Total Reverse Shoulder Arthroplasty: European Lessons and Future Trends

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Abstract

In the late 1980s, Grammont introduced a new reverse total shoulder arthroplasty (TSA), with a hemisphere directly attached to the glenoid surface and with medial positioning of the center of rotation to overcome former shortcomings. Over the past few years, results from several mid- and long-term clinical studies of this new TSA have demonstrated that unexpectedly good functional outcomes and pain relief (Constant-Score, 60-69) could be achieved, even in patients with progressive superior migration, joint destruction, and rotator cuff deficiency. In all these studies, however, limited range of passive internal rotation and no improvement in active external rotation capacity were reported. In addition, glenoid erosion ("inferior glenoid notching") was reported in all these studies as a frequent phenomenon, occurring in 10% to 42%. The clinical impact of inferior notching is the subject of controversy, and its correlation with glenoid component loosening is not clear. In addition, rates of perioperative and postoperative complications (eg, dislocations, infections, hematomas, fractures) seem to be higher with this new TSA than with the conventional TSA. Improvements in prosthesis design and implantation technique (eg, easier and more reproducible surgical technique) should contribute to better range of motion, lower complication rates, and a lower frequency and lesser amount of inferior glenoid notching.

The low grade of the intrinsic stability of the shoulder joint limits the indication for conventional anatomical shoulder arthroplasty as soon as the most important biomechanical factor contributing to the concavity compression of the joint (ie, the rotator cuff) is significantly damaged and irreparable. Reverse shoulder arthroplasty (RSA), with its high degree of intrinsic stability and constraint, enables a successful arthroplasty even in such highly unstable, biomechanically decompensated, and pseudoparalytic shoulders. The typical clinical feature is a static or dynamic anterosuperior escape of the joint.

By changing the concavity and convexity at the joint, the geometry of the RSA prosthesis introduces high intrinsic stability and creates a stable center of rotation even in a shoulder that was nearly devoid of rotator cuff function. The design creates the constraint in the prosthesis by the deltoid reaction force, in which the degree of constraint depends on the abduction position of the arm (principle of coadaptation).[1] Because the joint partners are not permanently linked by a hinge, RSA can be considered a semiconstrained arthroplasty. Furthermore, the design places the center of rotation on the glenoid resection surface and therefore simultaneously minimizes potential glenoid component loosening by lever and shear forces and increases the lever arm of the deltoid muscle more than 100% (Figure 1).

The specific reverse prosthesis design of the Delta prosthesis (DePuy International Ltd, Leeds, England), introduced by Grammont and Baulot[1] in the early 1990s, has many advantages over the reverse and constrained total shoulder arthroplasty models of the 1970s, which disappeared very quickly because of their high rates of glenoid component loosening and poor functional results. Since Grammont and Baulot's encouraging early results, use of the Delta RSA has increased in Europe. The prosthesis was initially designed for *cuff-tear arthropathy,* any joint disease concomitant with an irreversible loss of rotator cuff function. The encouraging short-term results obtained with use of this prosthesis for cuff-tear arthropathy led surgeons to use the design for various indications in which conventional shoulder arthroplasty was prone

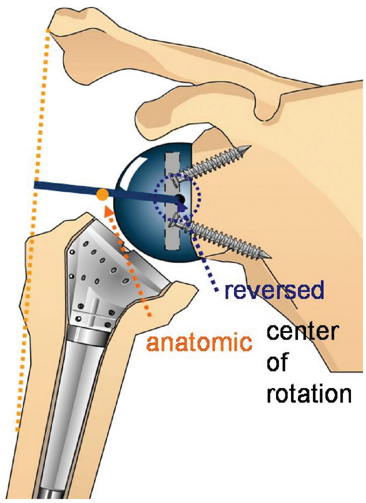

Figure 1. Design rationale of the Grammont reverse prosthesis (Delta prosthesis; DePuy International Ltd, Leeds, England). A stable center of rotation is created by reversing the concavity–convexity relations in the joint (semiconstrained design). Positioning of the center of rotation on the glenoid resection levels minimizes lever and shear forces to the glenoid component and increases the deltoid lever arm by more than 100%. Courtesy of DePuy Orthopaedics, Inc.

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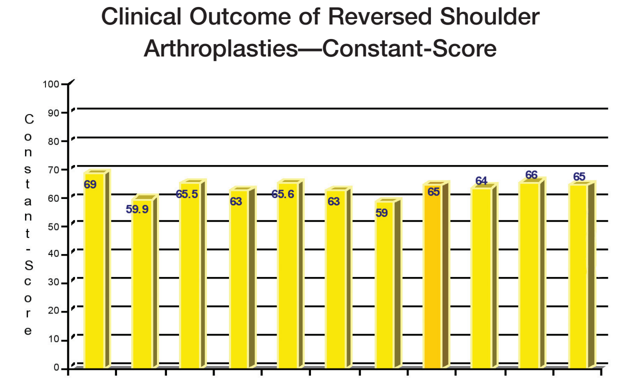

Figure 2. Clinical outcome of reverse shoulder arthroplasties for cuff-tear arthropathy. Meta-analysis of the literature: Baulot (1995),[10] De Buttet (1997),[11] Favard (2001),[12] Valenti (2001),[13] Sirveaux (2004),[5] Rittmeister (2001),[14] Boulahia (2002),[4] Seebauer (2005),[3] Werner (2005),[6] Boileau (2006),[7] Favard (2006).[15]

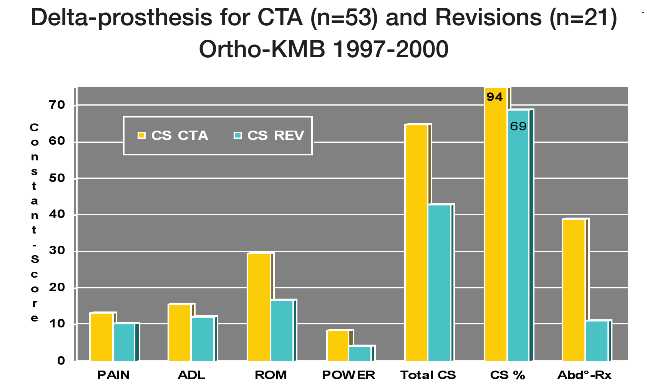

Figure 4. Comparison of Constant-Score parameters, total and age- and sex-related Constant-Scores, and glenohumeral motion under fluoroscopic control for primary cuff-tear arthropathy and revision cases in our prospective clinical study—a consecutive series of patients operated on between 1997 and 2000 at our institute.

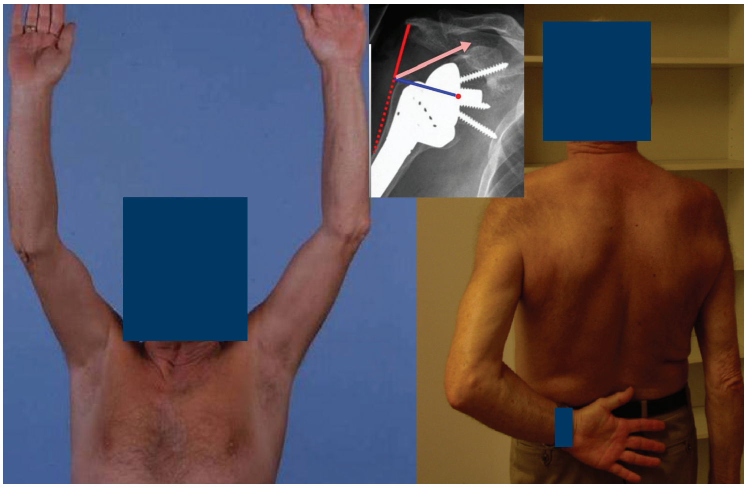

Figure 3. Typical clinical outcome after 7-year follow-up of reverse shoulder arthroplasty of the right shoulder. Excellent abduction and flexion, some limitation in internal rotations. Plain film insert shows significant medialization and lowering of the center of rotation and the increased deltoid lever arm (blue bar).

to failure because of a pseudoparalytic, biomechanically decompensated anterosuperior unstable joint situation (eg, failed prosthetic reconstruction with superior, anterior, or posterior instability; failed reconstruction; or a traumatic injury with pseudoparalysis and instability).

Clinical Results

Results are available for 457 patients operated on between 1992 and 2002 in a multicenter study in France.[2] In addition, we have presented results from our continual prospective clinical and radiologic follow-up of more than 400 RSAs performed at our institute between 1997 and 2006,[3,4] and a few more peer-reviewed clinical outcome papers were published within the past 2 years.[5-9] All the outcomes and study results have a uniform message: Despite the difficult preoperative condition of the joint and rotator cuff, the clinical outcome is unexpectedly good.

Clinical outcome depends significantly on underlying indication. Results for cuff-tear arthropathy are superior to those for revision of failed hemiarthroplasty or total arthroplasty and to those for RSA in fracture sequelae.

For cuff-tear arthropathy indications, reported overall Constant-Scores are 55 to 65, which means an age- and sex-related value of 80% to 95% in this older population (Figure 2).

Concerning range of motion (ROM) and function, RSA restores active elevation, but not active rotation, in completely cuff-deficient shoulders. The gain in active flexion is surprisingly high in cuff-tear arthropathy; postoperative values ranging from 110° to 140° have been reported for this patient group (Figure 3). If some parts of the posterior cuff (ie, the inferior third of the infraspinatus and teres minor) are still functioning, the external rotation function that is obtained with RSA is also acceptable, and a gain of 20° of external rotation in abduction but no improvement of external rotation with the arm at the side can be expected. In patients undergoing RSA for revision of failed hemiarthroplasty or total shoulder arthroplasty, the ROM and functional results are not as good as those obtained in patients undergoing primary RSA, and the absolute Constant-Scores range from 43 to 53 (60%-75% age- and sex-related value; Figure 4, Table I). Overall, in both indication groups, pain relief is substantial, even in the difficult subgroup of revisions of failed hemiarthroplasty for fracture.

Table I. Clinical Results (Constant-Score) of Delta™ Prosthesis in Revision Indications

Author	Revision of Failed …	n	Constant-Score
Seebauer[16]	Fracture hemiarthroplasty	21	43
Jouve[17]	Hemiarthroplasty for all indications	65	49
Gohlke[18]	Fracture hemiarthroplasty	20	45
Wall[19]	Total shoulder prosthesis	24	53

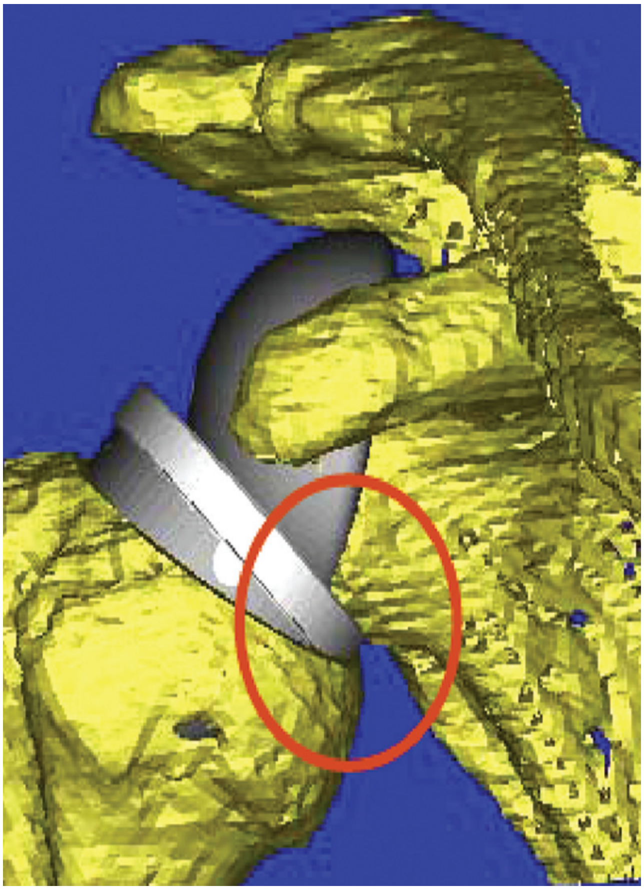

Figure 5. Problem of anterior and posterior glenoid impingement by the reverse prosthesis design—cause for limited internal and external rotation. Courtesy of DePuy Orthopaedics, Inc.

A common problem in both primary and revision groups is the limited amount of internal rotation (active and passive) that can be achieved, and this is directly related to the reverse prosthesis design and implantation technique.[20] Theoretically, greater internal rotation can be achieved with a more anteverted orientation of the humeral component[15] (Figure 5). With the reverse prosthesis, however, an extreme anteverted deviation from the physiologic retroversion is limited by the bony geometry of the head anteriorly and also increases the existing head-shaft offset of the humerus posteriorly.

Long-Term Results: Inferior Glenoid Notching

Good clinical results seem to deteriorate after 6 to 7 years.[9,21] Survivorship is significantly worse in the revision group and in the fracture-sequelae group. Whether this is directly related to the parallel progression of inferior glenoid bone erosion (inferior notching) is still a matter of discussion.[22-24] In 2007, Simovitch and colleagues[22] proved that clinical results are significantly worse in patients with higher grades of glenoid notching. However, the French multicenter study investigators did not find a correlation between notching and clinical outcome.[23] It is not clear whether inferior notching is a precursor, or warning sign, of a clinically significant glenoid component loosening. Indirect proof of the potential risk posed by high-grade inferior notching is the parallel increase in degrees of notching and number of revisions for component loosening after 6 years.[21,22] Although there is not yet a proven relationship between notching and component loosening, notching should not be considered a harmless and unavoidable phenomenon of RSA. Rather, we should consider whether it is a consequence of the extra-anatomical design of the Grammont reverse prosthesis: The hemisphere is positioned directly on the glenoid surface. Notching rates from numerous studies range from 40% to 100% (Tables II, III, IV). There are 5 grades of notching; grade 3 is ero-

Table II. Inferior Glenoid Notching: Reported Frequency in the Literature

Author	Follow-Up (mo)	Notching (Distribution %) 0	1	2	3	4
Boulahia[4]	16	38.9	61.1% notching, 6.3% loosening			
Sirveaux[5]	44	32.4	33.8	22.1	7.8	3.9
Valenti[13]	60	13.6	36.4	13.6	36.4	0
Favard[12]	45	35	65% notching, 4.4% loosening			
Nérot[25]	67	22	25.1	33.4	15.1	4.4
Levigne[21]	42	40	22	18	12	8
Werner[6]	38	4	54		42	
Simovitch[22]	44	18	8	18	16	3
Seebauer[24]	39	5.9	15.7	58.9	17.9	1.9

Table III. Complications of Reverse Shoulder Arthroplasty (Delta Prosthesis) in Correlation to Approach

	Walch et al (2006)[26]		Seebauer et al (2006)[3]		Werner et al (2005)[6]	
Approach	DP	SL	DP (Revision)	SL (CTA)	DP (Primary)	DP (Revision)
Follow-up period	1992-2002		1997-2004	1997-2002	Unknown	
n	363	94	26	56	17	41
Complications						
Instability	5.8%	1.0%	11.5%	0.0%	6.3%	9.8%
Infection	3.3%	2.1%	7.7%	5.4%	18.8%	7.3%
Humeral fracture	3.0%	1.0%	3.8%	0.0%	0.0%	0.0%
Glenoid loosening	1.1%	3.2%	3.8%	1.8%	0.0%	7.3%
Humeral loosening	1.4%	0.0%	3.8%	0.0%	0.0%	2.4%
Glenoid unscrewing	0.2%	3.2%	0.0%	1.8%	0.0%	0.0%
Humeral unscrewing	1.1%	0.0%	0.0%	0.0%	0.0%	0.0%
Scapular fracture	0.8%	0.0%	0.0%	0.0%	6.3%	7.3%
Hematoma	0.5%	1.0%	3.8%	1.8%	18.8%	22.0%
Neurologic	0.8%	2.1%	7.7%	1.8%	0.0%	2.4%
Miscellaneous	0.2%	2.1%	7.7%	1.8%	0.0%	0.0%
PE debris	0.0%	0.0%	3.8%	1.8%	6.3%	0.0%
Total	**18.2%**	**15.7%**	**53.8%**	**16.1%**	**56.3%**	**58.5%**
Notching	**56%**	**86%**	**NA**	**84%**	**NA**	**NA**

*DP indicates deltopectoral; SL, superolateral; CTA, cuff-tear arthroplasty; PE, polyethylene; NA, not applicable.

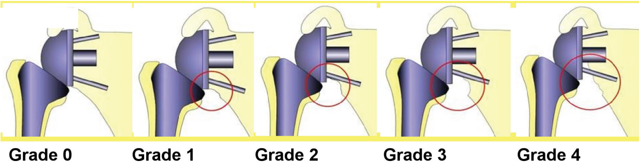

Figure 6. Grading system of inferior glenoid erosion ("glenoid notching") according to Nérot.[13] Courtesy of DePuy Orthopaedics, Inc.

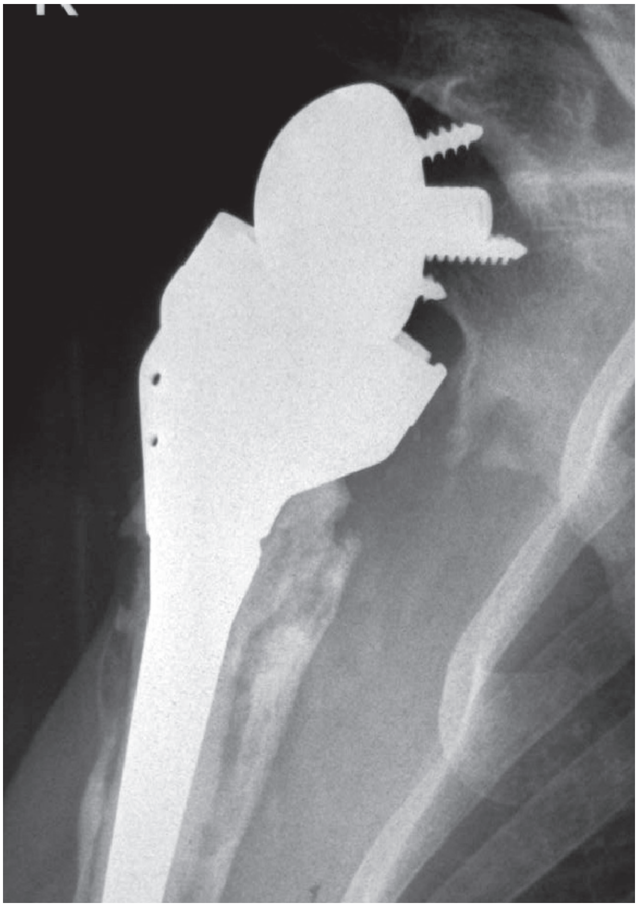

Figure 7. Progressive (3°-4°) glenoid notching with secondary development of radiolucent lines along the humeral stem as an indirect sign of chronic osteolysis caused by polyethylene wear.

sion beyond the inferior screw, indicating evolution, and grade 4 is erosion under the baseplate, implying potential for loosening (Figures 6, 7). Interestingly, Simovitch[22] and colleagues found inferior notching in 44% of cases, but 8% also had anterior notching, and 30% had posterior notching. In summary, whether inferior glenoid notching should be considered a complication or an inevitable phenomenon of the Grammont RSA is still being discussed.

Complications

In contrast to the very satisfactory short- and mid-term results for functional outcome, there is a high rate of intraoperative and postoperative complications and revisions.[4,7,8,26-28] In some studies, the overall reported complication rate is as high as 60%, with a perioperative revision rate of 33%.

The high rate of complications is related to several factors—the specific prosthesis design (much dead space around and within the prosthesis favors infection), the surgical approach, the difficulty of the surgical procedure, and, above all, the specific circumstances of the indications in the selected patient group (older age, many previous operations, poor bone and soft-tissue quality, bad general health status). Some complications could be seen as intraoperative surgical technical errors, others as unavoidable events. Intraoperative fractures of the proximal humerus are almost unavoidable when removing a well-cemented or cementless fixed hemiarthroplasty stem, which is often surrounded by a paper-thin cortex. Even under conditions of controlled osteotomy or fenestration of the proximal humerus, there are unforeseeable complications.

Recurrent dislocations after RSA are troublesome complications. Their incidence seems dependent on the surgical approach, with a significantly higher incidence seen with the deltopectoral approach. Reattaching as much tendon tissue of the subscapularis to the anterior humeral neck as possible seems to reduce the frequency of postoperative dislocations with the deltopectoral approach. On the other hand, the rate and severity of inferior glenoid notching seem lower with this approach.[22] The most common perioperative complications are instability, infection, and humeral fracture, which is mostly a problem in revisions

Table IV. Complication Rate of Reverse Shoulder Arthroplasty in Correlation to Indications

Author	Indication	n	Intraoperative	Postoperative	Overall
Werner et al (2005)[6]	Primary reverse shoulder arthroplasty	17	53%		
	Revision of arthroplasty	21	62%		
	Revision of other shoulder operation	20	55%		
	Total	**58**			**50%**
Boileau et al (2006)[7]	Primary reverse shoulder arthroplasty	21	19%		
	Revision of arthroplasty	19	47%		
	Fracture sequelae	5	20%		
	Total	**45**			**24%**
Walch et al (2006)[26]	Primary reverse shoulder arthroplasty	297	2.7%	12.6%	
	Revision of arthroplasty	90	31%	33%	
	Revision of other shoulder operation	70			
	Total	**457**			**25.6%**

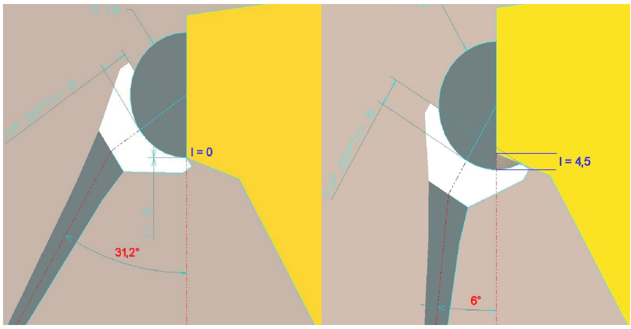

Figure 8. Two-dimensional computed-tomography analysis of glenoid position and risk for inferior impingement. Lowering the inferior edge of the glenosphere by 4.5 mm gives 25° more adduction and therefore reduces the inferior impingement. Courtesy of DePuy Orthopaedics, Inc.

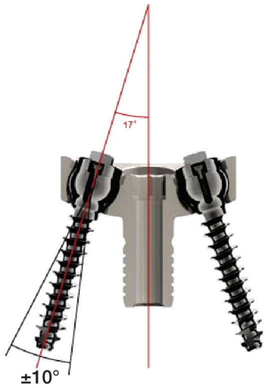

Figure 10. Better glenoid fixation by convex back side of the metaglene and apolyaxial locking screws. Courtesy of DePuy Orthopaedics, Inc.

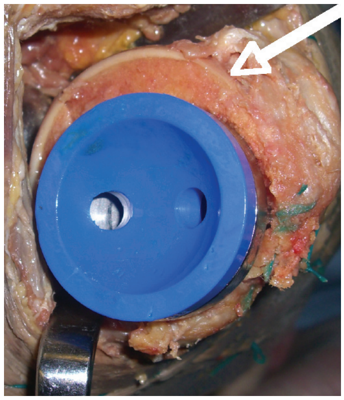

Figure 11. Problem of posterior offset in the resection plane with the old prosthesis.

Figure 9. Less glenoid bone removal by curved back side of the metaglene. Courtesy of DePuy Orthopaedics, Inc.

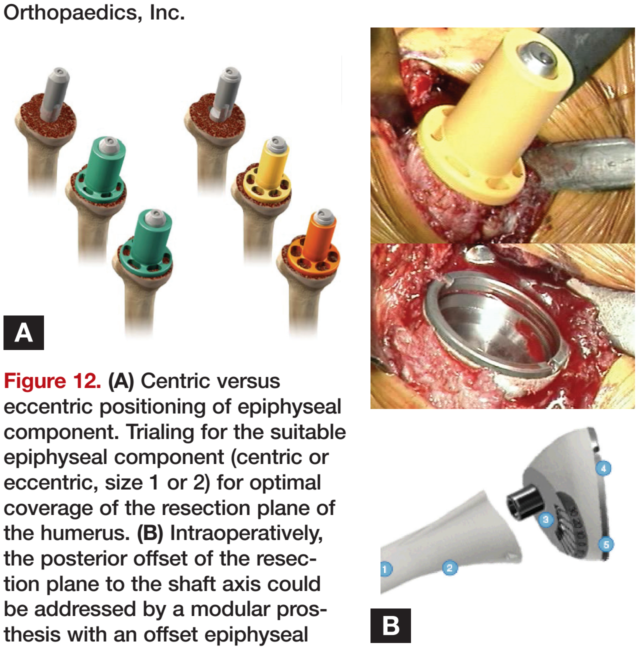

Figure 12. **(A)** Centric versus eccentric positioning of epiphyseal component. Trialing for the suitable epiphyseal component (centric or eccentric, size 1 or 2) for optimal coverage of the resection plane of the humerus. **(B)** Intraoperatively, the posterior offset of the resection plane to the shaft axis could be addressed by a modular prosthesis with an offset epiphyseal component. Courtesy of DePuy Orthopaedics, Inc.

of failed stemmed conventional prostheses. Hematoma and neuropraxia are more frequent than in conventional shoulder arthroplasty but seldom are cause for surgical revision. Glenoid disassembly and humeral disassembly are rare, but the latter sometimes is a problem in revision cases with significant bone defects of the proximal humerus. Scapular spine fractures are very infrequent, mostly in patients with very osteopenic rheumatism or in extremely eroded acromions with a long history of cuff-tear arthropathy. Postoperative stiffness is less a problem than in conventional shoulder arthroplasty.

Future Trends

Future RSA designs must meet 4 requirements if they are to address the shortcomings of currently available designs: avoid or minimize inferior glenoid notching; optimize glenoid component fixation with minimal glenoid bone removal and safe secure fixation; provide better ROM (especially internal rotation); and improve external rotation strength. The first 3 of these requirements are addressed by optimizing prosthesis design.

Anatomical and computed-tomography (Figure 8) biomechanical investigations have shown that caudalizing the glenoid component is the most effective way to minimize impingement of the humerus against the inferior glenoid.[23,29] A convex glenoid back side improves the contact area and minimizes the amount of bone removed, especially from the anterior and posterior glenoid rim (Figure 9). Use of locking screws with adjustable angulations should improve primary stability of the cementless metaglene, as the screws can be directed into the bone stock that permits best purchase (Figure 10).

Increasing internal rotation ROM involves implanting the reverse humerus component as anteverted as possible. The optimal action is to position the stem in 0° of version (eg, commonly 30° less retroverted than the physiologic head/transepicondylar axis), which increases the physiologic offset of the shaft axis in relation to the center of the head resection plane. This is of much greater importance in RSA than in conventional shoulder arthroplasty, as rotation

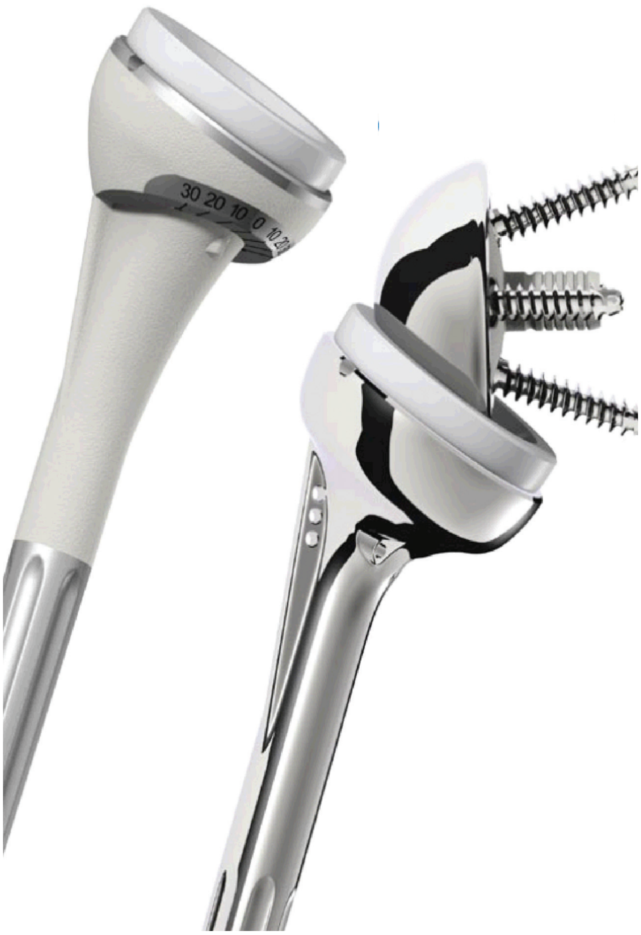

Figure 13. Modular versus monobloc stem of a modern, next-generation reverse shoulder arthroplasty. Courtesy of DePuy Orthopaedics, Inc.

in RSA works as hinged rotation, not spinning rotation.[30] Use of a modular prosthesis with eccentric epiphyseal components could solve the problem and enables perfect prosthetic coverage of the resection area of the proximal humerus (despite the extra-anatomical anteverted orientation of the resection plane) and the best biomechanics for the spinning rotation (Figures 11, 12). This not only helps improve passive internal rotation but also minimizes impingement against the posterior glenoid bone stock and potentially reduces bone erosion and notching.

In revision surgery with significant proximal humeral bone loss, a monobloc design with a short- or long-stem option could avoid the problem of the unscrewing of the humeral components. This design is also very useful in difficult revision cases (Figure 13).

No improvement of external rotation with the arm at the side can be achieved with Grammont RSA,[20] especially if all posterior parts of the cuff are absent. In a recent study, a technique of a modified transfer of the latissimus and teres major tendon in combination with RSA by an anterior approach[31] was reported as a possible solution to the problem of external rotational weakness.

Conclusions

RSA offers reliable pain relief and improved function in patients with glenohumeral arthritis and irreparable cuff deficiency. In patients with anterosuperior instability, functional return is not possible with any other treatment option. For this reason, interest in RSA is likely to continue. High complication and revision rates can be partially mitigated through proper patient selection and surgeon experience. However, specific design changes (eg, modularity allowing humeral metaphyseal offset, convexity of metaglene baseplate, variability in angling of baseplate locking screws, inferior placement of glenosphere) should help improve RSA results. Finally, there is no substitute for good surgical technique. Therefore, surgeons interested in performing RSA should first dedicate themselves to learning and perfecting anatomical shoulder arthroplasty and then transition to the difficult art of RSA.

Authors' Disclosure Statement

Dr. Seebauer wishes to note that he is a consultant for DePuy International Ltd.

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