Factors influencing functional internal rotation after reverse total shoulder arthroplasty

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Background: Functional internal rotation (fIR) of the shoulder is frequently limited after reverse shoulder arthroplasty (RTSA). The objective of this study was to study a cohort of satisfied patients after RTSA who had comparable active mobility except for fIR and to identify factors associated with selective loss of fIR.

Methods: A retrospective cohort study was conducted to compare 2 patient groups with either poor ($\leq$ 2 points in the Constant-Murley score [CS]) or excellent ($\geq$8 points in CS) fIR after RTSA at a minimum follow-up of 2 years. Influencing factors (demographic, surgical or implant related, radiographic parameters) and clinical outcome were analyzed.

Results: Fifty-two patients with a mean age of 72.8 ($\pm$9.3) and a mean follow-up of 41 months were included in the IR$\leq$2 group and 63 patients with a mean age of 72.1 ($\pm$8.0) and a mean follow-up of 59 months in the IR$\geq$8 group. All patients had undergone RTSA with the same implant type and only 2 different glenosphere sizes (36 and 40) for comparable indications. A multivariate analysis identified the following significant risk factors for poor postoperative fIR: poor preoperative fIR (pts in CS: 3 [range: 2-6] vs. 6 [range: 4-8], P<.0001), smoking (17.3% vs. 6.5%, P = .004), male gender (59.6% vs. 31.7%, P = .002), less preoperative to postoperative distalization of the greater tuberosity (Δ 19.4 mm vs. 22.2 mm, P = .026), a thin humeral insert ($\leq$3 mm: 23.1% vs. 54.8%, P = .039), and a high American Society of Anesthesiologists score ($\leq$ III: 30.8% vs. 14.3%, P = .043). Subscapularis repair status and glenosphere size had no influence on fIR. Clinical outcome scores improved in both groups from preoperatively to last follow-up. The IR$\geq$8 group had overall significantly better outcome scores compared to the IR$\leq$2 group (Δ 9.3% SSV and Δ 9.5% relative CS, P < .0001). There was no difference in CS between the cohorts when the score for fIR was discarded.

Conclusion: Independent risk factors for poor postoperative fIR after RTSA are poor preoperative fIR, smoking, male gender, less preoperative to postoperative distalization of the greater tuberosity, a thin humeral insert height, and a high American Society of Anesthesiologists score. Except for male gender, these factors are modifiable. These findings may be a valuable addition to patient counselling as well as preoperative planning and preoperative and intraoperative decision-making. The relevance of fIR for overall satisfaction is substantiated by this study.

Although many specific surgical variables are associated with outcome after reverse total shoulder arthroplasty (RTSA), the most important determining factors of patient satisfaction are subjective measures of pain and function. Therefore, pain relief and restoration of function are primary goals of shoulder arthroplasty.

Improvements regarding flexion and abduction can be expected postoperatively.[3,11,14,28,36] Functional internal rotation (fIR) of the shoulder, however, frequently remains limited or is even lost after RTSA. Activities of daily living are not assessed by default in postoperative evaluation. Nevertheless, according to Kim et al[23] 6 years after RTSA only 36% of patients were able to wash their back or close their bra in the back, 65% were able to manage the toilet, and 75% were able to use a back pocket.

To date, multiple potential technical (surgery-related) or implant-related factors have been analyzed in view of fIR. Biomechanical studies suggest that lateralization of the center of rotation

(COR),[22,31,35] inferior positioning of the baseplate,[38,49] decreased glenosphere size,[32] decreased humeral insert thickness,[27,47] a neck-shaft angle of less than 155°,[29] an intact subscapularis[33] and a humeral retrotorsion <20°[19,21,26] are positively associated with fIR after RTSA. The majority of these biomechanical results have not been reproduced in clinical studies.[23,41,45,50] The objective of the present study was to identify factors correlated with good or poor fIR in patients who have been treated with a RTSA with one specific implant geometry who obtained comparable ranges of active motion (ROM) except for fIR and satisfactory subjective and functional outcome scores.

Materials and methods

The responsible review board approved this comparative cohort study (KEK-ZH-Nr.2018-01494). Between January 2005 and February 2018, 833 primary RTSAs were performed in our institution. In all cases the Anatomical Shoulder™ Inverse/Reverse prosthesis (Zimmer-Biomet®), an onlay type implant with a neck-shaft angle of 155°, was implanted for irreparable rotator cuff tear, rotator cuff arthropathy or primary arthritis through a deltopectoral approach. If present, the subscapularis tendon was sharply released from the lesser tuberosity and reattached transosseously. Patients with poor fIR at latest follow-up (defined as internal rotation buttock or less; ≤ 2 points in Constant-Murely score [CS],[7] group: IR≤2) were compared to patients with good fIR (defined as internal rotation to T12 or higher; ≥ 8 points in CS, group: IR≥8) at latest follow-up. To be included, patients needed to have a follow-up examination no less than 2 years after surgery. Patients with prosthetic revisions, more than 2 previous shoulder surgeries, as well as patients with additional muscle transfers were excluded. Furthermore, patients with overall limited ROM defined as external rotation ≤0° and abduction ≤90° were excluded as well. All these exclusion criteria were applied to generate comparable groups and to exclude obvious reasons that could lead to a reduced function and outcome. Finally, 52 patients were included in the IR≤2 and 63 in the IR≥8 group. Demographic parameters (age, gender, American Society of Anesthesiologists (ASA) score, body mass index [BMI], nicotine or alcohol abuse and number of previous surgeries) and surgery-related parameters (implant-related characteristics, glenoid bone graft, subscapularis reattachment, experience of the surgeon) were evaluated. A subgroup analysis of 4 groups (group 1: preoperative IR≥8 and postoperative IR≤2; group 2: preoperative IR≥8 and postoperative IR≥8; group 3: preoperative IR≤2 and postoperative IR≥8; group 4: preoperative IR≤2 and postoperative IR≤2) was performed. This analysis allowed to analyze patient groups with similar preoperative "baseline" fIR but different fIR outcomes.

Clinical and radiographic assessment

Preoperative and postoperative clinical assessments were done by an independent examiner who had not operated on the patients. This was done in an institutionally standardized manner preoperatively and at final follow-up (2 years, 5 years, 7.5 years, 10 years, and afterwards every 5 years).

Clinical examination included measurement of the active ROM using a handheld goniometer and assessment of the absolute and relative CS scores (aCS and rCS)[6,7] and the Subjective Shoulder Value (SSV).[16] The correctness of documented fIR was additionally confirmed with the standardized photo and video documentation before inclusion of patients. If there were any ambiguities regarding the documented fIR in the CS or the image material, the patient was excluded. Abduction strength was measured with a validated electronic dynamometer (Isobex; Cursor).[15]

Preoperatively and postoperatively, standardized radiographs were obtained for all patients. Preoperative radiographs were used to classify rotator cuff arthropathy according to Hamada,[20] measure the critical shoulder angle,[39] the acromiohumeral distance, the medialization of the COR (Fig. 1), the lateralization of the humerus (Fig. 2), and the distalization of the greater tuberosity (Fig. 3). On preoperative CT scans, glenoid inclination, glenoid version,[13] and anterior or posterior humeral head subluxation (relative to the axis of the scapula) were measured. Fatty infiltration of the rotator cuff muscles was evaluated according to Goutallier.[18]

For the analysis of parameters regarding implant positioning, we used the first anteroposterior radiograph optimally fulfilling the criteria for standardized radiographs (central beam exactly parallel to base plate, shoulder in internal rotation) which was taken between 6 weeks and 1 year postoperatively. The inclination of the glenoid baseplate (Fig. 4),[8] the glenosphere "overhang distance"[8] (Fig. 5), the medialization of the COR (Fig. 1), the lateralization of the humerus (Fig. 2), and the distalization of the greater tuberosity (Fig. 3) were measured on these radiographs. The distalization was only measured when the preoperative and postoperative abduction angle were within 5°. Radiographic outcome measurements evaluated at the latest follow-up were inferior scapular notching according to Sirveaux,[46] glenoid or humeral loosening, and the occurrence of heterotopic ossifications (triceps spur). All measurements were performed by 2 blinded shoulder surgeons and interrater reliability was assessed for all postoperative measurements.

Statistical analysis

Binary variables were compared between the two outcome groups with Fisher's exact tests. All other group comparisons were performed with Mann Whitney U tests. Continuous variables are reported with mean and standard deviation, for categorical variables, the respective level frequencies are reported. Inter-reader reliability was assessed using weighted Kappa with linear weights for categorical variables and intra-class correlation coefficients (ICC) based on absolute agreement in a two-way random effects model reporting single-rater estimate. Measures that were rated by two readers were averaged over both readers before analysis. For every variable a univariate logistic regression analysis was performed. For this analysis every value was considered continuous. To control for confounding among the variables, a multivariate model was subsequently employed using a stepwise selection approach based on all pre-identified risk factors. Correlations of significant risk factors were tested with Spearman Rank Correlation Tests. P-values below .05 were considered statistically significant. Statistical analysis was conducted with SPSS (Version 26.0.; IBM Corp., Armonk, NY, USA).

Results

Demographic, surgical, clinical, and radiographic parameters of 52 patients in the IR≤2 group and 63 in the IR≥8 group were analyzed. Mean follow-up was 41 and 59 months, respectively.

Demographic parameters and comorbidities

Evaluated demographic parameters are presented in Table I. Demographic risk factors for poor postoperative fIR were male gender, a high BMI, smoking, the number of previous surgeries, and a high ASA score. A multivariate logistic regression showed that male gender, smoking, and a high ASA score are independent demographic risk factors (Table II). Notably, the preoperative fIR was not different in the groups of smokers and nonsmokers. In the
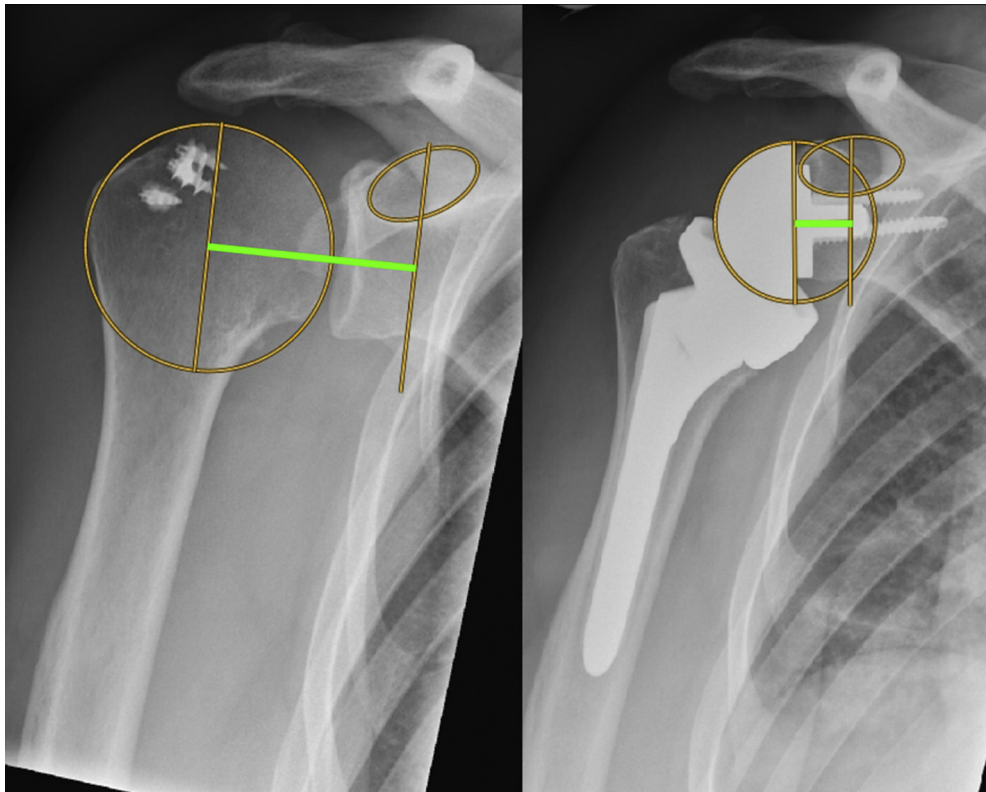
Figure 1 The medialization of the COR was measured as the distance from the base of the coracoid (center of ellipse) to the COR of the humeral head (preoperatively) or the COR of the glenosphere (postoperatively) in millimeter (parallel to the glenoid or baseplate).
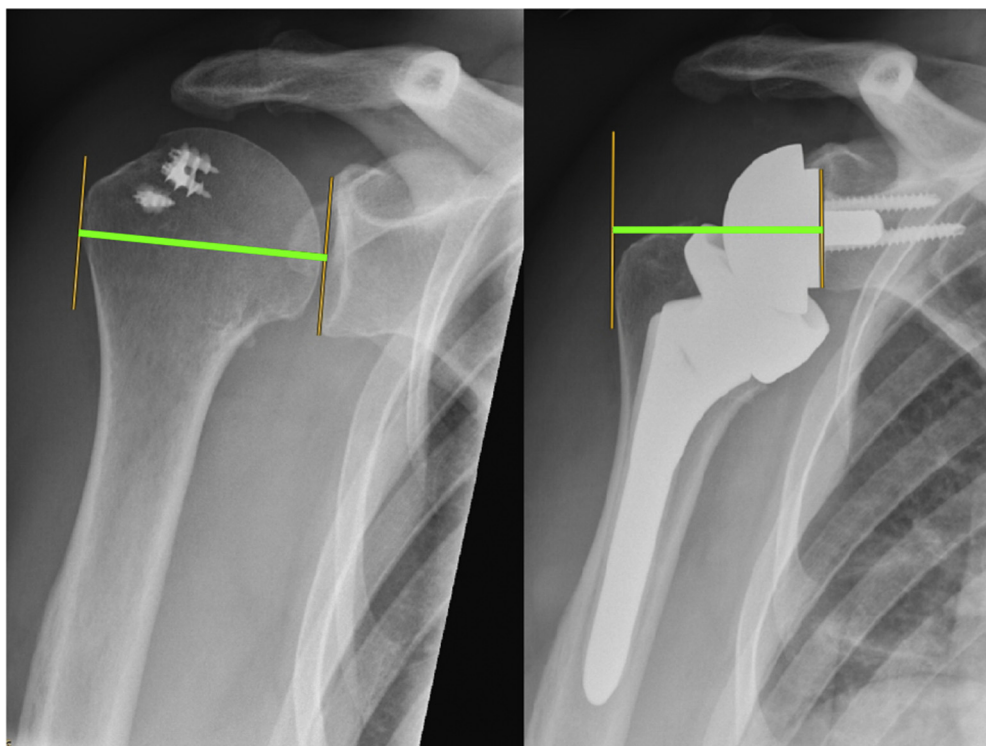
Figure 2 The lateralization of the humerus was measured as the distance from the glenoid to the greater tuberosity in mm (parallel to glenoid or baseplate).
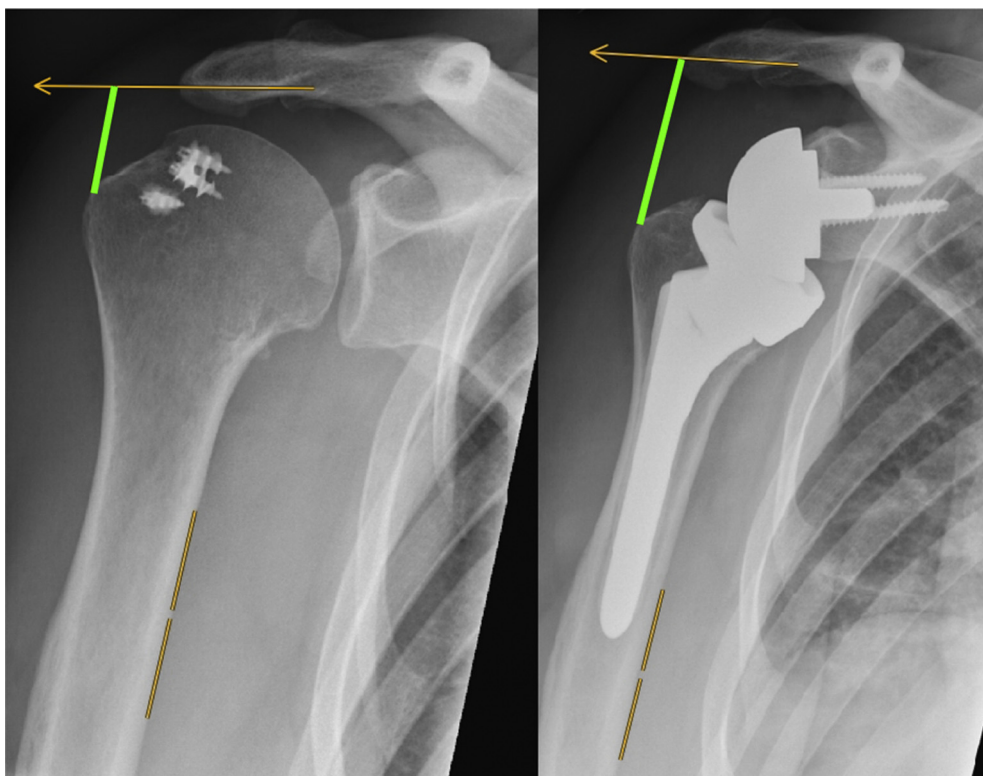
Figure 3 The distalization was measured as the distance from the acromion undersurface to the greater tuberosity in millimeter (in line with the humeral shaft and with comparable abduction angles within 5°).

postoperative course, however, a significant, linear correlation between clinically relevant functional improvement of fIR in non-smokers and deterioration of fIR in smokers was undeniable.

Implant-related parameters

In the IR≥8 group, significantly more patients received a higher insert (Table I). Whereas 77% of patients in the IR≤2 group received a 0 mm insert, 56% of patients in the IR≥8 group received a 3 mm insert or higher. Statistically, a thin insert was shown to be an independent risk factor for poor fIR. Glenosphere size had no influence on fIR. In both cohorts, a size 36 glenosphere was implanted in 73% of cases and a size 40 glenosphere in 27% of cases. The humeral stem size was significantly larger in the IR≤2 group. This was attributed to the higher proportion of male patients in this group.

Surgical parameters

The rate of subscapularis repair versus nonrepair was not different in the 2 groups (Table I). In the univariate analysis, surgeon experience played a relevant role: Only 33% of the patients operated on by the head of the department had postoperative fIR ≤2 as opposed to 57% of the patients operated on by a less experienced member of the faculty. On multivariate analysis, however, surgical experience was shown not to be an independent prognostic factor.

Clinical outcome

Clinical outcome scores (SSV, CS) improved significantly in both groups (Table III). There was no difference in SSV or CS between the 2 groups preoperatively. However, postoperatively the IR≥8 group
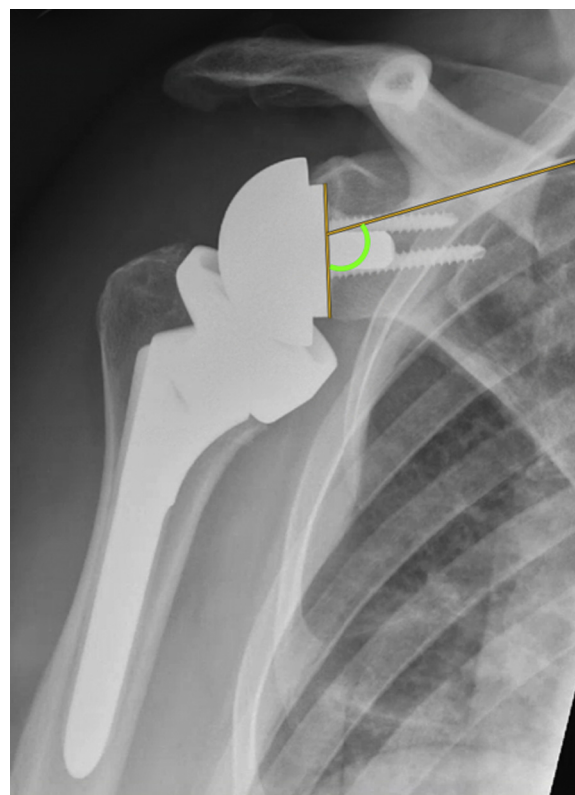
Figure 4 The inclination of the glenoid baseplate measured according to Maurer et al[37] representing the angle between the supraspinatus fossa and the back side of the glenoid component.
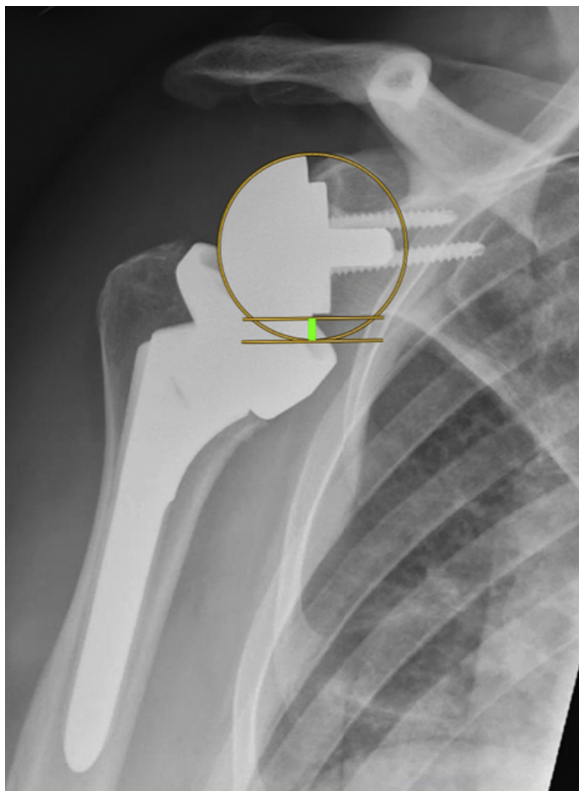
Figure 5 The glenosphere "overhang distance"[8] representing the distance between the most inferior point of the glenosphere and the most inferior point of the glenoid (measured as the distance from a line at the inferolateral edge of the glenoid drawn parallel to the peg, to a parallel line at the most inferior aspect of the glenosphere in millimeter).

had significantly better overall outcome scores (SSV and rCS). Detailed analysis showed that the difference in the rCS was closely related to the results of fIR. If the values for fIR were discarded in both groups, the rCS was not different. Flexion and abduction were not significantly different preoperatively in the 2 groups, but differed postoperatively (IR≤2: 12° less mean flexion, 15° less mean abduction). Significant postoperative differences were also seen in the subsections "pain" and "activities of daily living" of the CS.

Only preoperative fIR differed significantly between the 2 groups. Although associated with higher BMI values, the multivariate regression analysis indicated preoperative fIR to have the most significant association with postoperative fIR when adjusting for other significant factors of the univariate analysis (BMI, gender, and smoking).

Radiographic parameters

Preoperatively evaluated parameters showed a significant difference between the groups with respect to posterior subluxation (increased subluxation in the IR≥8 group) and lateralization of the humerus (less lateralization of the greater tuberosity in the IR≥8 group). Of the evaluated postoperative radiographic parameters, only scapular notching differed significantly between groups with higher grades in the IR≥8 group. An interesting aspect is the analysis of preoperative and postoperative changes (Δ) in the medialization of the center of rotation and the distalization of the greater tuberosity. Although the analysis of the absolute preoperative and postoperative values does not show significant differences, in the IR≥8 group the center of rotation had been less

medialized and the greater tuberosity had been more distalized than in the IR≤2. Statistically, the change in distalization of the greater tuberosity was an independent risk factor for poor IR in the multivariate analysis and not related or correlated with the height of the humeral insert. Intraclass correlation coefficient is shown in Table IV.

Subgroup analysis

Comparison of group 1 (preoperative IR≥8 and postoperative IR≤2) and group 2 (preoperative IR≥8 and postoperative IR≥8) demonstrated that patients in group 1 who had lost fIR had a significantly higher number of previous shoulder surgeries (60% one or two surgeries vs. 30%), a thinner insert (0 mm vs. 3 mm), more smokers (33% vs. 8%), less scapular notching (66% notching grade 0, 33% notching grade 1 vs. 44% notching grade 0 and 28% notching grade 1 and 28% notching grade 2 or higher), more preoperative pain (5 points vs. 7 points in mean preoperative rCS), and better preoperative abduction (90° vs. 70°). Postoperatively median rCS was significantly lower in group 1 (83 [78.5 – 88.7] vs. 92 [87.8 – 95.9]).

Comparison of group 3 (preoperative IR≤2 and postoperative IR≥8) and group 4 (preoperative IR≤2 and postoperative IR≤2) showed that patients in group 3 had a significantly lower percentage of male patients (17% vs. 57%), lower BMI (26.7 vs. 29.3), lower percentage of ASA III patients (4% vs. 38%), and less smokers (3% vs. 11%).

Discussion

The aim of this study was to evaluate parameters that influence fIR after RTSA in a cohort of patients treated with RTSA for comparable indications with the same implant. Our data show that poor preoperative fIR, smoking, male gender, a thin insert height, a small change in preoperative to postoperative distalization, and a high ASA score are independent risk factors for poor postoperative fIR.

Factors affecting fIR after RTSA are well studied biomechanically[2,4,5,10,17,19,21,22,24,26,27,29–31,35,38,40,49,51] but not clinically.[9,23,41–43,45,48,50] Results of biomechanical studies, however, do not necessarily correspond with clinical findings.[45] Functional internal rotation is indisputably important for activities of daily living and quality of life. Hygiene behind the back is not possible in 20-45% of patients according to a recent review,[44] that is, 23% of patients had to change hands and 5% required assistive mechanical devices for toileting.[43] The ability to perform tasks behind the back becomes particularly important after bilateral RTSA since it may result in a loss of independence.

Demographic parameters and comorbidities

Our results are highlighted in the subgroup analysis. When comparing patients who improve poor preoperative fIR to patients with poor preoperative and postoperative fIR, the first group consists of more female, nonobese, nonsmokers. These results are in line with the literature. BMI, general health (diabetes), and male gender have previously been reported to be associated with poorer postoperative fIR after TSA and RTSA.[9,33,45] Apart from gender, these factors can be modified (at least to a certain extent) and therefore should be discussed with the patient preoperatively. In addition, a higher number of previous surgeries are associated with poor postoperative fIR so that patients with multiple previous operations should be informed preoperatively that restoration of fIR is uncertain. Smoking has so far not been recognized as a risk factor for poor postoperative fIR; however, in our cohort the

Table I
Demographic, surgery/implant-associated and radiographic data and group comparison.

	IR≤2	IR≥8	P value[*]
Total (n)	52	63	
Age at surgery (y)[*]	72.8 (9.3)	72.1 (8.0)	n.s.
Sex (m/f)	m:31, f:21	m:20, f:43	**.003**
Involved side (l/r)	l:21, r:31	l:23, r:39	n.s.
BMI[*]	29.6 (5.8)	26.0 (3.5)	.005
Nicotine (y/n)	y: 17.3; n: 82.7	y: 6.5; n: 93.5	**.002**
Previous surgery (n, %)	0:52.9	0:74.6	**.018**
	1:35.3	1:19.0	
	2:11.8	2:6.3	
Indication (n, %)			
Irreparable RC tear OR insufficiency	30 (57.7)	36 (57.1)	n.s.
Cuff tear arthropathy	18 (34.6)	24 (38.1)	n.s.
Primary OA	4 (7.7)	3 (4.8)	n.s.
ASA score (%)	I: 1.9	I: 11.1	**.009**
	II: 67.3	II: 74.6	
	III: 30.8	III: 14.3	
FU (months)[*]	41.0 (29.7)	58.6 (33.4)	**.004**
Radiographic data (preoperative)			
CSA (°)[*]	33.4 (4.9)	34.2 (4.6)	n.s.
ACHD (mm)[*]	7.8 (5.0)	6.5 (4.3)	n.s.
Glenoid inclination (°)[*]	76.5 (5.0)	77.1 (5.9)	n.s.
Posterior subluxation (%)[*]	49.1 (9.2)	52.3 (7.9)	**.037**
Glenoid version (°)[*]	−2.1 (6.3)	−2.3 (6.9)	n.s.
Medialization COR (mm)[*]	45.2 (6.8)	42.3 (6.3)	n.s.
Lateralization humerus (mm)[*]	53.1 (5.8)	50.5 (5.3)	**.0093**
Distalization GT (mm)[*]	20.5 (6.2)	19 (6.7)	n.s.
Goutallier grade (0-4)			
SSP	3 (2;4)	4 (2;4)	n.s.
SSC	2 (1;3)	1 (1;3)	n.s.
ISP	3 (1;4)	3 (1;4)	n.s.
TMI	0 (0;2)	0 (0;1)	n.s.
Hamada (%)			n.s.
Grade I	1.9	3.2	
Grade II	65.4	47.6	
Grade III	15.4	31.7	
Grade IVa	7.7	6.3	
Grade IVb	3.8	7.9	
Grade V	5.8	3.2	
Surgery characteristics			
SSC repair (%)	86.5	79.4	n.s.
Surgeon experience (%)			**.028**
Junior consultant	38.5	23.8	
Senior consultant	34.6	30.2	
Head of the department	26.9	46.0	
Implant characteristics			
Glenosphere size (mm)	36 (36;40)	36 (36;40)	n.s.
Insert height (mm; %)	0: 76.9	0: 45.2	**.001**
	3: 15.4	3: 43.5	
	6: 7.7	6: 11.3	
Humeral stem size (mm)	12 (12;14)	12 (9;14)	**.002**
Humeral stem cemented (%)	48.1	38.1	n.s.
Radiographic data (postoperative)			
Baseplate inclination (°)[*]	79.8 (7.9)	81.5 (6.8)	n.s.
Glenosphere overhang distance (mm)[*]	3 (2.6)	2.7 (2.1)	n.s.
Medialization COR (mm)[*]	23.5 (5.5)	22.9 (4.7)	n.s.
Lateralization humerus (mm)[*]	55.7 (5.3)	54.1 (5.1)	n.s.
Distalization GT (mm)[*]	40 (8.4)	41.2 (6.7)	n.s.
Notching (%)			**.044**
Grade 0	58.8	44.4	
Grade 1	29.4	25.4	
Grade 2	0	9.5	
Grade 3	9.8	7.9	
Grade 4	2	12.7	
Heterotopic ossification (%)	51.9	47.6	n.s.
Loosening shaft (%)	0	0	n.s.
Loosening glenoid (%)	0	1.6	n.s.
Radiographic data (preoperative to postoperative change)			
Medialization COR (mm)[*]	−21.7 (6.3)	−19.4 (5.2)	**.036**
Lateralization humerus (mm)[*]	2.6 (5.03)	3.5 (5.3)	**n.s.**
Distalization GT (mm)[*]	19.4 (7.7)	22.2 (5.2)	**.04**

n.s., not significant; *BMI*, body mass index; *ASA*, American Society of Anesthesiology Score; *FU*, follow-up; *CSA*, critical shoulder angle; *ACHD*, acromio-humeral distance; *COR*, center of rotation; *GT*, greater tuberosity; *SSC*, subscapularis tendon.
All other values in median with percentile in brackets. Values in mean, with ± standard deviation in brackets or exact values if not applicable; significant *P*-values are in bold.
  [*] Fisher's exact test or Mann-Whitney U test.

Table II
Multivariate regression analysis of significant variables.

	P value
BMI	n.s.
Surgeon status	n.s.
Posterior subluxation	n.s.
Medialization COR (preop-postop change)	n.s.
Preoperative fIR	**.001**
Nicotine	**.003**
Sex	**.004**
Insert height	**.022**
Distalization GT (preop-postop change)	**.026**
ASA score	**.043**

ASA, American Society of Anesthesiologists Score; *BMI*, body mass index; *COR*, center of rotation; *fIR*, functional internal rotation; *GT*, greater tuberosity.
Bold indicates significant parameters in multivariate regression analysis.

association was robust. It is particularly interesting that smokers did not have poor fIR preoperatively but lost fIR after surgery.

Surgical and implant-related parameters

We evaluated surgical or implant-related parameters. Interestingly, with the utilized prosthetic system, a thin insert was shown to be an independent risk factor for poor fIR. Glenosphere size, however, was irrelevant. These findings partly contradict previously published cadaveric, biomechanical studies. Krämer et al[27] tested 2 different glenosphere designs (38 and 42 mm, concentric and eccentric) with 2 different inserts (normal and thin, 2 mm difference) and reported a significant improvement of fIR with the thin insert and the eccentric glenosphere design whereas the size of the glenosphere did not play a role. Tashjian et al[47] tested different component combinations of the Tornier Aequalis prosthesis and found that increasing insert thickness was associated with decreased passive ROM progressively from 6 to 12 mm whereas glenosphere size, eccentricity, and tilt did not have a significant influence on internal rotation.

In our study, a higher insert and a higher operative distalization of the greater tuberosity (Δ), which surprisingly were independent variables, are compatible with a good fIR after RTSA. We cannot explain these results with a valid and reasonable hypothesis at the moment. Should our data be confirmed in further studies, an explanation would have to be sought.

The most experienced surgeon restored fIR better than the more experienced faculty and the more experienced faculty restored fIR better than the junior faculty. These observations, however, were only significant in a univariate analysis and not in a multivariate analysis. The exact nature and relevance of possible confounding factors such as patient selection, surgical planning, and technique or rehabilitation are subject of an ongoing study in view of improving teaching performance.

The relevance of subscapularis repair for fIR after RTSA has been discussed controversially.[1,9,10,12,43,45] We found no effect of subscapularis repair on fIR and concur with recent clinical studies.[41,45] The observed data in the present study suggest that fIR is not determined by the subscapularis but by other muscles such as the deltoid, the pectoralis major, the latissimus dorsi, or the teres major muscle.

Clinical parameters

Clinical shoulder scores (SSV, CS) were not different preoperatively but improved roughly 10% more in the IR≥8 group. As the difference in score between the groups was statistically explained by the difference in fIR alone, the study shows the subjective clinical relevance of fIR. As no other functional parameters were different, the lower scores in activities of daily living are most likely related to loss of fIR. Postoperatively poor fIR was, however, also correlated with slightly increased pain. Nevertheless, vice versa pain was not associated with poor fIR.

Preoperative fIR and higher BMI values followed by smoking status ASA score and gender were clearly relevant and future clinical studies should determine whether addressing the modifiable factors BMI, smoking, and potentially ASA status can improve postoperative function.

Radiographic parameters

Interestingly, we found higher rates of scapular notching in the IR≥8 group. Thus, scapular notching is compatible with good fIR as well as with good overall outcome in this cohort. The absence of scapular notching was associated with poor fIR. This would be compatible with (1) repetitive internal rotation leads to anteroinferior notching. In our study, the average follow-up in the IR≥8 group was significantly longer than in the IR≤2 group. If external rotation had been good from the beginning and fIR would have increased over time, this would be a reasonable hypothesis; or (2) low humeral component retrotorsion allows a very good internal rotation amplitude from the beginning with (initially) limited external rotation. Repetitive external rotational movements lead to posteroinferior notching over time. Based on the available data, neither the change in fIR nor the humeral torsion could be analyzed. Nevertheless, hypothesis 2 is more probable in view of the available literature. Kolmodin et al[25] identified osseous impingement using patients' actual ROM after RTSA with CT scans and video-motion analysis. They found that scapular notching most

Table III
Clinical outcome of RTSA and group comparison.

	IR≤2		IR≥8		P value*	
	Preoperative	Last FU	Preoperative	Last FU	Preoperative	Last FU
SVV (%)	30.9 (15.1)	76.9 (18.3)	33.4 (17.1)	86.2 (12.4)	n.s.	**.005**
aCS (pts)	38.2 (15.8)	66.5 (9.0)	36.9 (13.4)	75.4 (7.0)	n.s.	**.000**
rCS (%)	48.9 (18.7)	80.4 (9.4)	47.1 (15.7)	89.9 (7.3)	n.s.	**.000**
Flexion (°)	96.3 (36)	123 (18.2)	92.0 (42.6)	133.3 (15.6)	n.s.	**.000**
Abduction (°)	81.0 (34.3)	138.9 (22.3)	80.3 (39.9)	148.7 (19.4)	n.s.	**.010**
ER (°)	37.6 (24)	27.7 (14)	35.9 (23.2)	30.1 (15.5)	n.s.	n.s.
fIR (pts)	3 (2;6)	2 (2;2)	6 (4;8)	8 (8;8)	**.000**	**.000**
Pain level (pts)	5 (4;8)	15 (13;15)	7 (4;8)	15 (15;15)	n.s.	**.018**

FU, follow-up; *n.s.*, not significant; *Diff.*, difference; *SVV*, subjective shoulder value; *aCS*, absolute constant score; *rCT*, relative constant score; *pts*, points; *ER*, external rotation; *fIR*, functional internal rotation.
All values in mean with ± standard deviation or median and percentile (); significant *P*-values are in bold.
* Fisher's exact test or Mann-Whitney U test.

Table IV
Interreader reliability.

	ICC (95% CI)
Medialization COR	0.549 (0.405, 0.666)
Lateralization humerus	0.904 (0.863, 0.933)
Distalization GT	0.876 (0.8181, 0.916)
Baseplate inclination	0.884 (0.820, 0.924)
Glenosphere overhang distance	0.865 (0.809, 0.905)

CI, confidence interval; *COR*, center of rotation; *GT*, greater tuberosity; *ICC*, intraclass correlation coefficient.

commonly occurs on the posteroinferior scapular pillar in external rotation with the arm at the side. Although, at least biomechanically, an increase in humeral component retrotorsion leads to loss of internal rotation,[19,21,26] this has not been proven clinically.[2,5,42] Therefore, future research should analyze humeral retrotorsion in combination with scapula position in further detail.

Controversy exists regarding the influence of glenoid inclination on rotational movements.[25,34,45] We found no difference in preoperative glenoid inclination or postoperative baseplate inclination between groups.

Limitations

The first limitation of the present study is that many, biomechanically interesting, parameters for this specific research question could not be evaluated. Because of the lack of postoperative CT or MRI scans, we were not able to three-dimensionally analyze baseplate positioning, humeral component torsion, offset or different neck-shaft angles. On the other hand, this can also be considered a strength of the study, as only one implant design was used. The fact that a large proportion of patients showed very good fIR indicates that the implant design is probably only a secondary factor and other factors must be more relevant.

Second, since a significant difference in the subgroup "pain" could be demonstrated, it cannot be excluded with certainty that the restriction of internal rotation is pain-related, at least for a certain proportion of the IR≤2 group. However, the majority of patients in the IR≤2 group reported no or very little pain and vice versa pain was not associated with poor fIR. For this reason, pain-related restriction of fIR in our cohort is unlikely.

Third, the study is a retrospective review of patients' and therefore suffers the inherent limitations of retrospective analysis. However, to provide comparability, patients were operated in a single center with the same surgical technique, using 1 implant system and a standardized postoperative protocol. Furthermore, postoperative data was collected prospectively in an institutional database. Follow-up was at least 2 years with a mean follow-up of 41 and 59 months, respectively. Inclusion criteria were strict. ROMs were measured rigorously by our study nurses and documented using photographs and video. Radiographs were independently read and their parameters measured by 2 fellowship-trained shoulder surgeons (A.H., B.H.) and a resident (J.H.). Further research in our institution is going to assess and analyze rotator cuff and deltoid muscle quality as well as implant positioning on MRI and fIR in motion analysis with a special focus on scapulothoracic motion.

Conclusion

Independent risk factors for poor postoperative fIR after RTSA are poor preoperative fIR, smoking, male gender, less preoperative to postoperative distalization of the greater tuberosity, a thin humeral insert height, and a high ASA score. Except for male gender these factors are modifiable. These findings may be a valuable

addition to patient counseling as well as preoperative planning and intraoperative decision-making. The importance of fIR is substantiated by this study.

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