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Original article

Factors associated with internal rotation outcomes after reverse shoulder arthroplasty☆

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ABSTRACT

Background: Reverse shoulder arthroplasty (RSA) was introduced in 1985 by Grammont for patients with gleno-humeral osteoarthritis and severe rotator cuff damage. Internal rotation (IR) is limited in some patients after RSA. The objective of this study was to identify pre- and intra-operative factors associated with good IR outcomes 6 months after RSA.
Hypothesis: The condition of the residual cuff (usually the sub-scapularis and teres minor) and inferior glenosphere overhang are the main factors associated with IR outcomes after RSA.
Material and Method: A total of 36 patients who underwent RSA between 2 November 2015 and 10 January 2017 were enrolled prospectively. The inclusion criterion was massive rotator cuff tear with or without osteoarthritis and gleno-humeral osteoarthritis with asymmetrical glenoid wear. The pre-operative work-up included determination of the Constant score, Subjective Shoulder Value (SSV), and passive and active motion ranges; standard radiographs; and computed tomography. The same clinical and radiological parameters were recorded in all patients during a visit 6 months after surgery.
Results: After surgery, all motion ranges were improved except IR with the elbow by the side (IR1, ability to place the hand on the back). IR1 to or above L3 was significantly associated with a lower body mass index ($p = 0.04$), good passive IR before surgery ($p = 0.056$), a smaller pre-operative glenoid inclination angle, and greater glenosphere overhang ($p = 0.03$). Neither the condition of the sub-scapularis nor sub-scapularis repair were significantly associated with post-operative IR1. IR1 was significantly more limited in patients whose teres minor was normal.
Conclusion: Satisfactory active IR1 correlated with good passive IR1. IR1 was better in thin individuals who had non-concentric gleno-humeral osteoarthritis. Inferior glenosphere overhang of 6 mm or more was associated with a greater range of IR.
Level of evidence: IV, prospective observational cohort study.

1. Introduction

After a period of some reluctance, anatomic shoulder prostheses gained acceptance as the treatment of choice for incapacitating shoulder arthropathies. Reverse shoulder arthroplasty (RSA) was introduced in 1985 by Grammont et al. [1] as a treatment for gleno-humeral osteoarthritis with severe rotator cuff damage. RSA medialises the centre of rotation and increases the lever arm of the deltoid muscle, thereby ensuring satisfactory active ranges of motion (ROMs). Drawbacks of medialisation include scapular notching [2] and limited rotational ROMs, notably with the elbow by the side [3,4].

Major insights gained into the factors associated with scapular notching have led to the development of preventive methods. In contrast, little is known about the factors that influence rotational ROMs. Most patients experience little or no improvement in arm rotation with the shoulder by the side [3,4]. Boileau et al. [3] reported that RSA improved internal rotation (IR) by only two vertebral levels and external rotation (ER) by only 4°. Medialisation of the centre of rotation may have deleterious effects including an increased risk of impingement, decreased tension of the residual rotator cuff [3–5,6], and recruitment of the most medial deltoid muscle fibres. ER gains achieved by lateralising the centre of rotation by 8.5 mm ranged from 15° (Kalouche et al. [7] and Valenti et al. [4]) to 36° (Franckle et al. [8] and Boulahia et al. [9]). No data are available on the range of IR after RSA.

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Table 1
Range of motion values before surgery.

	Passive (°)	Active (°)
Forwards elevation	113° ± 27°	80° ± 34°
Abduction	107° ± 31°	71° ± 34°
ER1	19° ± 21°	9° ± 16°
ER2	37° ± 28°	24° ± 24°
IR1	3 ± 3	3 ± 3
IR2	17° ± 24°	17° ± 24°

ER1: external rotation with the elbow by the side; ER2: external rotation with the arm abducted at 90°; IR1: internal rotation with the elbow by the side; IR2: internal rotation with the arm abducted at 90°.

The objective of this study was to identify pre- and intra-operative factors associated with good IR outcomes 6 months after RSA. The working hypothesis was that the condition of the residual cuff (usually the sub-scapularis and teres minor) and inferior glenosphere overhang are the main factors associated with IR outcomes after RSA.

2. Material and Methods

Consecutive patients who underwent RSA between 2 November 2015 and 10 January 2017 were enrolled in a single-centre prospective study. The inclusion criterion was a massive rotator cuff tear with or without gleno-humeral osteoarthritis or concentric gleno-humeral osteoarthritis with asymmetrical glenoid wear. We excluded patients with other aetiologies, those managed with both RSA and latissimus dorsi transfer, and those with complications that precluded an evaluation of rotational ROMs.

The study was approved by the appropriate ethics committee in compliance with French law (No. 94-548, 1 July 1994).

At the time of surgery, the 36 included patients had a mean age of 75 ± 6 years (range, 63–85 years) and a mean body mass index (BMI) of 28 ± 6 (range, 19-44).

The pre-operative clinical assessment included determination of the Constant score [10], Subjective Shoulder Value (SSV), and passive and active ROMs. Standardised photographs were used for goniometer measurements of the following ROMs: forwards elevation, abduction, ER with the elbow by the side (ER1), ER with the arm abducted at 90° (ER2), IR with the elbow by the side (IR1), and IR with the arm abducted at 90° (IR2). IR1 was assessed according to the Constant score [10] (Table 1). IR1 was deemed satisfactory if the patient could actively place the hand on or above L3 and unsatisfactory otherwise. The L3 cut-off was chosen because it reflects the ability to independently perform toileting and dressing tasks.

The pre-operative radiological work-up included radiographs taken under fluoroscopic guidance (antero-posterior views in neutral, internal, and external rotation and Neer's view) and computed tomography (CT) to assess the rotator cuff and to perform an automated analysis of glenoid version and inclination using 3D image analysis software (Glenosys; Imascap, Brest, France). The radiographs were read and the parameters measured by two observers, who resolved any disagreements by consensus.

Cases of osteoarthritis were classified as either concentric gleno-humeral osteoarthritis without massive rotator cuff tears or non-concentric gleno-humeral osteoarthritis with massive rotator cuff tear (Fig. 1).

The following were recorded on the pre-operative images: Gh0 angle defined by the horizontal and a line tangent to the glenoid, as

Fig. 1. a: concentric osteoarthritis, B1 glenoid by computed tomography; b: Non-concentric osteoarthritis, E0 glenoid on the antero-posterior view.

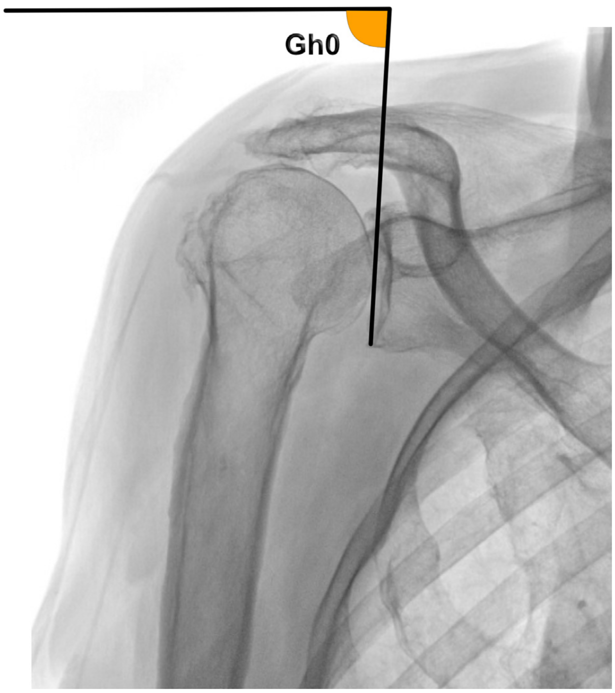

Fig. 2. Measurement of the Gh0 angle.

described by Falaise [2], whose mean value was 94° ± 10.2° (Fig. 2); glenoid version and inclination as computed by the Glenosys software, whose mean values were 15° ± 12° (range, 6°–38°) and 7.5° ± 11° (range, 17°–41°), respectively; and fatty muscle degeneration, recorded according to the Goutallier classification [11].

The same clinical parameters were recorded for all patients during a visit 6 months after surgery. Radiographs acquired under fluoroscopic guidance were used to determine (Fig. 3) the Gh1 angle, intrinsic inclination (β angle) measured relative to Maurer's line [12], and inferior glenosphere overhang measured using the glenosphere diameter as a corrective factor.

Surgery was performed via the delto-pectoral approach. If still present, the sub-scapularis was detached flush with the bone. In the 26 patients for whom lateralisation or correction of asymmetric glenoid wear was deemed necessary, a bone graft was harvested from the humeral head. Retroversion of the humeral cut was assessed intra-operatively; the mean value was 18° ± 5° (range 5°–30°). The implant was Aequalis Reverse® with 155° inclination in 6 patients and Aequalis Ascend Flex® with 145° inclination in 30 patients (Tornier, Bloomington, IN, USA). The stem was cemented in 7 patients.

Table 2
Comparisons of data before and after reverse shoulder arthroplasty.

	Before RSA	After RSA	*p*
Constant score	24 ± 10	74 ± 12	< 0.0001
SSV	36% ± 10%	79% ± 12%	< 0.0001
Forwards elevation	80° ± 34°	134° ± 32°	< 0.0001
Abduction	71° ± 34°	125° ± 33°	< 0.0001
ER1	9° ± 16°	16° ± 13°	< 0.0001
IR1	3 ± 3	4 ± 2	0.06
ER2	24° ± 24°	61° ± 19°	< 0.0001
IR2	17° ± 24°	34° ± 21°	0.001

SSV: subjective shoulder value; ER1: external rotation with the elbow by the side; ER2: external rotation with the arm abducted at 90°; IR1: internal rotation with the elbow by the side; IR2: internal rotation with the arm abducted at 90°.

The glenoid baseplate was positioned flush with the inferior rim of the glenoid cavity, taking care to tend towards an inferior orientation. Baseplate size was 25 in 22 patients and 29 in 14 patients. Glenosphere size was 36 in 32 patients and 42 in 4 patients. An eccentric glenosphere (2 mm) was used in 2 patients.

After implantation of the final humeral prosthesis, transosseous sub-scapularis re-implantation was performed in 23 patients. This procedure was not feasible in the remaining 13 patients, due to excessive soft tissue tension ($n = 11$) or to pre-operative absence of the sub-scapularis ($n = 2$).

The arm was immobilised on an abduction pad for 3 weeks after surgery. Gentle rehabilitation therapy was started immediately.

Statistical tests were performed using XL STAT software (Addinsoft). Between-group comparisons of quantitative variables were performed using the Mann-Whitney U test and Wilcoxon's test for paired data. The Kruskal-Wallis test was used for comparisons of more than two groups. Qualitative data were compared using the chi-square test. The Monte-Carlo correction was applied for small samples. Values of p smaller than 0.05 were considered significant.

3. Results

Six months after surgery, the Constant score was significantly improved (mean, 74 ± 12; range, 40–92). A significant improvement was also found in the SSV (mean, 79% ± 13%) (range, 50%–100%). Significant ROM increases were noted for forwards elevation, ER1, ER2, and IR2. However, IR1 was not significantly improved (Table 2).

Post-operatively (Fig. 3), the Gh1 angle was 101° ± 13° (range, 78°–137°) and intrinsic inclination relative to Maurer's line was

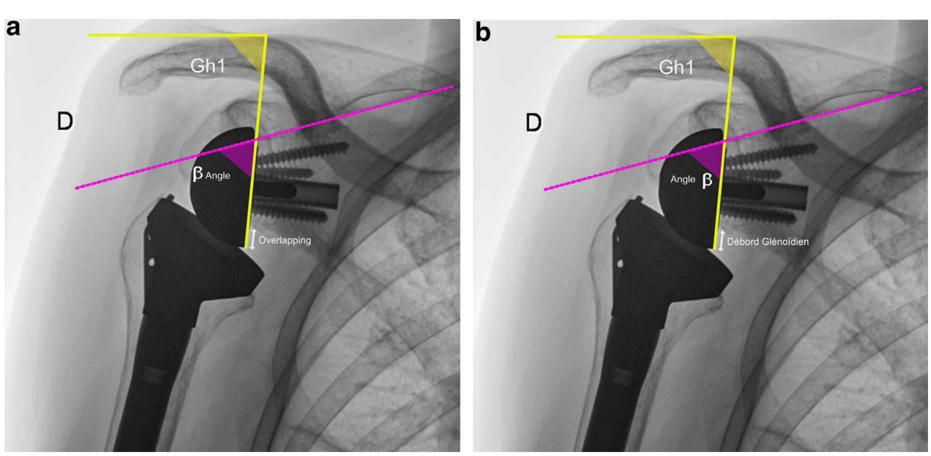

Fig. 3. Measurement of glenosphere overhang, the Gh1 angle, and the beta angle.

Table 3
Parameters significantly associated with the range of internal rotation after reverse shoulder arthroplasty.

	Satisfactory IR1 L3 or higher	Unsatisfactory IR1 < L3	p
BMI	25 ± 5	29 ± 6	< 0.05
OA/OMEX	3/10	9/14	0.03
Passive IR1 before surgery	4° ± 4°	2° ± 3°	0.05
Glenoid inclination	2° ± 9°	11° ± 10°	< 0.05
Glenosphere overhang	6.6 ± 2.5 mm	4.8 ± 2.5 mm	< 0.05
Passive forwards elevation	153° ± 24°	136° ± 22°	< 0.05
Active forwards elevation	146° ± 41°	127° ± 24°	< 0.05
Passive IR1	7 ± 1	2 ± 1	< 0.0001
Active IR1	7 ± 1	2 ± 1	< 0.0001
Beta angle after surgery	86° ± 7°	80° ± 9°	0.06
Spur	5	1	< 0.05

BMI: body mass index; OA: primary osteoarthritis; OMEX: non-concentric osteoarthritis; IR1: internal rotation with the elbow by the side.

Table 4
Influence of teres minor status on internal rotation.

	No TM function	Preserved TM function	p
Passive IR1	6 ± 1	4 ± 2	< 0.05
Active IR1	6 ± 1	3 ± 2	< 0.05

TM: teres minor; IR1: internal rotation with the elbow by the side.

82° ± 8.5° (range, 62°–97°). Inferior glenosphere overhang was 5.4 ± 2.6 mm (range, 0–9 mm).

Pre-operatively (Table 3), compared to the group with unsatisfactory IR1 ($n = 23$), significant differences in the group with satisfactory IR1 ($n = 13$) were a lower mean BMI ($p = 0.04$), a higher proportion of patients with non-concentric gleno-humeral osteoarthritis ($p = 0.03$), and less pre-operative upwards orientation of glenoid inclination ($p = 0.02$). A trend towards greater pre-operative passive IR1 was also noted in the group with satisfactory post-operative IR1.

Intra-operatively (Table 3), the only factor that differed significantly between the two groups was inferior glenosphere overhang, which was significantly greater in the group with satisfactory IR1 ($p = 0.03$). The two groups were not different regarding sub-scapularis re-attachment, humeral retroversion, glenosphere diameter, or use of bony increased offset (Bio-RSA). All 6 patients with 155° stems were in the group with unsatisfactory IR1, but the difference was not statistically significant.

Post-operatively (Table 3), the group with satisfactory IR1 had greater passive and active ROMs in forwards elevation and IR2. Presence of a spur was significantly associated with satisfactory active IR1 ($p = 0.008$). A trend ($p = 0.06$) towards a greater post-operative β angle in the group with satisfactory IR1 was noted. The 5 patients with loss of teres minor function (fatty degeneration score of 3 or 4) had significantly greater active and passive IR1 ROMs ($p = 0.02$) (6 ± 1.4 points versus 3.5 ± 2.5 points) (Table 4).

4. Discussion

Predictors of IR range after RSA are not well known, notably regarding IR1, which allows positioning of the hand on the back. In this prospective study, post-operative IR1 was significantly associated with greater pre-operative passive IR1, low BMI, and greater glenosphere overhang. Good teres minor function was associated with a smaller IR1 range. These results partially confirm our working hypothesis: glenosphere position was significantly associated with IR1, but whether the sub-scapularis was re-attached or not had no effect. In contrast, teres minor function appeared as a major factor.

This study has many limitations. The sample size was small. However, all patients were managed at the same centre using the same technique. Outcomes were assessed after 6 months, whereas Collin et al. [13] and Wirth et al. [14] reported continuing ROM gains until the end of the first year. Thus, our results after 6 months probably do not reflect the final outcomes. The use of L3 to separate IR1 into satisfactory and unsatisfactory categories is arbitrary but relevant to the ability to perform daily activities. The subgroups defined by glenosphere size and humeral inclination were small. Nevertheless, enrolment was prospective. ROMs were measured rigorously using photographs. The radiographs were acquired according to a stringent protocol to ensure good visualisation of the flat surface of the baseplate. Finally, the radiographs were read and their parameters measured by two observers working independently.

In this study, RSA was followed by significant ROM improvements in all planes except IR1. Nevertheless, a trend ($p = 0.06$) towards an IR1 gain was noted, and the difference might have been significant with a larger sample size, as shown in other studies [3–15]. Nevertheless, the gains were modest. IR remained difficult in 75% of patients. The main persistent problem reported by the patients was difficulty placing the hand on the back.

Published data come chiefly from biomechanical and cadaver studies and show that factors associated with satisfactory IR outcomes are inferior glenosphere overhang [3–13], a shallow polyethylene insert [16], less than 155° of humeral inclination [17], and limited humeral retroversion [18,19]. Berhouet et al. [18] reported better IR1 outcomes with larger glenosphere sizes, but Langhor et al. [20] did not replicate this finding. The shape of the scapular pillar seems to have no influence [5]. Among these factors, glenosphere overhang was associated with IR1 in our study. The number of patients with 155° of inclination was too small to show a significant difference, but all these patients had unsatisfactory IR1, and all patients with satisfactory IR1 had 145° of inclination. We found no significant association with humeral retroversion.

In our study, re-attaching the sub-scapularis was not associated with better IR1 outcomes, in keeping with reports by Boileau et al. [3] and Vourazeris et al. [21]. However, Friedman et al. [22] reported greater post-operative IR after sub-scapularis re-attachment.

We believe that the near identity of passive and active IR ROMs after surgery and the absence of correlations with sub-scapularis re-attachment or pre-operative fatty degeneration indicate that IR limitation is chiefly ascribable to impingement due to insufficient space for the humerus to rotate around the glenosphere. Middernacht et al. [23] demonstrated that the reverse shoulder prosthesis functions like a hinged door and the anatomical prosthesis like a revolving door. IR requires combined extension and abduction [16]. Lädermann et al. [15] reported that extension was the main factor in the development of notching after RSA, due to the rapid development of impingement on the posterior scapular pillar. In any case, inferior glenosphere overhang places the humerus at a greater distance from the scapular pillar and correlated with better IR1 in our study and most previous reports. In contrast, neither glenosphere lateralisation using Bio-RSA nor post-operative glenosphere inclination were associated with IR1 outcomes. However, pre-operative glenoid inclination as measured by Glenosys software seems associated with better IR outcomes, perhaps by promoting optimal glenosphere positioning.

Finally, the status of the teres minor had a major role in our study. Absence of teres minor function was associated with greater IR1. Thus, the teres minor may act as a passive restraint during IR1.

5. Conclusion

Factors associated with satisfactory IR1 outcomes after RSA consist of non-concentric gleno-humeral osteoarthritis, low BMI, absence of excessive upwards orientation of the glenoid before surgery, and at least 6 mm of glenosphere overhang. Good teres minor function is associated with a smaller range of IR1.

Disclosure of interest

L. Favard is a consultant for and perceives royalties from Wright. The other authors declare that they have no competing interest.

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Contributions of each author

M.R. and J.B. drafted the manuscript.
L.F. revised the manuscript for important intellectual content.

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