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Improved accuracy of glenoid positioning in total shoulder arthroplasty with intraoperative navigation: A prospective-randomized clinical study

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Hypothesis: The correct implantation of the glenoid component is of paramount importance in total shoulder arthroplasty (TSA). We hypothesized that the accuracy of the glenoid positioning in the transverse plane can be improved using intraoperative navigation.

Materials and methods: This prospective, randomized clinical study comprised 2 groups of 10 patients each with osteoarthritis of the shoulder TSA, with or without intraoperative navigation. Glenoid version was measured on axial computed tomography scans preoperatively and 6 weeks postoperatively.

Results: The operating time was significantly longer in the navigation group (169.5 ± 15.2 vs 138 ± 18.4 min). We found an average change of retroversion from $15.4^\circ \pm 5.8^\circ$ (range, 3.0° - 24.0°) preoperatively to $3.7^\circ \pm 6.3^\circ$ (range, -8.0° to 15.0°) postoperatively in the navigation group compared with $14.4^\circ \pm 6.1^\circ$ (range, 2.0° - 24.0°) preoperatively to $10.9^\circ \pm 6.8^\circ$ (range, 0.0° - 19.0°) postoperatively in the group without navigation ($P = .021$).

Conclusion: We found an improved accuracy in glenoid positioning in the transverse plane using intraoperative navigation. The validity of the study is limited by the small number, which advocates continuation with more patients and longer follow-up.

Level of evidence: Level 2; Therapeutic study.

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Proper implant positioning together with soft tissue balancing are key issues in shoulder arthroplasty both for postoperative function and long-term survival of the implant.^{15,20} Pathologic retroversion angles with dorsal orientation of the glenoid cavity lead to dorsal instability and decentering of the humeral head. Per degree of increasing

retroversion, a dorsal subluxation of 0.5 mm was experimentally observed, which led to a dorsal shift of the force vectors away of the glenoid center of 2° per 4° of altered retroversion.²² This leads to an eccentric loading of the glenoid component with increased contact pressure, which has been described as the anteroposterior “rocking horse” phenomenon.²⁸

Furthermore, experiments have shown that the stress to the cement mantle or the bone stock can increase up to 326% or 162%, respectively, due to excessive retroversion of 20° . Micromotion at the bone-cement interface can increase up to 706% compared with neutral version.^{9,13}

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Surgical landmarks for intraoperative orientation are the glenoid cavity, the coracoid process, and the acromial border. The position of the scapula and, therefore, the glenoid orientation can neither be absolutely controlled nor validated on the operating table. The surgeon has to rely on experience and the diagnostic images to determine the right angle for alignment of the glenoid component. In symmetrical wear (Walch type A1 and A2), the surface is well-balanced and reamed to the subchondral bone, which automatically maintains the individual retroversion of the patient.³² In cases of pathologic retroversion with posterior wear (Walch glenoid morphology type B1 and B2), the surgeon needs to correct the retroversion by asymmetrical reaming (“lowering of the high side”), but the amount of correction can only be estimated. The glenoid centering point as introduced by Barrett et al,² which means palpation with the fingertip at the anterior glenoid neck, is a helpful assistance but still an estimation in all 3 planes.

The usefulness of intraoperative computer navigation in orthopedic surgery has been proven in a number of studies, but few studies exist about computer navigation in shoulder arthroplasty, and those are mostly in experimental setups using cadaveric specimens.^{1,3,19} Edwards et al⁸ used an image-free navigation system in a combined cadaveric experiment and in 24 patients with anatomic and 3 patients with an inverse shoulder arthroplasty. They found an accuracy of $2.6^\circ \pm 2.5^\circ$ with their system but did not give exact values of achieved glenoid version nor inclination angles and did not compare these with a control group.⁸

The objective of our study was to prove the applicability of the computed tomography (CT)-based navigation system in a routine clinical setup in TSA and to investigate the possibility of improving component orientation in the transverse plane. To our knowledge, this is the first prospective, randomized clinical trial to compare the radiologic results in TSA using computer navigation or the traditional freehand implantation.

The glenoid version cannot be accurately assessed on standard axillary radiographs, but CT scans are necessary preoperatively and postoperative.²¹ We are not aware of any publication that compares the preoperative and postoperative values of achieved correction of pathologic retroversion values in Walch type B1 and B2 morphology that are measured by standardized CT scans in a clinical study.

Materials and methods

This study received approval of the Institutional Review Board at ATOS Clinic Heidelberg, Shoulder and Elbow Surgery, in December 2006.

We conducted a prospective, randomized clinical study with 2 groups of 10 patients each undergoing TSA. An intraoperative navigation system was used in group 1, and the conventional operation technique was performed in group 2, which served as the control. Six patients were

excluded from group 1 because attempted intraoperative navigation failed owing to problems with referencing and matching. After these steps had been performed, the accuracy control by pointing surgical landmarks with the probe was routinely performed and failed in these cases. If after repetition, the accuracy control failed again, navigation was stopped to limit the overall operating time. To gain the full number of $n=10$ patients for group 1, the intraoperative navigation was started in $n=16$ patients. The data of the 6 patients with aborted intraoperative navigation were included in group 2 (additional operation time for the navigation was recorded and deducted for statistical analysis).

Because no anatomic or surgical reasons were responsible for navigation failing, but rather technical reasons with the navigation system and there was no further effect on the entire workflow, there is no statistical bias expected with this approach. Therefore the data of 20 patients included in the study underwent statistical analysis.

Inclusion criteria in the study were osteoarthritis of the shoulder with Walch³² glenoid morphology type B1 or B2 and an intact rotator cuff. Exclusion criteria were Walch glenoid type A or C, revision surgery, or persisting instability.

Standardized CT scans were performed before and 6 weeks after operation, and retroversion of the glenoid or the glenoid component was measured according to the method described by Friedman et al,¹⁰ which has been used by other authors (level of measurement at the midportion of the glenoid cavity just below the tip of the coracoid process).³² As shown in Figures 1 and 2, the measurement of retroversion angles using CT scans has difficulties, because the position of the scapula or the scout view definition, respectively, and the level of measurement in the transverse plane influence the measurement.⁴ The level at which the axial layer for measurement is selected may significantly influence the values because the glenoid cavity shows a spiral twist with progressive decrease in retroversion from the upper to the lower part in most shoulders.^{16,27} Therefore, the level of measurement (midlevel) and the position of the scapula (scout view, gantry tilt) have to be standardized as described previously to get precise and comparable data. The measurements were performed twice by the first (consultant orthopedic surgeon) and the second author (senior orthopaedic resident), and the results averaged and rounded to 1° .

We used the Nano Station (Praxim, Grenoble, France) with a passive optical tracking system for intraoperative navigation. Just before the operation, the CT data were transferred to the workstation, and surgical landmarks, consisting of the upper and lower pole of the glenoid and the tip of the coracoid process, were defined on the screen by the surgeon. After complete preparation of the glenoid cavity for drilling, these landmarks were intraoperatively validated by the surgeon with a navigated pointer that had been previously registered to the system. After completion,

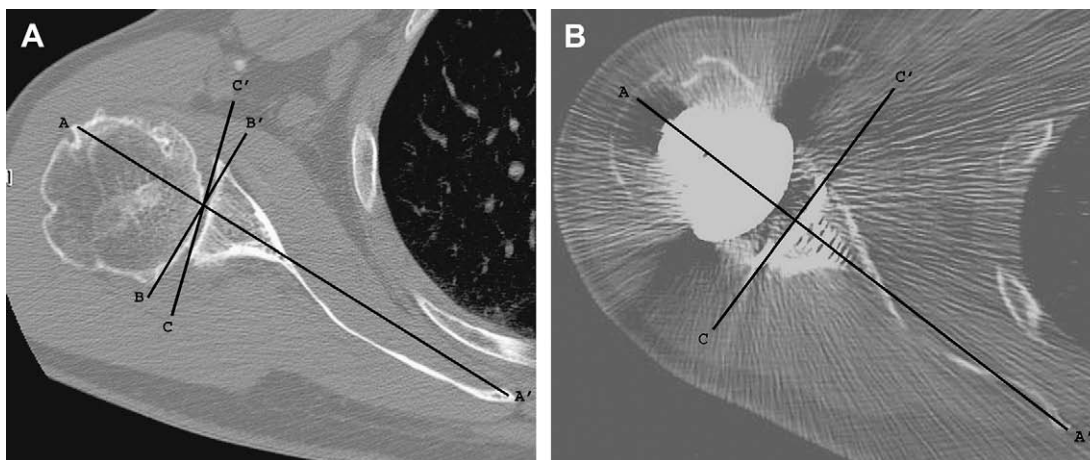


Figure 1 (A) Preoperative and (B) postoperative computed tomography scans show the scapula with measurements of glenoid version angles. Line A-A' connects the center of the glenoid cavity with the medial border of the scapula. Line B-B' is rectangular to line A-A' at the glenoid. Line C-C' connects ventral and dorsal bony border of the glenoid cavity. The angle between Line B-B' and C-C' is the glenoid version angle with negative values defined as retroversion. Note that in B, lines B-B' and C-C' coincide and are rectangular to line A-A' corresponding to a retroversion of 0°.

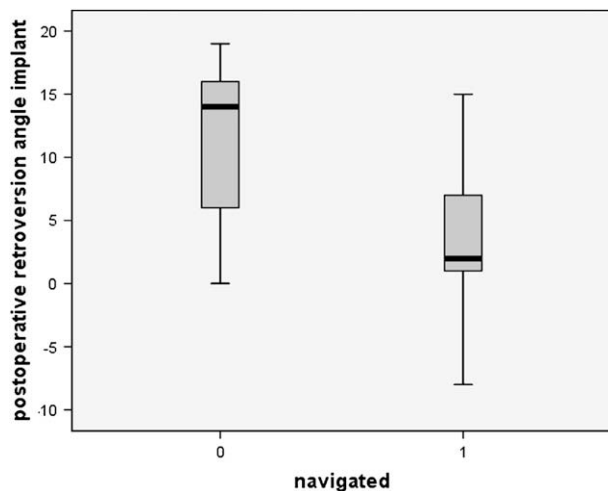


Figure 2 Box-and-whisker plot shows postoperative glenoid version angles of the implant in group 2 (0), which underwent a conventional procedure, and group 1 (1), which underwent navigation. The horizontal line in the middle of each box indicates the median; the top and bottom borders of the box mark the 75th and 25th percentiles, respectively. The whiskers mark the 90th and 10th percentiles.

a surface matching was performed at the anterior and posterior glenoid rim, the coracoid process, and the acromion. Finally, the accuracy of the navigation system was checked by pointing to surgical landmarks and comparing them with the result on the screen.

With the Eclipse implant system (Arthrex, Naples, FL) that was used, drilling of the glenoid cavity is performed using a central K-wire, which guides the direction of drilling and therefore control of the correction of inclination and retroversion. The insertion of this K wire with a power drill was controlled by the navigation system in real-time in

all 3 planes and the 3-dimensional (3D) reconstruction on the screen. The senior surgeon (P. H.) aimed for maximal correction of retroversion to neutral by respecting the amount of lowering of the anterior glenoid rim and the underlying bone stock for implant fixation in each case. All surgical key steps during the operation besides the navigation were the same for both groups. Because most TSA systems use the principle of reaming with a central K-wire, the described method is neither dependant on nor special for implant that was used in the study.

Because the corresponding author has been familiar with intraoperative navigation systems and TSA for several years, and the senior author is an experienced surgeon in TSA, a learning curve of the procedure, but not of the navigation system that was used, can be excluded.

Statistical analysis was performed with SPSS 13.0 software (SPSS Inc, Chicago, IL). The *t* test was used for independent samples for retroversion angles, and χ^2 test was used for age, gender, glenoid morphology, and etiology. $P < .05$ was set as the level of significance. A post hoc power analysis was performed using the G-power 3.0.10 software (University of Kiel, Germany).

Results

Navigation was aborted for technical problems in 6 patients (37.5% in group 1). The study was completed with 10 out of 16 patients in both groups. The operating time was significantly longer by a mean of 31 minutes in the navigation group (169.5 ± 15.2 min vs 138 ± 18.4 min in group 2; $P = .001$), but the entire workflow was not altered using the navigation system. No intraoperative or postoperative complications occurred in either group during the 6-week follow-up.

Table I Glenoid version values for healthy shoulders

First author	Year	No.	Subject	Modality	Version values*			
					Mean	SD	Min	Max
Randelli ²⁵	1986	50	Human	CT	-7	...	-2	-15
Friedman ¹⁰	1992	63	Human	CT	2	5	-12	14
Mullaji ¹⁸	1994	19	Human	CT	-3
Churchill ⁶	2001	172	Human	Direct	1.23	3.5	-9.5	10.5
von Schroder ³¹	2001	30	Cadaver	Direct	-7.9	3.7	-17	0
Inui ¹⁶	2001	40	Human	3D MRI	-0.6	1.9
DeWilde ⁷	2003	49	Human	CT	-3.73	3.8	-14	3
Meyer ¹⁷	2007	50	Human	MRI	-4	...	-9	0
Scalise ²⁶	2008	14	Human	CT	-7	...	-14	0
Hoenecke ¹²	2008	40	Cadaver	3D CT	-3.3	4.5

3D, 3 dimensional; CT, computed tomography; MRI, magnetic resonance imaging; SD, standard deviation.

* Negative values correspond to retroversion.

From preoperatively to postoperatively, we found an average change of the retroversion angle from $15.4^\circ \pm 5.8^\circ$ (range 3.0° - 24.0°) to $3.7^\circ \pm 6.3^\circ$ (range -8.0° to 15.0°) in group 1 and from $14.4^\circ \pm 6.1^\circ$ (range, 2.0° - 24.0°) to $10.9^\circ \pm 6.8^\circ$ (range, 0.0° - 19.0°) in group 2 (Figure 2).

The correction of retroversion was statistically significant in both groups ($P < .05$). The improvement in accuracy in the navigated group with higher values of correction of retroversion to normal was statistically significant ($P = .021$). The actual power ($1-\beta$) of the study in a post hoc power analysis with the above postoperative means and standard deviations was 0.64, with an effect size of 1.09 ($\alpha = 0.05$).

There was no statistical difference for gender, age, type of glenoid morphology, and preoperative retroversion values between group 1 and group 2.

We found an average difference in postoperative retroversion values between the glenoid bone stock and implants of $0.4^\circ \pm 0.7^\circ$ in group 1 and of $0.6^\circ \pm 0.9^\circ$ in group 2, without statistical significance. Seven patients in both groups had a difference in bone stock and glenoid component version. Only 1 patient was uncemented with a deviation of 1° . All others were cemented. One patient had 3° of deviation, 1 patient had 2° , and 5 patients had 1° . Three of the patients were in the navigated group, with 2 patients with 1° and 1 patient with 2° of deviation.

Discussion

The proper insertion of the glenoid component is crucial in TSA. Malalignment leads to eccentric loading, shift of vector forces, increased contact pressure and rim-loading, increased stress at the implant-bone or bone-cement interface and the glenoid bone stock, and in the long-term, to an increased rate of glenoid failure.^{9,11,13,14,22,28,30,32}

Without a navigation system, the surgeon has to rely on experience to match the intraoperative findings with preoperative images. Barrett et al² described the glenoid centerline and the centering point at the anterior glenoid

neck as surgical landmarks to determine the glenoid version and degree of correction, which is frequently used in clinical practice. Other authors have developed drill guides using the centering point or anterior neck angle as auxiliaries, but no controlled studies have proved the accuracy of such devices.

Others have advocated that difficulties or inability to correct the glenoid retroversion could and should be addressed with alteration of the humeral component retroversion. Spencer et al²⁹ showed in an experimental setup that this procedure resulted in no significant changes in energy or peak load. This emphasizes the importance to correct the glenoid version as accurately as possible.

Our study has validated the improved accuracy of the glenoid component positioning in the transverse plane using an intraoperative navigation system with greater values of correction to neutral retroversion.

Friedman et al¹⁰ have suggested "to consider 2° of anteversion to be a goal for surgeons who seek to restore normal version to a glenoid" based on their CT measurements on 20 shoulders in 13 patients with osteoarthritis and a control group of 63 patients with healthy shoulders who underwent CT scans of the chest.

Churchill et al⁶ have shown in a study of 172 matched cadaveric pairs that only a little variance exists between men and women, but the differences between races are considerable. The overall average retroversion in their study group was 1.23° .

All published data about glenoid version values using conventional radiographs must be cautiously interpreted because the method has inaccuracies, and CT scans or direct measuring are needed for exact data.^{10,23}

Table I gives an overview of published glenoid version angles in individuals with healthy shoulders. The mean appears to be close to neutral. Interindividual heterogeneity of glenoid version is generally recognized, but Scalise et al²⁶ assumption about homogenous bilateral intraindividual findings remains questionable. The authors cite von Schroeder et al,³¹ who investigated 30 cadavers by direct measurement,

but only state that there were no differences between left and right and do not provide data for this statement. The second publication cited by Scalise et al²⁶ is an investigation of 12 cadavers³³ that stated that version would have been nearly the same for left and right shoulders but give a difference of almost 1° and a value of $P > .05$.

Differences in our study in postoperative retroversion between the implant and the bone stock, especially for cemented glenoid components, suggest the use of navigation devices also for the insertion of the components. This is confirmed by similar findings for navigated cemented total knee arthroplasty by Catani et al,⁵ who found that in a considerable number of patients, benefits of the navigation can be lost between bone resection and final implant positioning.

It is so far uncertain, whether the improvement in implant positioning in the transverse plane found in our study leads to an improved clinical outcome or long-term survival of the endoprostheses, but the above-cited literature strongly supports this hypothesis.

Glenoid inclination is another important issue in the positioning of the glenoid component, and experiments have shown that decreased component inclination angles result in decreased superior humeral head subluxation and glenoid component tilting.^{11,24}

As the same limitations for surgical landmarks and orientation for the glenoid retroversion apply for inclination the use of navigation systems for control of inclination angles also appears to be sensible and necessary. The use of navigation systems for TSA has been described in experimental setups, cadaveric studies, and recently in patients, but not in a prospective randomized trial.^{1,3,8,19} This study provides such data and closes this gap.

There is a comparable trend to improved accuracy of implant positioning using intraoperative navigation systems in total hip and knee arthroplasty, which is emphasized by this study. We suggest the further use of navigation systems in TSA given that this prospective randomized clinical study showed excellent results and improved accuracy of glenoid positioning.

The small number of patients in both groups limits the validity of the study and advocates continuation with more patients and longer follow-up. The fact that in a considerable number of cases navigation had to be aborted and the limitation for control of glenoid version only for the used navigation system underlines that the method cannot serve as a standard procedure yet. Until now, there have been no validated outcome studies investigating glenoid version measured by CT scans and survival or function after TSA. Owing to the multitude of factors influencing these end points such as the type of implant used, preoperative condition, soft tissue balancing, and patient variability, among others, a very high number of patients is expected to be necessary to confirm the hypothesis that correction of pathologic retroversion to neutral is beneficial for function and long-term survival of implants.

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