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Review Article

A history of the reverse shoulder prosthesis

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ABSTRACT

In this article, we document the history of the shoulder prosthesis in cases of gleno-humeral arthropathy with severely damaged peri-articular structures, in particular, the rotator cuff. Charles Neer was the first to search for a solution to this difficult problem and his work encouraged others including Paul Grammont to develop his revolutionary principles applied to the reverse shoulder prosthesis. Even now, newer versions of reverse prostheses continue to advance our understanding of how these difficult cases can be treated optimally.

Key words: Reverse shoulder prosthesis

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INTRODUCTION

Anatomical, non-constrained total shoulder arthroplasty has an established role in the treatment of degenerative and traumatic lesions of the shoulder, in cases in which the peri-articular soft tissues (in particular the rotator cuff) are of adequate quality to stabilize the joint. This type of implant was introduced by Charles Neer, who was also the first to search, albeit unsuccessfully, for solutions to the problem of damaged, fragile or absent peri-articular structures.[1] Subsequently, semi-constrained or constrained implants were attempted in both anatomical and reverse forms but all the early prostheses resulted in implant failure with excessive constraint causing loosening of the glenoid component and poor functional results.[2] In 1985 Paul Grammont[3] defined the bio-mechanical principles of medialization and lowering of the center of rotation of reverse shoulder prostheses and the importance of this new philosophy soon became clear. Adherence to these principles allowed him to design a successful implant. Grammont's principles are recognized today as the gold standard for treatment of degenerative arthropathy of the shoulder associated with an irreparable tear of the rotator cuff. Since 1985, there have been numerous modifications and now many models of reverse prostheses are available. In this paper we present a historical review of the development of these prostheses from the initial trials and complications, through the development of Grammont's prosthesis, to the latest ideas of how to overcome the difficulties and challenges which remain.

A HISTORICAL REVIEW

The first shoulder arthroplasty, performed in 1893 was a constrained prosthesis designed by the French surgeon Jules Emile Pean. The humeral stem was made of platinum and leather and it articulated with a head made of rubber coated with paraffin. The prosthesis was used to treat a case of tuberculosis[2,4] but while the functional results were reasonable, they were also short-lived and the prosthesis was removed two years later as a result of infection. There followed half a century without any reference to shoulder prostheses in the literature before Charles Neer performed the first simple, non-constrained humeral prosthesis in a case of fracture of the humeral head. This was a one block implant made of vitallium which reproduced the anatomy of the superior part of the humerus (Neer 1).

Between 1950 and 1970, the indications for shoulder arthroplasty widened. As a result of the failure of non-constrained prostheses in cases where the rotator cuff was torn, Neer was drawn to consider new concepts that might be useful in such complicated cases. The lack of a rotator cuff can result in proximal migration of the prosthesis with eventual superior impingement, glenoid loosening and a poor functional outcome. In order to avoid this, various prostheses were designed in an

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attempt to increase the intrinsic stability of the implant with increasing conformity and constraint of its components.[5] In the Neer Mark II prosthesis[1,6] the glenoid was modeled on the acetabulum. The English MacNab prosthesis[7] and the DANA shoulder[8] followed the same principles. However loosening of the glenoid component at short and medium term follow-up rendered these non-constrained prostheses unreliable and they were therefore abandoned. In a further variety, there was an attempt to mimic normal anatomy with a glenoid cup and a humeral head, a fixed center of rotation and a fixed fulcrum. In these prostheses the components were totally constrained. These early prostheses proved unsuitable in cases of shoulder arthropathy with irreparable rotator cuff tears. However, it was from these early failures that the principles of the reverse shoulder arthroplasty were born.

THE REVERSE SHOULDER PROSTHESIS

The principle of the reverse shoulder prosthesis is that the head which forms a part of a sphere is fixed to the glenoid and the cup in which it articulates is on the humeral side. From a historical perspective, three clear periods of progress can be defined:

1. Pre-Grammont.
2. The period during which Professor Grammont developed his principles.
3. Post-Grammont.

Pre-Grammont: Early setbacks

1970. Neer's experiments

Shoulder arthroplasty began in 1970 with the Neer- Averill prosthesis "Mark I".[6] The idea of reversing the prosthesis emerged because of difficulties encountered in implanting an anatomical glenoid implant large enough to stabilize the prosthesis and prevent proximal migration. This was a particular problem in cases with a small glenoid and inadequate bone stock. The Mark I model had a large glenosphere which did not permit re-attachment of the cuff or its remnants. Charles Neer felt it very important to be able to reconstruct the cuff around the prosthesis; his philosophy preceding the Grammont concept of replacing the irreparable rotator cuff with the deltoid, the only intact muscle available for shoulder elevation. To allow for the repair of the cuff, Neer developed the Mark II prosthesis; a "three element" prosthesis[9] with a smaller glenosphere which allowed for a better periprosthetic reconstruction. However, the smaller radius of curvature of the sphere limited the range of motion and therefore increased the constraint of the joint.

Neer then developed the Mark III prosthesis. To limit the constraint on the glenoid component he used a smaller glenosphere than in the Mark I. He also introduced an axial rotation between the humeral stem and the diaphysis to overcome the limited range of motion of the Mark II prosthesis. After this trial, Neer abandoned his constrained prosthesis experiments in 1974 concluding that constraint did not eliminate the requirement to repair the rotator cuff, particularly the supraspinatus, in order to recover a good range of motion.

1972. The Reeves prosthesis

This prosthesis remained experimental. Its center of rotation was that of normal anatomy.[10,11]

1972. The Gerard and Lannelongue prosthesis

22 cases in which this model was used were reported in two papers.[12,13] The large number of complications (three dislocations, four implant breakages, two infections) could not be attributed simply to the design of the prosthesis. The cases were particularly challenging and included reconstruction following tumour resection, revision surgery and post-traumatic reconstruction.

1973. The Kolbel prosthesis

This constrained implant was designed especially for reconstruction of bone loss after tumor resection.[14-16] Its use was reported in six cases, for resection of malignancy from the humerus, the glenoid or both. The glenoid implant was fixed with a central screw and two plates with the screws directed towards the coracoid process and/or the axillary border of the scapula.

1973. The Kessel prosthesis

This prosthesis fixed to the glenoid by a large central screw, was placed laterally. It theoretically allowed anterior elevation of 180 degrees, just 90 degrees of abduction, but a good functional range of rotation from the point of view of the essentials of daily life.[17] However the theoretical mobility was not demonstrable clinically. In Brostrom's article,[18] 23 patients with rheumatoid arthritis with this prosthesis were considered. 17 patients were reviewed with a follow-up of 87 months. The patients demonstrated flexion of up to between 90 and 105 degrees, lateral rotation of between 20 and 45 degrees and no improvement in abduction. Moreover radiolucent lines appeared around the glenoid screw in all cases within a year. This was confirmed by Wretenberg[19] on the same series of patients seven years later.

1973. The Bayley-Walker prosthesis

This prosthesis was a modification of Kessel's design with the central glenoid screw being coated with hydroxyapatite. Ahir[20] assessed a prosthesis in a patient who had undergone an amputation as a result of a sarcoma recurrence. He reported that he felt that it would be an improvement if the center of rotation of the joint were lowered and medialized. The prosthesis had been used in 81 non-tumor cases and 43 cases of malignancy since 1994.[20] With five years of follow-up, no loosening had been noted.

1975. The Jefferson prosthesis of Fenlin

Fenlin stressed in his first article[21] the necessity of a large glenosphere. Contrary to the principles of Grammont, Fenlin believed that with a large glenosphere the deltoid muscle would

compensate for the absent rotator cuff. The glenosphere in his prosthesis was so large that in order to lighten the total implant weight, it was made with polyethylene, while the humeral cup was metallic. Fenlin reported on his prosthesis in five patients and concluded that the ideal indication was rotator cuff arthropathy. In a further article published ten years later in 1985,[22] he described a number of failures due to loosening, mechanical breakage and instability.

1975. The Liverpool prosthesis of Beddow

Use of the Liverpool prosthesis was anecdotal. The design was the same as a Charnley hip prosthesis with the stem fixed into the pillar of the scapula.

1978. The Buechel-Pappas-DePalma prosthesis

This prosthesis is similar to the Neer Mark III. A small glenosphere articulates with a mobile intermediate polyethylene cup. This intercalated element also articulates with a humeral head.[23,24] While not strictly speaking a reverse prosthesis. The Buechel-Pappas-DePalma prosthesis and the example to follow are similar in that they include a glenosphere.

1978. The trispherical prosthesis of Gristina

The name "trispherical" is derives from the fact that it consists of a glenosphere, a spherical humeral head and a third, intermediate sphere articulating with the other two.[24]

All the prostheses described thus far resulted in only marginal functional improvement or were abandoned as failures. It was not until the work of Grammont that a reliable solution for the treatment of rotator cuff arthropathy was achieved.

Paul Grammont's reverse shoulder prosthesis

In 1985, a new era began with the birth of the revolutionary concept of medialization and lowering of the center of rotation. According to Grammont, success of the design relies solely on the strength of the deltoid muscle. Medialization of the center of rotation by 10 mm increases the moment of the arm by 20%. Lowering the center of rotation by 10 mm increases the moment of the arm by 30% and additionally reduces superior impingement. The rotator cuff constrains the shoulder preventing dislocation during abduction and elevation i.e. the rotator cuff transforms the dislocating forces into centripetal forces. The reverse orientation of the prosthesis allows the resulting forces to be directed towards the center of the glenosphere which in turn act on the neck of the scapula. Medialization of the center of rotation increases the lever arm of the deltoid muscle and reduces the shearing forces, except at the initiation of abduction, hence the use of divergent screws.

1985. The first version of Grammont's prosthesis

This first prototype was composed of two elements. The glenoid component formed two-thirds of a sphere and was cemented to a glenoid prepared with a bell-shaped saw. The polyethylene humeral stem was the shape of an inverted trumpet and was also cemented. The articulating part had a concavity corresponding to one-third of a sphere. In 1987, the results of this prototype in a variety of cases were published in a series of eight patients.[3] The center of rotation of the glenoid component was lateral to the centre of the glenoid resulting in increased shearing forces. This led Grammont to modify his first design.

1989. The second version of Grammont's prosthesis

The DELTA 3 prosthesis (DELTA for deltoid, the only motor for this prosthesis) came on the market in 1991. In the first generation, the metaglenoid was a circular plate with a central peg for press-fit impaction. It was fixed with divergent 3.5 mm screws superiorly and inferiorly in order to resist to the shearing forces. The glenosphere was screwed directly onto the peripheral edge of the plate. This concept of peripheral screwing of the glenosphere had to be abandoned because of secondary loosening of the screws.

In the second generation the periphery of the metaglenoid was conical and smooth with a Morse-Taper effect. The metaglenoid was coated with hydroxyapatite on its deep surface to improve bony fixation. The center of the metaglenoid was hollow in order to allow locking of the glenosphere with a central securing screw. The humeral component was a monobloc with a cup of standard thickness.

The third generation became available in 1994 with the new features pertaining to the humeral component. In order to obtain a better fit, a diaphyseal stem was screwed on to a metaphyseo- epiphyseal block of one of three available sizes. The polyethylene cup (a third of a sphere) was fitted over the epiphyseal end. However the cup was of insufficient size and rapidly deteriorated as a result of medial impingement. The cup was therefore replaced by a lateralized cup available in two diameters of 36 mm and 42 mm. A metallic wedge is available to allow correction of length problems in the cases with loss of metaphyseal bone. A retentive cup can be used in cases of major instability.

The Delta III prosthesis (DePuy International Limited, Leeds, England) has been used for the last 15 years worldwide and its results have been extensively reported.[25-30] In cases of pseudo-paralytic shoulders with massive irreparable cuff tears and gleno-humeral arthritis all series have shown a recovery of active abduction of between 120 and 130 degrees. Currently no other technique produces equivalent functional results in these difficult cases.

The drawbacks of the reverse shoulder prostheses are now well documented:[25,29-32]

Medial notching of the scapula due to impingement between the polyethylene cup and the axillary border of the scapula

is seen early after surgery [Figure 1]. A series from Nice reported this complication in 74% of cases (45 cases)[25] and another from Sirveaux in 65% (77 cases).[29] A recent article by Gerber[33] studied the passive range of motion of the prosthesis in specimens in which the glenosphere was fixed superiorly. This confirmed previous reports[31,32] that contact between the humeral cup and the pillar of the scapula is much more significant when the metaglenoid is fixed high on the glenoid. Other problems include superior loosening on humeral lowering and a modified shoulder contour as a result of the low and medial placement of the glenoid component. Adjustment of the tension of the deltoid can be another source of complications in that low tension causes instability and high tension can cause fracture of the acromion.

At a congress in Nice in June 2006, cases were reviewed. The discussion confirmed the perceived wisdom that with these prostheses, good elevation was complicated by poor rotation.

Limited external rotation has several possible explanations:[25,31,32]

- Medialization of the humeral component limits external rotation by increasing the medial impingement against the scapula. It also accounts for the medial notch.
- Medialization of the center of rotation reduces the strength of the posterior deltoid fibers.
- The status of the teres minor is important for lateral rotation;[25] if intact, lateral rotation is significantly better.
- Injury to the suprascapular nerve while fixing the metaglenoid may also be a cause of lack of external rotation.[32]

Limitation of internal rotation has three possible causes:

- Prosthesis design.
- Medialization reducing the strength of the anterior deltoid fibers.[13]
- The state of subscapularis. Active medial rotation will be better if part of subscapularis remains intact. The superior approach allows preservation of the inferior part of this muscle; this is not usually possible with a deltopectoral approach.

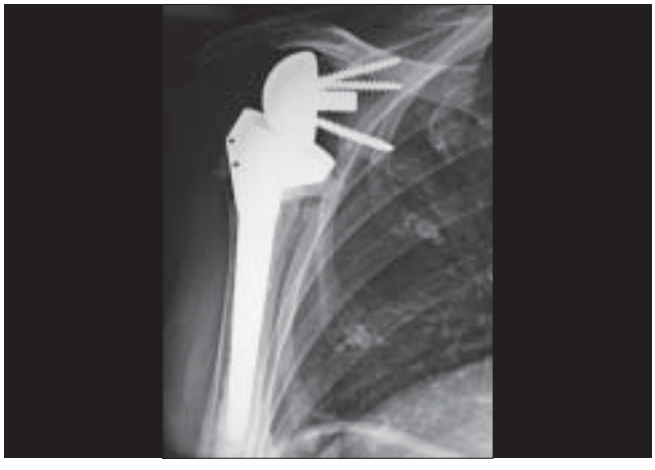

Figure 1: Glenoid notch

The reverse shoulder prosthesis: Post-Grammont

Based on the experiences described above several new designs are under development:[34-36]

- The Tornier Company has developed a reverse prosthesis which fulfills the bio-mechanical principles described by Grammont, but with certain new innovations. The metaglenoid is fixed with divergent locking screws. Wedges and polyethylene cups of varying thickness are used to correct tension of the deltoid and metaphyseal bone loss. Following the recent work of Gerber,[33] users of the DELTA and TORNIER prostheses have recommended that the metaglenoid be implanted lower on the glenoid with a small amount of inferior tilt.
- In 1998, Frankle designed the REVERSE prosthesis (ENCORE Medical, Austin-Texas, U.S.A.). It was placed less medially than the DELTA and the center of rotation was closer to its usual anatomical location.[35] In 60 cases with more than two years follow-up his patients obtained less abduction than in the DELTA series but a better total range of rotation. However the design of the glenosphere, which was two-thirds of a sphere, increased shearing of the screwed metaglenoid. A series of complications involving the glenoid component have been reported, including loosening (7 cases) and breakage of the platinum and screws. Frankle's biomechanical studies concluded that a concave metaglenoid was better than a flat one.[36]
- Various other prostheses exist which are very similar to the DELTA, but do not yet have long term follow-up. In the Duocentric prosthesis the risk of medial impingement is avoided by an inferior extension of the glenosphere. Unlike the REVERSE, this model respects Grammont principles with the centre of rotation lying at the level of the glenoid.
- In order to improve the range of rotation (which had been found to be poor in Grammont's design) and to eliminate the risk of medial impingement, the authors of this article have designed the UNIVERSAL ARROW SYSTEM [Figure 2] (FH orthopedics, Heimsbrunn, France) which was has been available commercially in Europe since 2002. The centre of rotation is the glenoid, but the design allows the prosthesis to be placed less medially than the Delta prosthesis. In addition, the humeral cup has an inbuilt medial notch [Figure 3] to avoid friction against the pillar of the scapula. The metaglenoid is concave, adapting to the normal curvature of the glenoid fossa. In an experimental work, DeWilde[34] has confirmed that medialization and lowering the implant affect the moment arm of the deltoid and improve the arc of rotation, which is essential in performing activities of daily life.

A retrospective study was presented at the last French Congress of Orthopedic Surgery in Paris in November 2006 which

Figure 2: Arrow Universelle

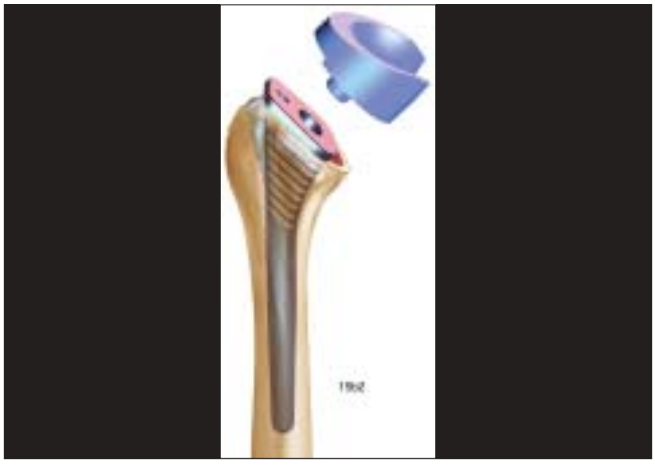

Figure 3: Inbuilt medial notch on humeral cup

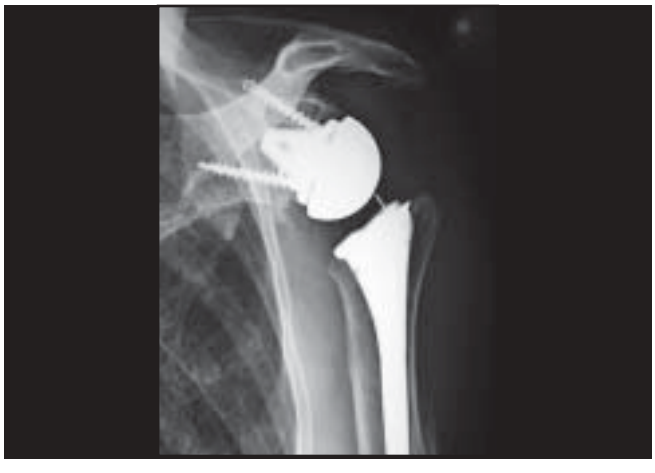

Figure 4: No sign of scapular notching

compared the results of 40 DELTA and 40 ARROW prostheses. Radiologically, it was shown that ARROW SYSTEM allowed for less medialization but that the extent of humeral lowering was the same with both systems. With a minimum follow-up of 12 months, the ARROW series did not show any signs of scapular notching [Figure 4] or glenoid loosening, while the Delta group showed notching in 62%.[37]

In our series, active anterior elevation is 135 degrees, which is only minimally less than with the DELTA prosthesis (140 degrees). However, the arc of rotation of the ARROW prosthesis is better than the DELTA and comparable to the Frankle REVERSE prosthesis, with an average external rotation of 25 degrees and an average internal rotation of 6.33 degrees (Constant score). In addition, there has been no medial impingement seen to date.

CONCLUSION

The idea of the reverse shoulder prosthesis was introduced in the 1970s but initial trials were unsuccessful. Attempts to reproduce normal anatomy generated a number of complications. The pioneering work of Paul Grammont and the development of the DELTA III prosthesis have been fundamental to all subsequent shoulder arthroplasty systems. After more than 10 years of follow-up of these reverse prostheses, glenoid loosening remains a problem. This is a particularly difficult challenge given the frequent lack of glenoid bone stock. There is still room for innovation and progress in the treatment of arthritis associated with rotator cuff deficiency.

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