analyze the deviations of the postoperative results with respect to the preoperative planning, the standard deviations had lower values in the NAV group compared to those recorded in the non-NAV group, showing a trend toward more predictable results close to the target mean values sought with preoperative planning.

Regarding the impact of navigation on clinical outcome, a recent study by Gaj et al has shown no statistically significant differences in range of motion, patient reported outcome measures, and satisfaction between patients after computer-navigated and standard rTSA at a short-term follow-up (16 months, 12-18).[8] However, although they also showed no significant differences between groups regarding baseplate postoperative glenoid version and inclination, these groups were not comparable concerning the preoperative glenoid defect, having a greater proportion of B1 and B2 glenoids in the group of patients operated on with navigation. Our study, on the contrary, had similar preoperative glenoid bone deformity in each groups (P = .064), allowing us to demonstrate the higher accuracy in the NAV group concerning rTSA angle, Friedman angle, and type C glenosphere positioning (odds ratios = 3.75, 4.58 and 12.5, respectively). Therefore, the question to be answered would be whether these differences in glenoid positioning correlate with better functional results and implant survival in the long term.

Although our study did not include the analysis of functional results, the literature demonstrates that there are benefits in favor of correct implantation of the glenoid component. In a long-term comparative study by Collotte et al, for instance, they demonstrated that glenospheres in the C position led to better Constant score results (improvement in Constant score: +40 vs. +32, P = .036).[3]

In addition, the relationship between glenoid inclination and functional outcomes was addressed by Franceschetti et al, showing that values less than 5 degrees had statistically significantly better outcomes in terms of forward flexion (149.9° vs. 139.3°) and abduction (136.4° vs. 126.7°).[6] Unfortunately, most of the available studies that analyze the relationship between the position of the glenoid components and functional results have low levels of evidence or are of biomechanical nature.

Superior inclination and excessive anteversion of the baseplate in rTSA have been linked to complications, such as joint instability, scapular notching, and loosening of the glenoid component.[3,11,13,16,17] In regard to the glenoid inclination, Knighton

Table V
Radiologic findings in glenoids with mild deformity.

Variable	NavG (n = 15)	CoG (n = 21)	*P* value*
rTSA angle (degrees)	−1.93 ± 4.10	2.65 ± 7.80	.044*
Glenoid version Friedman (degrees)	−4.57 ± 7.63	−0.36 ± 5.93	.078
Glenoid version vault (degrees)	−10.73 ± 7	−7.17 ± 6.48	.188
Central pin and peg positioning (mm)	15.60 ± 3.50	18.17 ± 3.27	.009
Sup_Screw length (mm)	29.87 ± 3.50	25.78 ± 2.30	<.001*
Sup_Screw length of perforation (mm)	3.20 ± 2.91	7.17 ± 6.48	.320*
Sup screw bone purchase (mm)	26.67 ± 4.58	18.61 ± 6.97	<.001
Inf_Screw length (mm)	32.27 ± 4.71	33.22 ± 2.39	.416
Inf_Screw length of perforation (mm)	2.27 ± 1.03	5.39 ± 4.69	.103*
Inf screw bone purchase (mm)	30 ± 4.41	27.83 ± 4.71	.162
Glenosphere position			
A	0	0	.015
B	2	12	
C	13	9	

rTSA, reverse total shoulder arthroplasty; *NavG*, navigation group; *CoG*, control group.
*Paired T-Test analysis, Mann-Whitney U test and chi-square test were performed according to the sample.

Table VI
Radiologic findings in glenoids with severe deformity.

Variable	NavG (n = 13)	CoG (n = 7)	*P* value*
rTSA angle (degrees)	0.308 ± 3.33	4.43 ± 9.32	.026*
Glenoid version Friedman (degrees)	−3.61 ± 7.13	2.29 ± 4.79	.04
Glenoid version vault (degrees)	−8.69 ± 6.18	−2.71 ± 7.13	.046
Central pin and peg positioning (mm)	14.84 ± 1.57	18.71 ± 3.74	.004
Sup_Screw length (mm)	29.84 ± 5.06	29.43 ± 3.41	.848
Sup_Screw length of perforation (mm)	2.46 ± 1.66	7.86 ± 4.26	.007*
Sup screw bone purchase (mm)	27.38 ± 5.32	21.57 ± 6.48	.044
Inf_Screw length (mm)	34.46 ± 3.48	30.29 ± 5.35	.053*
Inf_Screw length of perforation (mm)	2.00 ± 1.50	1 ± 1.29	.046*
Inf screw bone purchase (mm)	32.46 ± 3.48	29.29 ± 5.12	.116
Glenosphere position			
A	0	2	.002
B	1	4	
C	12	1	

rTSA, reverse total shoulder arthroplasty; *NavG*, navigation group; *CoG*, control group.
*Paired T-Test analysis, Mann-Whitney U test and chi-square test were performed according to the sample.

Table VII
Comparison of positioning objectives achieved in severe glenoid wear.

Variable	*P* value	Odds ratio 95% CI
rTSA angle	.018	3.75 (0.176-0.908)
Friedman	.02	4.58 (0.05-0.48)
Vault	.995	1.0171 (0.001-0.0001)
Glenosphere position	<.001	12.5 (0.03-0.397)

rTSA, reverse total shoulder arthroplasty; *CI*, confidence interval.

et al tested compression, superior-inferior shear, and anterior-posterior shear forces from a 6° of freedom load cell in the joint and deltoid and rotator cuff muscle forces with different glenoid inclination angles from −20° to +20° in eight cadavers.[10] They concluded that superior inclination increased the superior-inferior shear forces and decreased joint compression, which may lead to rTSA instability and loosening.

Accuracy in the glenoid version can reduce the risk of subluxation caused by impingement, leading to dislocation. Permeswaren et al showed using validated finite elements modeling that glenoid component version higher than 5° were associated with the highest amount of subluxation for all polyethene liner rotations due to a reduced impingement-free range of motion during external rotation and extension.[17] Although our analysis of the glenoid version was based on the average of the total in both groups, in an individual analysis, we saw that 4 cases of the non-NAV group had anteversions of the glenoid component greater than 5 degrees, while in the NAV group only one case exceeded 5 degrees of anteversion, showing a tendency in favor of the second.

The position of the glenosphere also plays an important role in the biomechanics of rTSA. In 2005, Nyffeler et al showed in a cadaveric study that glenospheres with an extension beyond the inferior border of the glenoid neck significantly improved adduction and abduction angles.[16] Since new technologies, such as preoperative planning software, have supported these findings, showing better range of motion with this configuration.[12,26] Inferior eccentricity of the glenosphere also decreases scapular notching in Grammont-type rTSA, which may lead to increased risk of loosening in advanced stages.[3,11,25] Our results show that navigation improves optimal position of the glenosphere (type C) in glenoids with severe defects. One simple and trigonometrical explanation could be that in patients with superiorly facing glenoid wear patterns, the entry point using a standard guide aligned with the inferior border may be too superior to the definitive reamed glenoid surface. (Fig. 6) The authors have indeed noticed that during surgeries in patients with E3 glenoids, the entry point of the central pin dictated by navigation was counterintuitively low.

Peripheral screw malposition and inadequate purchase is a risk factor for glenoid loosening and spine fracture, two devastating complications after rTSA.[5,23] Our study showed that navigation improved screw length and position, optimizing bone purchase. This was especially true for the superior screw (NAV 26.67 ± 4.58 mm vs. non-NAV 18.61 ± 6.97 mm, $P < .001$) and could be due to the fact that

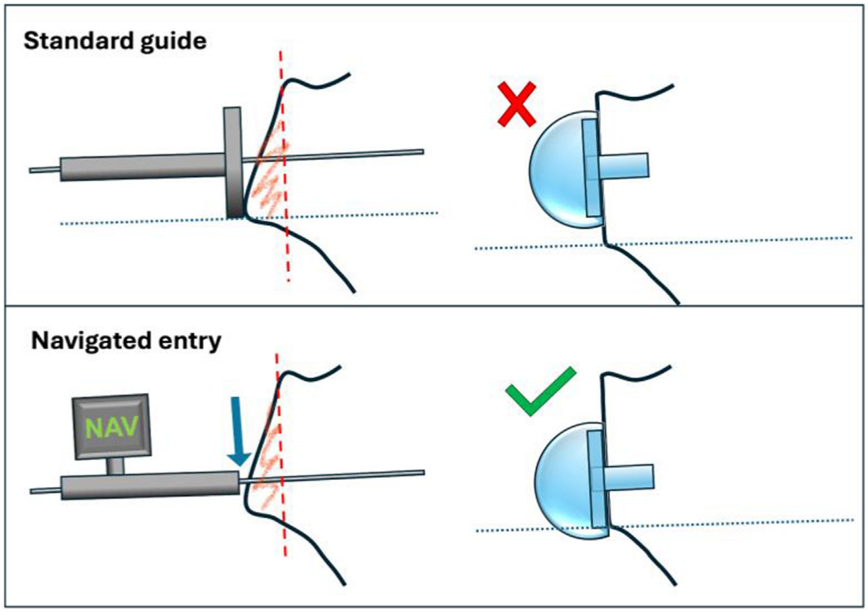

Figure 6 Entry point in glenoid with superior wear, with the illustration showing how the entry point in glenoid with superior wear (E3) is lower using navigation (inferior part) than what would be achieved using the standard centering guide (superior part) to obtain satisfactory final glenosphere positioning on the reamed glenoid (*Right* side).

the orientation of the tip of the glenoid vault changes significantly above the mid-glenoid[4] and may thus be harder to aim without navigation. In their systematic review, Velasquez Garcia et al also showed that navigation not only yielded better screw bone purchase but also reduced the needed number of screws, suggesting that this technique increases surgeon confidence in the fixation strength of their constructs.[22] In accordance with our findings, similar results were shown in the study by Nashikkar et al, where the group of patients operated with navigation had significantly lower incidences of inadequate screw purchase (<22 mm) for the anterior (64.7% vs. 95.2%, $P = .03$) and posterior (70.6% vs. 100%, $P = .01$) screws.[15]

There were some limitations to this study. Firstly, although the inclusion of patients was carried out prospectively and properly powered, the selection of patients in whom navigation was used was done according to the availability of the technology rather than by randomized selection. Nevertheless, demographic characteristics, including those of the preoperative glenoid defect, were comparable, and this method did not introduce the bias of having more severe wear patterns in the navigated group as discussed above. We excluded glenoid deformities requiring metal compensation, as this option is not currently available from the implant manufacturer. Cases requiring bone grafts were also excluded due to the low number in the control group. Further studies are needed to assess these specific settings where navigation could be particularly useful. As this is a pilot study using a new technology (NextAR; Medacta, Castel San Pietro, Switzerland), we cannot yet correlate these radiologic findings to clinical outcomes and long-term implant survival. Also, as the costs of this technology vary according to insurance reimbursement plans and whether the hospital has purchased the technology or bills on a per-case basis, we were not able to perform a cost-effectiveness analysis. Further long-term clinical comparative studies are being carried out to assess if these results confirm the already well-established link between glenoid malposition and clinical complications.

Conclusion

Navigation significantly improves glenoid implantation accuracy, particularly in patients with severe glenoid wear patterns. While its applicability in standard cases is debatable for experienced shoulder surgeons, it could prove valuable for patients with severe bone defects. Further studies are needed to assess if this will impact clinical and long-term implant survival outcomes.

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