Reverse Total Shoulder Arthroplasty

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The reverse shoulder prosthesis is based on a concept introduced by Paul Grammont. It relies on the principles of a semiconstrained ball and socket configuration, medialization of the center of rotation, and tensioning of the deltoid muscle. This can allow flexion of the arm in, for example, rotator cuff tear arthropathies and revision situations. External rotation depends on intact external rotators (the infraspinatus and teres minor). Current data support the use of reverse total shoulder arthroplasty (RTSA), which has good short- and mid-term outcomes and allows the management of conditions that were previously beyond surgical treatment. However, significantly higher revision and complication rates compared with conventional TSA and functional deterioration after 5–10 years have been reported with RTSA. Although current changes in the design of reverse shoulder prostheses might reduce the complication rate in the future, currently this technique should be reserved for elderly patients and salvage situations. *Adv Orthop* 2010;**2**(1):1–7.

Total shoulder arthroplasty (TSA) can successfully improve shoulder function and reduce pain by restoring anatomically shaped and positioned articular surfaces in osteoarthritic shoulder joints with intact rotator cuffs. However, the design of TSA implants does not account for conditions such as irreparable, chronic rotator cuff ruptures and cuff tear arthropathies (CTAs). After failure of early reverse ball and socket designs in CTA, Paul Grammont introduced the concept of reverse TSA (RTSA) in the 1980s. Twenty years later, his original key ideas have been proven valid, and the superiority of RTSA in CTA has been documented (**Table 1**).

Principles

In 1987, Grammont et al. proposed the key elements of RTSA to be as follows [1]:

- The prosthesis must be inherently stable.
- The center of rotation must be medialized and distalized.
- The weight-bearing part must be convex, and the supported part must be concave.
- The center of the sphere must be at or within the glenoid neck.

In RTSA, a metal "metaglene", or base-plate, is fixed to the prepared glenoid. The spherically convex glenoid articular surface, the "glenosphere", is fitted to the metaglene. In addition, a concave articular surface is fixed to the proximal part of the humerus (**Figure 1**).

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Inherent stability

In contrast to conventional TSA, in which a large prosthetic head articulates with a small shallow glenoid, in RTSA the components are not mismatched. Usually the diameters of the humeral component and the glenoid curvature are both 36 mm or 42 mm. In addition, the concave humeral component is larger and deeper in TSA. The conforming concavity of the humeral articular surface in RTSA does not permit glenohumeral translation. While this constraint reduces the range of motion before contact occurs between the humeral and glenoid elements, it eliminates the possibility of rim-loading and the resulting problems of cold flow of the rim polyethylene and creation of eccentric forces that can contribute to component loosening. The angle that the total joint force vector can subtend without risk of dislocation is increased to 45° (compared with 30° in TSA). Furthermore, the head–neck–shaft angle of 155° for the humeral concave component does not cause the forces of the deltoid to superior dislocate the joint, but rotates (and abducts) the joint around a medialized, fixed center of rotation.

Medialization and distalization of the center of rotation

Grammont et al. reported in their initial publication that at 60° of abduction, medialization of the center of rotation by 10 mm

Table 1. Outcomes in studies of reverse total shoulder arthroplasty for cuff tear arthropathy.						
Study [Ref]	n	Mean follow-up, months	Active flexion improvement from preoperatively to follow-up (difference), °	Constant score improvement from preoperatively to follow-up (difference), %	Reoperation and revision rate, %	Dissociation of glenophere, %
Baulot et al. 1995 [36]	16	27	NA	14 to 69 (+55)	13	
Valenti et al. 2001 [37]	39	84	60 to 120 (+60)	21 to 63 (+42)	15	7
Sirveaux et al. 2004 [38]	80	44	73 to 138 (+65)	22.6 to 65.6 (+43)	5	7
Werner et al. 2005 [31]	17	38	43 to 103 (+58)	35 to 72 (+37)	18	
Seebauer et al. 2005 [26]	35	18.2	NA to 140	38 to 97 (+59)	8	
Frankle et al. 2005 [4]	66	33	55 to 120 (+50)	NA	10	
Guery et al. 2006 [8]	66	69.6	NA	NA	7	
Boileau et al. 2006 [10]	21	40	53 to 123 (+70)	18 to 66 (+49)	5	
Favard et al. 2006 [32]	129	49	70 to 135 (+65)	32.3 to 93 (+60.7)	5	

NA: not applicable.

Figure 1. A reverse total shoulder prosthesis consists (from left to right) of a humeral stem and metaphysis, the polyethylene humeral concavity insert, the glenosphere, and the metaglene with the central peg and the screws.

Image used with the permission of Tournier, Saint-Ismier, France.

yielded an increase in deltoid moment of 20% and distalization of 10 mm increased it by another 30% [1]. The lever arm and, therefore, the efficacy of the deltoid muscle are almost doubled with RTSA. Through medialization of the center of rotation, deltoid muscle fibers that are usually medial of the center of rotation come to lie lateral of the center of rotation, and become abductors and elevators. Consequently, one can presume that the higher lever arm results in higher recruitment of deltoid muscle fibers (**Figure 2**). On the other hand, medialization and distalization of the center of rotation cause an increase in the excursion of the minor and especially major tubercles [2]. This can cause mechanical conflicts with the acromion in abduction, the scapular spine in external rotation, and the coracoid in internal rotation [2]. In adduction, the inferior rim can impinge against the scapular neck [2]. This limits glenohumeral movement compared with TSA, in which the tubercles lie close to the center of rotation and the excursions remain small (**Figure 3A**).

Reversal of convex and concave parts

Grammont reversed the ball and socket, which medialized the center of rotation to the former glenoid surface. All forces acting on the prosthesis pass through a fixed center of rotation; thus, torque forces that would be created by a more lateral point of rotation are transformed into compressive forces at the prosthesis–bone interface. This solved the formerly inevitable problem of loosening of the convex glenoid component. This design, however, may cause impingement of the humeral component to the inferior scapular neck, also known as "scapular notching". This can lead to humeral polyethylene wear and erosion of the scapular bone (**Figure 4**).

Current operative techniques and prosthetic designs try to reduce this problem. Nyfeller et al. measured the impingement-free range of motion with different baseplate positions [2]. They found that glenosphere extending beyond the inferior glenoid rim significantly improved adduction and abduction angles compared with all other test configurations (**Figure 3B**). Some

Figure 2. **Biomechanics of the shoulder joint. A: The lever arm of the deltoid muscle (red line) is small with the arm in a neutral position. B: After implantation of a reverse shoulder prosthesis, the center of rotation is more medial and distal, which increases the lever arm of the deltoid muscle (red line). Furthermore, the arm is lengthened (green bar). Both features increase the moment of the deltoid muscle and facilitate the elevation/abduction of the arm.**

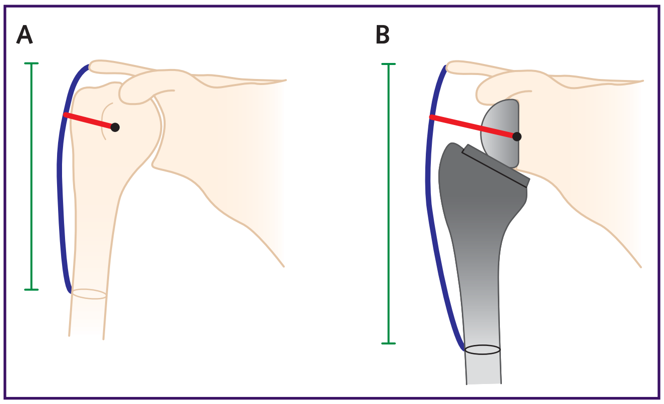
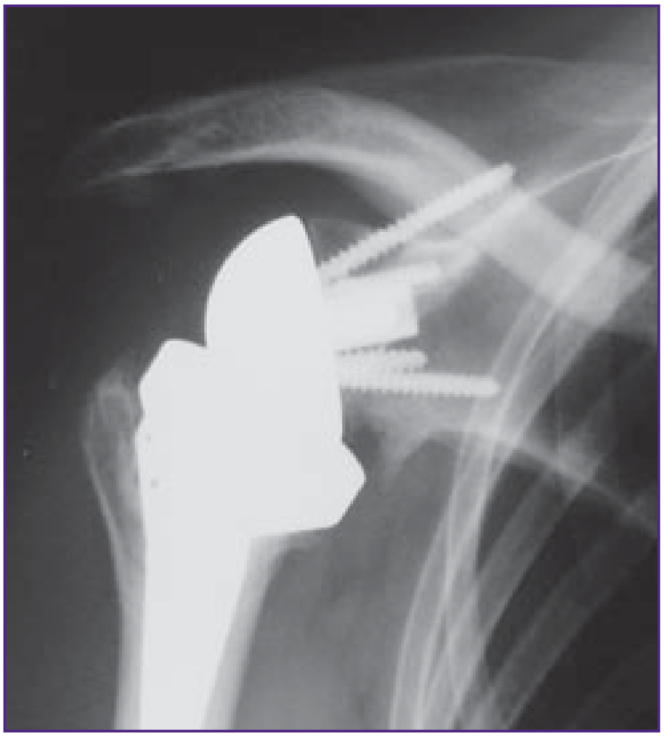
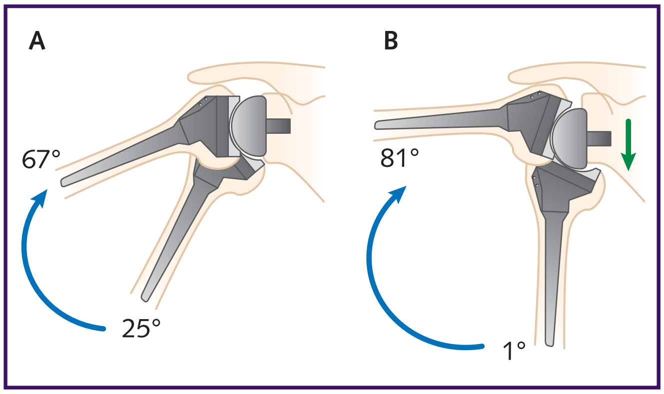


Figure 4. Anteroposterior view of a reverse shoulder prosthesis showing a bony erosion of the inferior glenoid neck by notching of the polyethylene insert in adduction of the arm.



authors lateralize the center of rotation, which increases the tilting forces at the interface, but also increases the range of motion [3,4]. Some prosthetic designs reduce the likelihood of impingement by having a shallower humeral component; this, however, also diminishes the inherent stability [5,6].

Figure 3. A: Positioning of the glenoid component in the middle of the glenoid allows a reduced range of motion before impingement against the acromion and the scapula occurs. B: Positioning of the glenosphere extending beyond the inferior glenoid rim increases the impingement-free range of motion.



Modified from [2].

Indications

As a matter of principle, RTSA as a semiconstrained implant can be indicated in all situations in which the humeral head has significantly lost the center of rotation of the glenohumeral joint causing significant loss of function. This might, for example, be caused by chronic cuff tears and, later on, CTA.

CTA with pseudoparalysis

CTA in the elderly is the main indication for RTSA [7]. This recommendation is based on the currently available data, which show significant improvements in the short- and mid-term [8]. Patients must be informed that the complication rate is three-times higher than in conventional TSA (**Table 2, Figure 5**) [5,6,9–11], and that the clinical and radiographic results deteriorate after 6–8 years [8]. These facts are the rationale behind the recommendation to reserve this implant for elderly patients (e.g. age 70–75 years) with low demands. The following conditions should be fulfilled:

- The patient should present with pseudoparalysis of the arm with, for example, 30–40° of elevation or abduction because of an irreparable rotator cuff tear. As an exception, painful, irrecoverable weakness of the arm may be an indication if the patient cannot cope with this problem.
- Deltoid function and structure must be preserved. Complete axillary nerve palsy is considered a contraindication because of a high probability of recurrent instability and minimal gain in function. Scarring of the deltoid with preserved innervation is not a contraindication.
- The glenoid should have sufficient bone stock to securely implant a glenoid component. This can be best evaluated by computed tomography.

Study [Ref]	n	Reoperation for cuff tear arthropathy (%)	Reoperation for other indications (%)
Baulot et al. 1995 [36]	16	13	NA
Rittmeister et al. 2001 [9]	8	NA	37.5 (rheumatoid arthritis)
Sirveaux et al. 2004 [38]	80	5	NA
De Wilde et al. 2005 [25]	5	NA	20 (revision)
Werner et al. 2005 [31]	58	18	39 (revision)
Seebauer et al. 2005 [26]	35	8	NA
Boileau et al. 2006 [10]	45	5	37 (revision, fracture)
Favard et al. 2006 [32]	129	5	NA
Valenti et al. 2008 [37]	39	15	NA

Table 2. Incidence of reoperation in reverse total shoulder arthroplasty studies.

NA: not applicable.

Figure 5. Dissociation of the glenosphere has become a rare complication with improvements in the design of reverse shoulder implants.

Preoperative planning should rule out excessive upward, posterior, or anterior tilt of an implanted glenoid component, because this can cause impingement or notching. Glenoid bony defects are a relative contraindication. In revision situations, glenoid implantation can be tried without additional bone grafting if the glenoid component can be securely seated within the original bone. If this is not possible, an additional bone graft (e.g. a tricortical iliac crest graft) can be screwed to the glenoid and a long-stem glenoid can be implanted without the other components. After 3 months, in a second-stage procedure, the glenosphere and the humeral implant can be inserted if the baseplate is stable. Active infections and neuropathy are absolute contraindications. Severe osteopenia is a relative contraindication that is becoming less important with improvements in glenoid fixation technology.

Pain is a common feature of CTA. If pain – rather than the functional deficiency – is the main complaint, however, RTSA is not the treatment of choice. Effective alternative treatment options include conservative treatment with strengthening of the anterior deltoid [12], biceps tenotomy for an instable and painful biceps tendon [13], arthroscopic reverse acromioplasty and debridement, and hemiarthroplasty for patients who can elevate their arm above 90° [14]. Pseudoparalysis of external rotation can be a predominant complaint in CTA. In classic RTSA with medialization of the center of rotation, this is not alleviated. Variations in the classic RTSA according to Grammont with designs that lateralize the center of rotation can improve external rotation (**Table 3**), but also increase the shear forces on the baseplate, which might cause loosening in the long term [4]. Another promising option for improving external rotation is to combine latissimus dorsi transfer according to the L'Episcopo procedure with RTSA [15,16].

Other indications

RTSA has been proposed for the treatment of revision cases after failed TSA and hemiarthroplasty as a salvage procedure [17–19]. Recently, short-term data showing good and consistent outcomes after acute or delayed four-part fractures have been published [20–23]. Other investigators have reported the use of RTSA in cases of tumors, rheumatoid arthritis, primary osteoarthritis (OA) with severe glenoid dysplasia type C according to Walch, and irreparable rotator cuff defects without OA [3,9,10,24–27]. Long-term follow-up is necessary before a general recommendation regarding these indications can be given.

Technique

RTSA can be performed through a deltopectoral or superolateral approach. Both approaches have their advantages and disadvantages. The superolateral approach carries less risk of dislocation and performs better in terms of preventing fractures of the scapular spine and the acromion [28]. The deltopectoral approach has the advantages of better preservation of the deltoid and potentially better orientation and positioning of the glenoid component because of better glenoid exposition, which

Table 3. Active external rotation in reverse total shoulder arthroplasty studies.

Study [Ref]	n	Mean follow-up, months	Active external rotation change from preoperatively to postoperatively with arm at side (difference), °	Prosthetic device	Active external rotation improvement from preoperatively to postoperatively with arm at 90° abduction (difference), °	Influence of intact teres minor
Sirveaux et al. 2004 [38]	80	44	3.5 to 11.2 (+7.7)	Delta III[1]	17 to 40 (+23)[2]	Significantly better Constant score, better external rotation
Werner et al. 2005 [31]	17	38	17 to 12 (–5)	Delta III[1]	NA	
Frankle et al. 2005 [4]	66	33	12 to 41 (+29)[2]	Encore Medical Corporation reverse shoulder prosthesis[3]	NA	
Boileau et al. 2006 [10]	21	40	9 to 14 (+5)	Delta III[1]	NA	
Favard et al. 2006 [32]	129	49	7 to 10 (+3)	Delta III[1] and Aequalis[4]	24 to 45 (+21)[2]	Significant on external rotation at 90°

[1]DePuy Orthopaedics Inc, Warsaw, IN, USA. [2]$p<0.05$. [3]Encore Medical Corporation, Austin, TX, USA (center of rotation more lateral). [4]Tournier, Saint-Ismier, France.

can prevent glenoid notching. Generally speaking, the approach can be selected according to previous surgical approaches and the surgeon's experience.

If the superolateral approach is chosen, the subscapularis can be left in place. This might reduce the risk of anterior instability and dislocation. While the multicenter study of Molé and Favard failed to show a significant difference between tenotomy and repair of the subscapularis muscle [28], others have shown lower dislocation rates after subscapularis refixation with the deltopectoral approach [29]. Therefore, refixation of the subscapularis tendon is recommended by some surgeons. The biceps tendon has to be tenotomized. Identification and preservation of the axillary nerve is extremely important, because otherwise pseudoparalysis of the arm will remain.

"We strongly recommend taking off all of the remaining cartilage of the glenoid before reaming in order to visualize the actual version of the bony glenoid"

Sufficient exposition of the glenoid is mandatory for exact positioning of the baseplate. In order to achieve this goal, periglenoidal and humeral release of the glenohumeral ligaments and the capsule is usually necessary. According to preoperative planning, the surgeon must assure that the baseplate is inserted flush with the inferior rim of the glenoid (which results in inferior overlap of the glenosphere) to prevent notching and maximize range of motion (**Figure 3**) [2]. We strongly recommend taking off all of the remaining cartilage of the glenoid before reaming in order to visualize the actual version of the bony glenoid. This allows the surgeon to carefully correct the version of the glenoid fossa to a perpendicular position in relation to the scapular spine. Reaming should be performed without superior, anterior, or posterior tilt, but perpendicular to the scapular spine. If necessary, bony deformities should be corrected by reaming. Superior tilt is associated with a higher risk of loosening of the glenoid component because of higher sheer forces. Inferior tilt of the glenoid component of 10° is recommended by some authors to reduce sheer forces, but this can induce inferior notching [2]. Locking screws are usually used to provide primary stability. Strong bone can be found in the base of the coracoid (by aiming 10° anteriorly and 10° superiorly, and palpating the base of the coracoid superiorly) and in the lateral pillar of the scapula. The latter can be marked by a forceps around the lateral pillar, which is usually at a 10° posterior and 10° inferior tilt. Then, the glenoid hemisphere is mounted on the baseplate.

Current results suggest that lower dislocation rates, less pain, higher range of motion, and better strength occur with the use of larger glenospheres. The space below the acromion (as a rough guide, at least a thumb should pass between the acromion and the glenosphere) and the humeral dimensions are limiting factors. It might not be possible to insert a large implant in a small individual.

Subsequently, the humerus is broached and the humeral cup is inserted. In Molé and Favard's multicenter study, neutral

Table 4. Radiological follow-up data from studies of reverse total shoulder arthroplasty.

Study [Ref]	Mean follow-up (months)	Glenoid loosening rate (%)	Humeral loosening rate (%)	Stable glenoid radiolucency rate (%)	Stable humeral radiolucency rate (%)	Scapular notching total (%)	Notching 1° + 2° according to Nero (%)	Notching 2° + 4° according to Nero (%)	Heterotopic ossification (%)
Sirveaux et al. 2004 [38]	44	6,25	1	25	25	63	46.5	16.5 (Significantly lower CS)	NR
Werner et al. 2005 [31]	38	6,25	2	10	16.5	96 (no effect on CS)	52	44	NR
Frankle et al. 2005 [4]	33	11	0	5	NR	0	0	0	NR
Boileau et al. 2006 [10]	40	0	2	45	60	68 (no effect on CS)	42	26	45
Favard et al. 2006 [32]	33	1	0.7	NR	20	76 (no notch = better CS)	48.5	27.5	50 (no influence on CS)
Valenti et al. 2008 [37]	72	2.5	0	NR	NR	86	50	36	NR

CS: Constant score; NR: not reported.

torsion of the humeral cup produced a better outcome than the use of the physiological 20° retroversion in terms of activities of daily living, strength, Constant score, radiographic loosening, and glenoid complications [28].

The height of the polyethylene insert should lengthen the arm approximately 2–3 cm measured from the tip of the acromion to the olecranon. The prosthesis should have a snug fit after relocation. The tension can be additionally palpated at the conjoint tendon. Stability is tested with the arm in abduction and internal/external rotation. During maximal external rotation and abduction, gapping of the implants is a regular finding. If there is an anterior dislocation in abduction and internal rotation (which is the most frequent position used to get out of bed and out of a chair), the antetorsion of the humerus has to be increased and the surgeon must check whether the glenoid component was implanted with too much anteversion.

If the subscapularis muscle was tenotomized, it should be readapted and one or two drains should be inserted. After implantation of the RTSA prosthesis, there is a large, empty space that should be sufficiently drained for 2–3 days. In early series, hematoma formation was the most frequent complication. A sling or an abduction pillow can be used for 4–6 weeks [30].

Outcome and complications

RTSA has proven to be effective in treating pseudoparalysis of elevation associated with massive rotator cuff tears at 2–10 years of follow-up (**Table 1**) [8,24,31]. There is substantial evidence that the outcome depends on the indication for which RTSA was used, and complication rates are distinctly different in primary versus revision cases (**Table 2**). However, even in CTA, there is a significantly higher rate of complications with RTSA compared with TSA (**Table 1**) [5,6,32].

Active external rotation depends not only on the integrity of the teres minor or infraspinatus muscle [32,33], but also on the amount of medialization of the center of rotation (**Table 3**). The more the center of rotation is medialized, the less external rotation can be expected. However, sheer forces are minimized in medialized centers of rotation.

There is a high rate of notching in the reported series that might be a problem in the future (**Table 4**) [3,5,8,9,11,34,35]. The current follow-up data show that this does not translate into high rates of glenoid or humeral loosening in the short- or mid-term. However, after 6–8 years, progressive deterioration of the functional result is observed [8].

Conclusion

RTSA has initiated a new era of shoulder surgery because conditions that had previously been beyond surgical treatment can now be successfully treated. However, the results deteriorate over time and the complication rate is significantly higher than in regular TSA. The possible explanations for this include overextension and fatigue of the deltoid muscle, and loosening of the implants. There is considerable interest in the possibility that TSA stems, particularly fracture stems, can be directly converted into RTSA implants. On a technical level, further improvements in rotational deficits (especially external rotation) are required. Currently, the correct indication and judicious use of RTSA is the key to future success.

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Disclosures

The authors have no relevant financial interests to disclose.

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