# History of Reverse Shoulder Arthroplasty

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## 1.1 Introduction

Degenerative and traumatic shoulder arthroplasty, with combined massive and irreparable rotator cuff tear, may lead to a painful and pseudo-paralyzed shoulder. The management of these conditions has long been challenging. It has been well addressed with the use of an anatomical, non-constrained total shoulder arthroplasty but with limited functional results or even contraindications.

The first introduction of such implants was by Charles Neer [1]. However, the problem of damaged or absent periarticular structures remained unsolved. Then, semi-constrained or constrained prostheses were tested in both anatomical and reverse types, but all these implants failed due to loosening of the glenoid component and poor functional outcomes [2, 3].

In 1985, Paul Grammont introduced a revolutionary design of reverse prosthesis that replaced the traditional glenoid socket with a "glenosphere" component fixed to the scapular neck and a small cup in the humeral component [4]. Grammont defined new biomechanical principles of medialization and lowering of the center of rotation. This medialization of the center of rotation in reverse shoulder prosthesis was crucial in successfully overcoming implant failures of previous designs mainly due to loosening.

The new ingenious idea of Paul Grammont has been decisive for all the next reverse shoulder arthroplasties in the treatment of degenerative arthropathies of the shoulder associated with an irreparable tear of the rotator cuff.

Since 1985, many new models, designed on the basis of Grammont reverse shoulder prosthesis, are now available with good clinical outcomes.

In this chapter, we present a historical review of the evolution of reverse shoulder arthroplasty, the biomechanical variations and the complications from the early models, through the development of Grammont's prosthesis, to the more recent ideas and designs to face the controversies and challenges that still remain.

## 1.2 Historical Review

The first shoulder arthroplasty was performed in 1893 by a French surgeon Jules Emile Péan to treat the tuberculous arthritis shoulder of a 37-year-old baker. Jean Porter Michaels, a Parisian dentist, designed for him a prosthesis

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with the humeral stem made of platinum and leather and a head made of rubber coated with paraffin [3, 5, 6]. It had moderate and short-lived functional results because the prosthesis was removed 2 years later for a recurrence of the infection.

Then, no references to the shoulder prostheses were done until 1955 when Neer [7] performed the first non-constrained humeral prosthesis which was a one block implant made of Vitallium which reproduced the anatomy of the superior part of the humerus (Neer I). He treated seven patients with fracture-dislocations of the shoulder by replacement of the humeral head and repair of the avulsed tuberosities and five patients with old fractures of the humeral neck complicated by avascular necrosis. He reported pain relief in 11 of 12 patients. In 1974, Neer [8] subsequently extended the use of his proximal humeral arthroplasty for the treatment of glenohumeral osteoarthritis. He reported excellent and satisfactory clinician results in 40 of 44 patients. Although pain relief was reliably obtained with hemiarthroplasty, Neer [8] reported variable strength and function in patients with irreparable rotator cuff tears. Superior humeral head migration was often seen postoperatively in patients who had lost the stabilizing function of the rotator cuff.

In fact, between 1950 and 1970, together with the widening of the indications for shoulder arthroplasty, many surgeons noticed poorer function in patients with a deficient rotator cuff. They recognized the stabilizing role of the rotator cuff and increased awareness that the development of glenohumeral prosthesis had to solve the challenges of balancing joint stability with the range of motion (ROM) impaired by tear and deficiency of the cuff [8–11].

Nevertheless, over the next years, a number of other studies followed reporting the use of hemiarthroplasty for traumatic and degenerative changes in the glenohumeral joint [8, 12–14].

However, the early attempts were unable to consistently alleviate pain and restore function in cases of rotator cuff tear arthropathy. Such unsatisfactory outcomes led surgeons to use designs that compensated for severe rotator cuff deficiency with a convex glenoid and a concave humerus, replicating the biomechanical design of other weight-bearing joints [10, 15–18]. Inspired by the success of total hip arthroplasty, several subsequent shoulder implant designs attempted to increase the conformity and constraint of the prosthesis [19].

In 1972, Neer and Averill, RG [1] designed three different types of fixed-fulcrum arthroplasty. The first of these reversed shoulder prostheses, Mark I (Fig. 1.1), included a large anatomical glenoid used to stabilize the prosthesis and prevent proximal humeral migration.

The second version, the Mark II, was modified to a smaller ball to allow rotator cuff repair but, unfortunately, with a decreased excursion and motion [20]. The Mark II and similar implants, including the English-MacNab prosthesis and

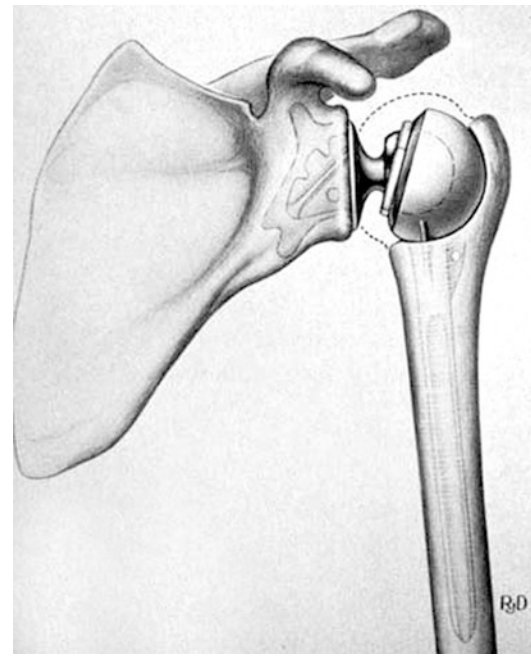

**Fig. 1.1** The Mark I system. A large glenoid implant to allow more motion and a large head (Reprinted with permission from Flatow EL, Harrison AK. A history of reverse total shoulder arthroplasty. Clin Orthop Relat Res. 2011;469:2432–2439)

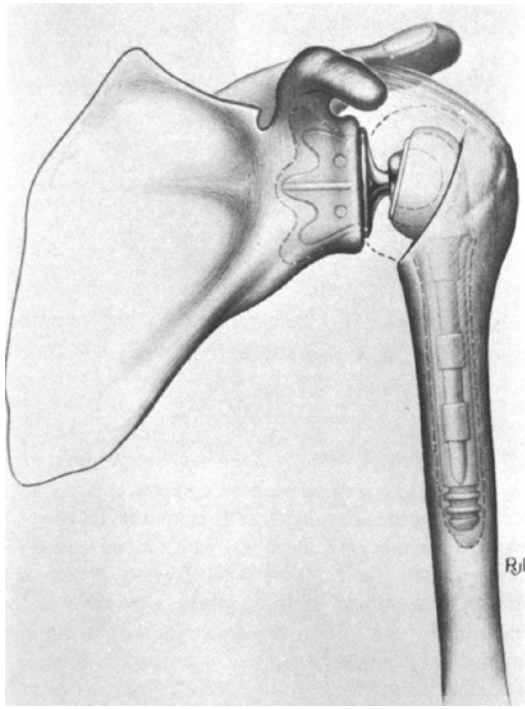

**Fig. 1.2** The Mark III reverse prosthesis. Smaller ball and rotating metallic stem within a polyethylene sleeve (Reprinted with permission from Flatow EL, Harrison AK. A history of reverse total shoulder arthroplasty. Clin Orthop Relat Res. 2011;469:2432–2439)

the DANA shoulder prosthesis, were quickly abandoned, secondary to high rates of loosening of the glenoid component [18, 21].

The third version, the Mark III, was subsequently developed with a new design that allowed axial rotation between the humeral stem and the diaphysis to limit constraint and to improve ROM (Fig. 1.2) [22]. Dislocation, loosening, and scapular fixation were still major concerns with this implant [23]. Therefore, Neer abandoned his constrained prosthesis designs, concluding that constraint alone cannot adequately compensate for a nonfunctional rotator cuff [22]. However, other surgeons continued to explore the reverse shoulder concepts.

In fact, new total shoulder arthroplasty designs in the 1970s reversed the normal anatomy by placing the socket in the proximal humerus and the prosthetic ball on the glenoid with different scapular fixations in order to improve motion and strength without increasing the risk of dislocation and loosening (Table 1.1) [4, 10, 18, 24–29].

**Table 1.1** Reverse shoulder arthroplasty models pre-Grammont

| Prosthesis name/author | Year of introduction | Main characteristics |
|---|---|---|
| Mark I, Mark II, Mark III/Neer and Averill | 1972 | Reverse ball-and-socket joint with a fixed-fulcrum. Mark I with a oversized ball to allow increased motion. Mark II modified to a smaller ball to permit rotator cuff reconstruction. Mark III with a small ball and an axial rotation in the humeral stem to regain motion |
| Leeds/Reeves | 1972 | Glenoid component with a divergent threaded peg; center of rotation coinciding with the anatomic center |
| Gerard and Lannelongue | 1972 | A central screw with an articulating sphere was placed through a base plate along with two more screws |
| Kölbel and Friedebold | 1973 | The glenoid fixation was secured with a central screw and two plates with the screws directed to the base of the scapular spine |
| Kessel | 1973 | Fixation of the scapula with a single large central glenoid screw; center of rotation placed laterally; cemented humeral stem |
| Bayley-Walker | 1973 | Implant similar to Kessel design with a large hydroxyapatite-coated glenoid screw; the center of rotation placed medially and distally. "Snap-fit" components to enhance stability |
| Jefferson/Fenlin | 1975 | Large polyethylene glenosphere to improve deltoid function. The glenosphere articulated with a large cup on a metallic humeral stem |
| Liverpool/Beddow | 1975 | Similar to hip prosthesis. The glenoid component has a stem fixed into the scapular pillar to achieve a secure fixation. This model mimics the anatomic center of rotation outside the scapula |
| Buechel-Pappas-DePalma | 1978 | Double glenosphere decreased in size realizing a "floating fulcrum" that increases shoulder motion over the anatomic limits |
| Trispherical/Gristina | 1978 | Two small ball joints on both humeral and scapular sides articulating with a third larger central polyethylene sphere |

### 1.2.1 1972: The Leeds/Reeves Prosthesis

This shoulder arthroplasty had the normal anatomic center of rotation. The glenoid component was fixed with a divergent threaded peg. It demonstrated higher pullout strength than other designs in *in vitro* testing. This implant was only experimental (Fig.1.3) [10, 29].

### 1.2.2 1972: The Gerard and Lannelongue Prosthesis

Gerard and Lannelongue reported in 2 papers the results of 22 cases, in which this model was used. This system showed many complications (four implant breakages, three dislocations, and two infections) not only related to the prosthesis design. In fact, the cases were particularly complicated and challenging because they included reconstruction following tumor resection or post-traumatic and revision surgery [17, 30].

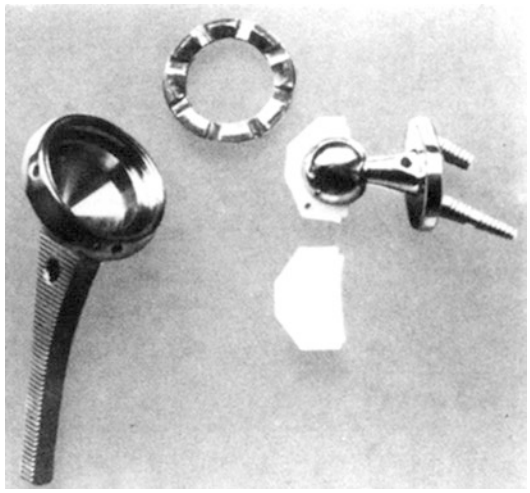

**Fig. 1.3** The Leeds/Reeves reverse shoulder system. It included a divergent threaded peg glenoid component. It had an instant center of rotation that recreated the normal anatomic center (Reprinted with permission from Flatow EL, Harrison AK. A history of reverse total shoulder arthroplasty. Clin Orthop Relat Res 469:2432–2439, 2011)

### 1.2.3 1973: The Kölbel and Friedebold Prosthesis

This constrained implant was designed to reduce the marked bone removal from the glenoid vault for implantation of the glenoid component, characteristic of the earlier constrained designs. Kölbel and Friedebold [18] introduced a new system to improve scapular fixation with a flange bolted to the base of the scapular spine and functioned in stress transfer. The glenoid implant was fixed with a central screw and two plates with the screws directed toward the coracoid process and/or the base of the scapular spine (Fig. 1.4). It was especially used for the reconstruction of bone loss after tumor resection [18, 21, 31]. Its use was reported in six cases, for resection of malignancy from the humerus, the glenoid, or both.

### 1.2.4 1973: The Kessel Prosthesis

In this model the glenoid component was fixed to the glenoid by a large and single central screw which was placed laterally, while the humeral stem was cemented. Both components were snap-fit coupled (Fig. 1.5).

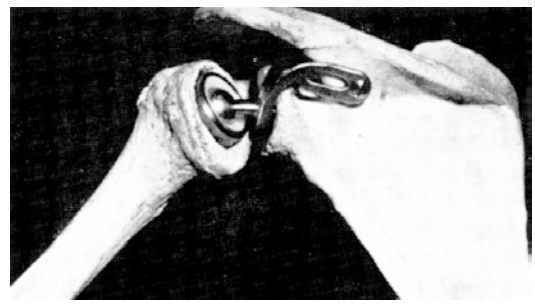

**Fig. 1.4** The Kölbel reverse shoulder prosthesis. The glenoid component is fixed with a flange bolted to the base of the scapular spine (Reprinted with permission from Matsen FA, Rockwood CA, Wirth MA, Lippitt SB: Artropatia gleno-omerale e suo trattamento. In: Rockwood CA, Matsen FA. La Spalla. eds. Roma: Verduci; 2000:823–944)

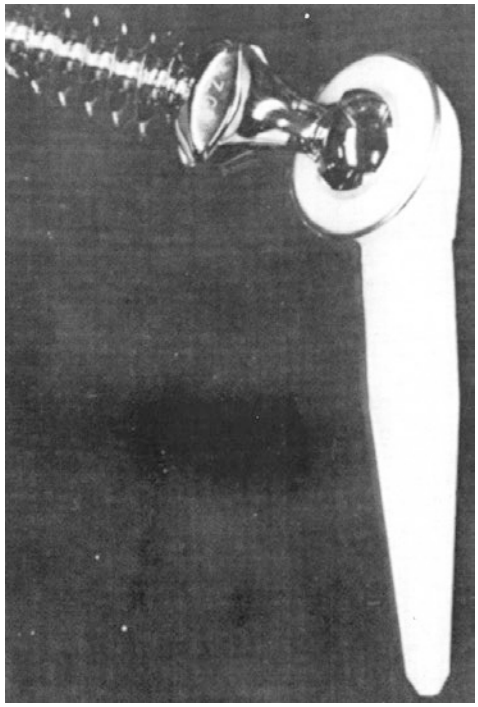

**Fig. 1.5** The Kessel reverse shoulder prosthesis. The glenoid component is screwed to the glenoid, while the humeral stem is cemented (Reprinted with permission from Matsen FA, Rockwood CA, Wirth MA, Lippitt SB: Artropatia gleno-omerale e suo trattamento. In: Rockwood CA, Matsen FA. La Spalla. eds. Roma: Verduci; 2000:823–944)

Bodey described decreased pain and some improvement in function [32].

Also, Broström et al. reported a series of 23 shoulders (all with rheumatoid arthritis), with a follow-up of 87 months, in which pain relief was good in over 90%, but average gain in active elevation was poor (35%) and the reoperation rate was high (26%). Moreover, all shoulders had radiolucent lines around the glenoid screw within a year [33]. Seven years later, Wretenberg confirmed this finding on the same series of patients [34]. Of the 22 patients, 13 were not available for the study (11 died and 2 had serious illness), and 1 had revision surgery after 2 years. The remaining 8 patients had a low functional level but were able to manage daily hygiene. Five patients were pain-free. The radiographs showed no radiolucent zones around scapular components in two of eight patients. No radiolucent zones were detected around the humeral components [34].

### 1.2.5 1973: The Bayley-Walker Prosthesis

In 1973, the Bayley-Walker system was developed on Kessel's model improving both design and fixation. A central glenoid screw coated with hydroxyapatite was introduced to achieve a secure glenoid fixation without a concomitant increase in loosening. In this prosthesis the center of rotation was moved medially and distally to increase the abductor muscle lever arm. Ahir reported no loosening and radiolucencies after 5 years of follow-up in 81 non-tumor cases and 43 cases of malignancy [24].

### 1.2.6 1975: The Jefferson Prosthesis of Fenlin

Fenlin developed a new model of reverse shoulder arthroplasty to increase the deltoid function. He introduced a large glenosphere with an enlarged ball-and-socket construct to compensate the absent rotator cuff [27]. The glenosphere was made of polyethylene to lighten the implant weight, while the humeral cup was metallic (Fig. 1.6).

In 1975, Fenlin described the early satisfactory results, and concluded that the right indication of this prosthesis was rotator cuff arthropathy [27]. However, in 1985 he reported implant mechanical breakage, prosthesis loosening, and anterior instability in a long-term follow-up [35].

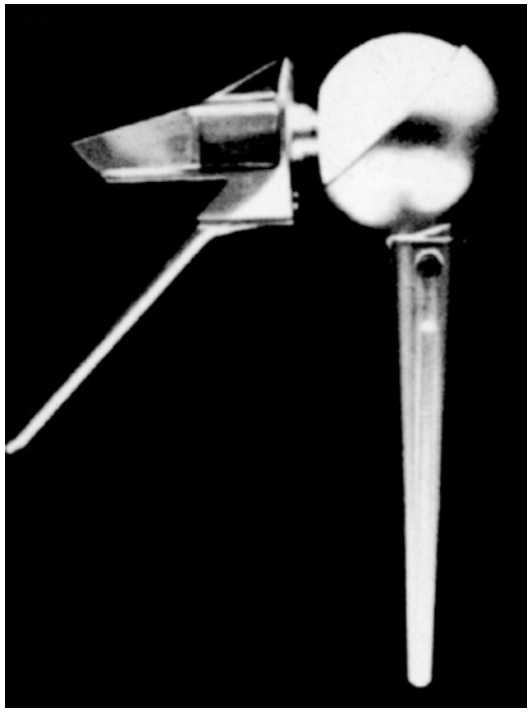

**Fig. 1.6** The Fenlin JM Jr. reverse shoulder prosthesis. It is characterized by a large polyethylene glenosphere to increase deltoid lever arm. A wedge is inserted to fix the scapula, and a column is placed along the axillary border of the scapula (Reprinted with permission from Matsen FA, Rockwood CA, Wirth MA, Lippitt SB: Artropatia gleno-omerale e suo trattamento. In: Rockwood CA, Matsen FA. La Spalla. eds. Roma: Verduci; 2000:823–944)

### 1.2.7 1975: The Liverpool Prosthesis of Beddow

This prosthesis was initially designed in 1969 by Beddow and Elloy and was similar to a Charnley hip prosthesis (Fig. 1.7) [25]. The glenoid component (ball diameter 20 mm) and the stem were fixed into the scapular pillar with the polyethylene socket cemented into the proximal humerus. This design mimicked the anatomic center of rotation outside the scapula. Nineteen prostheses were implanted, and 16 had a 5-year follow-up; 11 patients experienced almost pain-free, and 4 patients showed loosening of the scapular component [36].

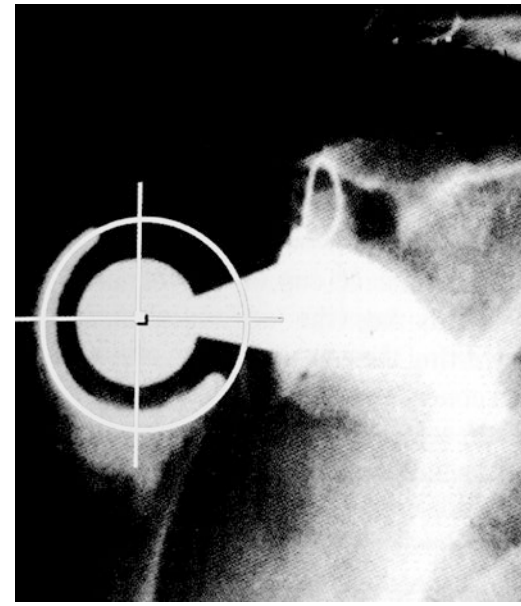

**Fig. 1.7** The Liverpool reverse shoulder prosthesis. The glenoid component has a stem fixed in the scapular pillar to a depth of about 50 mm and with the polyethylene socket cemented into the proximal humerus (Reprinted with permission from Boileau P, Walch G, et al. Shoulder Concepts. Reverse Shoulder Arthroplasty. eds. Montpellier: Sauramps Medical; 2016)

### 1.2.8 1978: The Buechel-Pappas-DePalma Prosthesis

In 1978, Buechel et al. [26] designed a prosthesis similar to the Neer Mark III (Fig. 1.8). This model was based on a supporting system with two spheres to realize a "floating fulcrum." It was characterized by a small glenosphere articulated with a larger and mobile intermediate polyethylene cup and with the humeral head to allow supraphysiologic motion [26, 37]. The early results in few patients were promising. They reveal superior fixation strength of both glenoid and humeral components and functional adaptation of the prosthesis without fracture of fixturing bone or prosthetic dislocation [26]. However, Buechel et al. [26] hypothesized that, at a longer follow-up, the muscle forces across the glenohumeral joint would lead to loosening at the bone-cement or humerus-glenoid interfaces of the prosthesis.

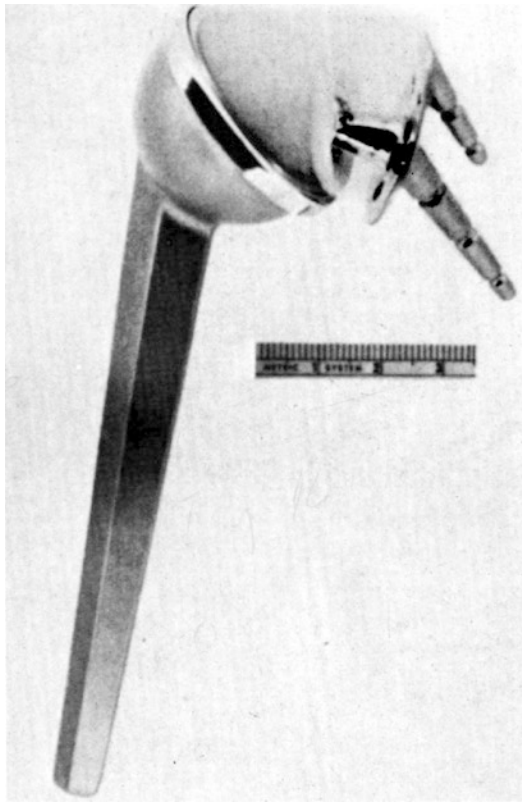

**Fig. 1.8** The Buechel reverse shoulder arthroplasty. This implant includes a supporting device with double spheres that functions as a "floating fulcrum." This system allows shoulder motion over the anatomic limits (Reprinted with permission from Matsen FA, Rockwood CA, Wirth MA, Lippitt SB: Artropatia gleno-omerale e suo trattamento. In: Rockwood CA, Matsen FA. La Spalla. eds. Roma: Verduci; 2000:823–944)

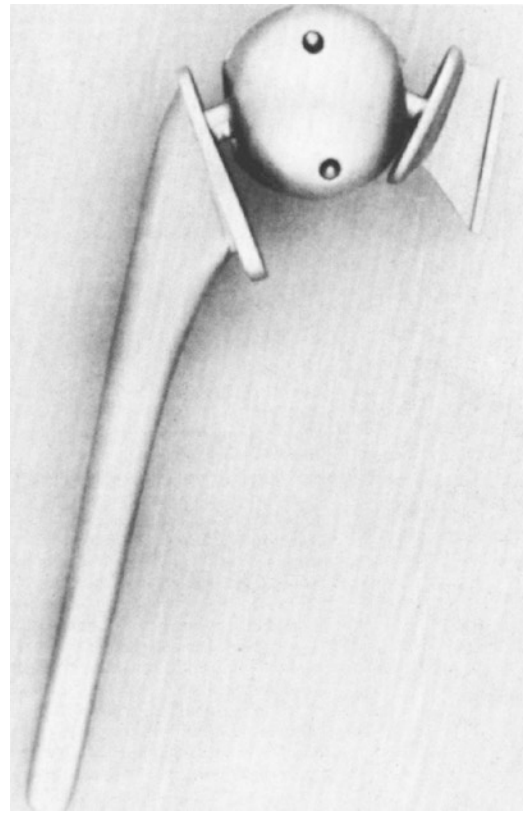

**Fig. 1.9** The trispherical total shoulder of Gristina and Webb. It consisted of Vitallium humeral and glenoid small balls, both incorporated in a larger polyethylene sphere (Reprinted with permission from Matsen FA, Rockwood CA, Wirth MA, Lippitt SB: Artropatia gleno-omerale e suo trattamento. In: Rockwood CA, Matsen FA. La Spalla. eds. Roma: Verduci; 2000:823–944)

### 1.2.9 1978: The Gristina Trispherical Prosthesis

In 1978, Gristina and Webb designed a system similar to Buechel's prosthesis [28] (Fig. 1.9). The name "trispherical" was related to the presence of a unique double ball-and-socket configuration. These two small ball joints, on both humeral and scapular sides, are articulated with a central polyethylene sphere inserted in a separate metallic socket [37]. This system was successful in improving pain and ROM but experienced several dislocations of the humeral sphere and glenoid component fracture.

These previous constrained reverse shoulder prostheses (reverse ball-and-socket designs) tended to fail because their center of rotation was lateral to the scapula with limited motion and, thus, they produced excessive torque and shear forces at the glenoid component-bone interface leading to early loosening (Fig.1.7). In most cases, the functional active elevation was limited, less than 90 degrees, and especially related to scapulothoracic motion. Many models remained experimental and were abandoned because of the failures, particularly for the prosthetic instability and loosening [27, 33, 38–41].

The challenge of finding a compromise among mobility, stability, mechanical efficiency, and resistance to loosening in the prosthesis design was considered impossible.

In 1985, Paul Grammont, unlike the previous reverse models, first introduced a new reverse shoulder prosthesis characterized by two major and revolutionary innovations: a large glenoid hemisphere without the neck and a small humeral cup almost horizontally inclined and covering less than half the hemisphere. In Grammont reverse prosthesis, the center of rotation was medialized and stabilized, minimizing torque on the glenoid component and recruiting more fibers of the anterior and posterior deltoid which led to an increase of the abduction force [39].

These innovations represent the main causes of the worldwide success of this prosthesis design.

**Fig. 1.10** Dr. Paul-Marie Grammont is shown in 2011 (Reprinted with permission from Boileau P. Biographical Sketch. Clin Orthop Relat Res. 2011;469:2422–2423)

## 1.3 Paul Grammont Biography

Paul Grammont was born on April 12, 1940 in Salins-les-Bains (Fig. 1.10). His father was a teacher and his mother was trained as a physicist. His father taught in different schools in Besançon, Alès, Quimper, Lons-le-Saunier, Troyes, and finally in Lyon, where Grammont took the baccalaureate in "Elementary Math," in 1957. After graduating from secondary school, he began his medical studies in Lyon as a resident in general and osteoarticular surgery. In Lyon, he worked as a university assistant in Michel Latarjet's anatomy laboratory from 1968 to 1971. From March 1972 to April 1974, he was a fellow and then a senior registrar in Professor Albert Trillat's orthopedic department in Lyon specializing in knee and shoulder surgery. He did his military service in French Guiana where he treated many difficult cases. In 1974, when he was 34, he became an Associate Professor of Orthopedic Surgery and Traumatology (Fig. 1.11). Then, he became the Chairman of the Orthopedic Department of the University Hospital in Dijon, in September 1974. It was in Dijon that he began his biomechanical experiments on the knee and the shoulder in his own garage before having the opportunity to work in the anatomical and biomechanical labs in the Medical University of Dijon. Innovation was Paul-Marie Grammont's keyword and he was really creative; besides developing the reverse shoulder prosthesis [4, 42], he also developed an early patellofemoral prosthesis [43] and one of the first nails with a self-advancing mechanism designed to lengthen long bones like the tibia and

**Fig. 1.11** Dr. Paul-Marie Grammont is shown about in 1970 (Reprinted with permission from Boileau P. Biographical Sketch. Clin Orthop Relat Res. 2011;469:2422–2423)

the femur (Albizia nail) [44]. The shoulder was the joint that he mostly studied. He firstly proposed a procedure named "Bristow-Trillat" for the anterior instability explaining its biomechanical rationale. But, his ingenious mind was developed in the degenerative pathology and prosthetic surgery of the shoulder. In 1985, Grammont designed a reverse prosthesis for arthritic shoulders with insufficient rotator cuff. In 1987, he published his first paper on the reverse prosthesis in the French literature [4, 45]. Six years later, in 1993, he summarized the results of his biomechanical studies in the English language [42].

In 1997, at 57 years old, he had a stroke with right hemiplegia and aphasia. Despite functional deficits, he continued his carpentry and plumbing activities in his home and became a painter using his left hand. Paul-Marie Grammont died on March 30, 2013 [45, 46].

## 1.4 The Principles of Grammont's Reverse Prosthesis

In 1981, Professor Paul-Marie Grammont directed two engineers in a study with a theoretical and mathematical approach entitled *Study of a Mechanical Model for a Shoulder Total Prosthesis: Realization of a Prototype* [47]. Grammont observed that, when the cuff is absent, the solution is to intrinsically balance the middle deltoid to strengthen its abduction component and lessen the elevation component responsible for loosening stress on the glenoid. Moreover, regarding the center of rotation, he said: "medializing the center of rotation of the scapulohumeral joint, and so increasing the deltoid lever arm, will compensate for the lack of activity of the supraspinatus muscle. In this way, we would move the mobile joint against the scapula without allowing a change in the position of the humerus in reference to the scapula. Indeed, if at the same time, we medialized the humerus itself, the deltoid lever arm would remain unchanged instead of being increased… In a first step, we'll have to lower the center of rotation" [47]. This is the concept of medializing the center of rotation.

The above method of strengthening the deltoid abduction component was consistent with, and validated by, the experience of the translation-rotation-elevation osteotomy of the scapular spine, described in 1975 [48–51]. After all, the increase of the middle deltoid lever arm induced by the acromial lateralization through this osteotomy was measurable [50]. Therefore, the deltoid can be affected in the same way by two different means: lateralizing the acromion without moving the center of rotation or medializing the center of rotation without moving the acromion [52].

### 1.4.1 1985. The First Version of Grammont's Arthroplasty, the Delta™ Reverse Prosthesis

This *first model* of Grammont's prosthesis was the *Delta™ reverse prosthesis* (Delta for deltoid, the only motor of this design) as it relied solely on the strength of the deltoid muscle for both movement and stability [42, 53] (Table 1.2). It was designed by Grammont in 1985.

This prosthesis, also named "Trompette," had only two components (Fig. 1.12). The glenoid component was a metallic or ceramic ball without a neck, initially two-thirds of a sphere, and 42 mm in diameter. It was designed to fit over the glenoid like a glove and fixed with cement. The humeral component was a polyethylene socket. Its concave surface was a third of a sphere, and its stem was trumpet-shaped for cementing into the humeral medullary canal. A "bell saw" was used to prepare the glenoid, and two broaches were used to prepare the different parts of the humerus, one for the epiphysis and one for the diaphysis. The initial Grammont reverse prosthesis was cemented on both humeral and glenoid sides.

The underlying principles which differentiate this prosthesis from the failed reverse semi-constrained designs of the past include (Fig. 1.5):

1. A fixed center of rotation with congruent large joint surfaces (cup on sphere instead of sphere on a "flat" surface) to compensate for the deficient rotator cuff muscles and increase stability

2. A medialized center of rotation (so that it actually lies at the glenoid bone-prosthesis interface) in order to:
   (a) Increase the deltoid lever arm.
   (b) Reduce the torque at the point of fixation of the glenoid component.
3. Lowering of the humerus relative to the glenoid to increase deltoid tension to overcome the weak/absent rotator cuff muscles

To achieve this, Grammont used a reverse ball-and-socket prosthesis, but he introduced two majors design innovations: (1) a large ball and no neck on the glenoid side and (2) a small cup, oriented with a nonanatomical inclination of 155°, and that covers less than half of the hemisphere on the humeral side. Almost all reversed prostheses designed before the Delta had a small prosthetic head and a neck and/or a more vertically oriented and covering cup, which created a very different biomechanical environment [3, 8, 18, 28, 34].

In 1987, Grammont et al. [54] reported a study on eight patients with his first design: three cases of post-radiotherapy necrosis, one case of inflammatory osteoarthritis, and four revisions of failed prostheses. The mean age was 70 years, and cuff was absent or destroyed in all cases. The mean follow-up was only 6 months. A transacromial approach (with osteotomy of the lateral acromion) was used in all but one case. Revision osteosynthesis of acromial nonunion was required in three of these cases. All shoulders were pain-free, but mobility was variable. In three cases, active anterior elevation was 100–130°, but in the three other cases, it was less than 60°. Unsatisfied with these results, Grammont made further modifications to progress to the current design. Since he experienced several

**Table 1.2** Reverse shoulder prosthesis of Grammont and post-Grammont

| Prosthesis name/author | Year of introduction | Main characteristics |
|---|---|---|
| *Grammont prostheses* | | |
| First prototype | 1985 | The humeral component was a polyethylene socket with a trumpet shape; the glenoid component was metallic or ceramic ball with a press-fit central peg; center of rotation medialized but lateral to native glenoid surface |
| Delta III—first generation | 1991 | The glenoid components included a circular glenoid baseplate with a central peg for press-fit impaction, reinforced with two divergent screws to resist initial shear forces. The glenosphere was directly screwed onto the peripheral edge of the plate |
| Delta III—second generation | 1991 | Morse taper with a central countersunk screw |
| Delta III—third generation | 1994 | A diaphyseal stem screwed onto a modular metaphyseo-epiphyseal block; the polyethylene cup fitted over the epiphyseal end |
| *Post-Grammont prostheses* | | |
| Aequalis® reversed | 1998 | The metaglenoid is fixed with divergent locking screws and implanted lower on the glenoid with a small amount of inferior tilt |
| Encore Reverse®/ Frankle | 1998 | Placed less medially than the Delta prosthesis; the center of rotation was closer to its usual anatomic location |
| Duocentric® reverse prosthesis | 2001 | Inferior extension of the glenosphere to avoid scapular notching and fixation peg to preserve the glenoid bone stock |
| Universal Arrow System | 2002 | Placed less medially than the Delta prosthesis; the COR is in the glenoid; the humeral cup has an inbuilt medial notch to avoid friction against the pillar of the scapula |
| Lima Corporate SMR™ | 2003 | The central peg is made of a Trabecular Titanium™ technology |
| TESS (Total Evolutive Shoulder System)—Biomet | 2006 | Uncemented glenoid baseplate secured by a full hydroxyapatite central peg with titanium plasma spray; the humeral implant is based on the short reverse corolla |
| Aequalis Ascend™ Flex | 2012 | Short, uncemented, and convertible humeral stem to preserve bone stock; 145° angle to avoid scapular notching. Onlay design |

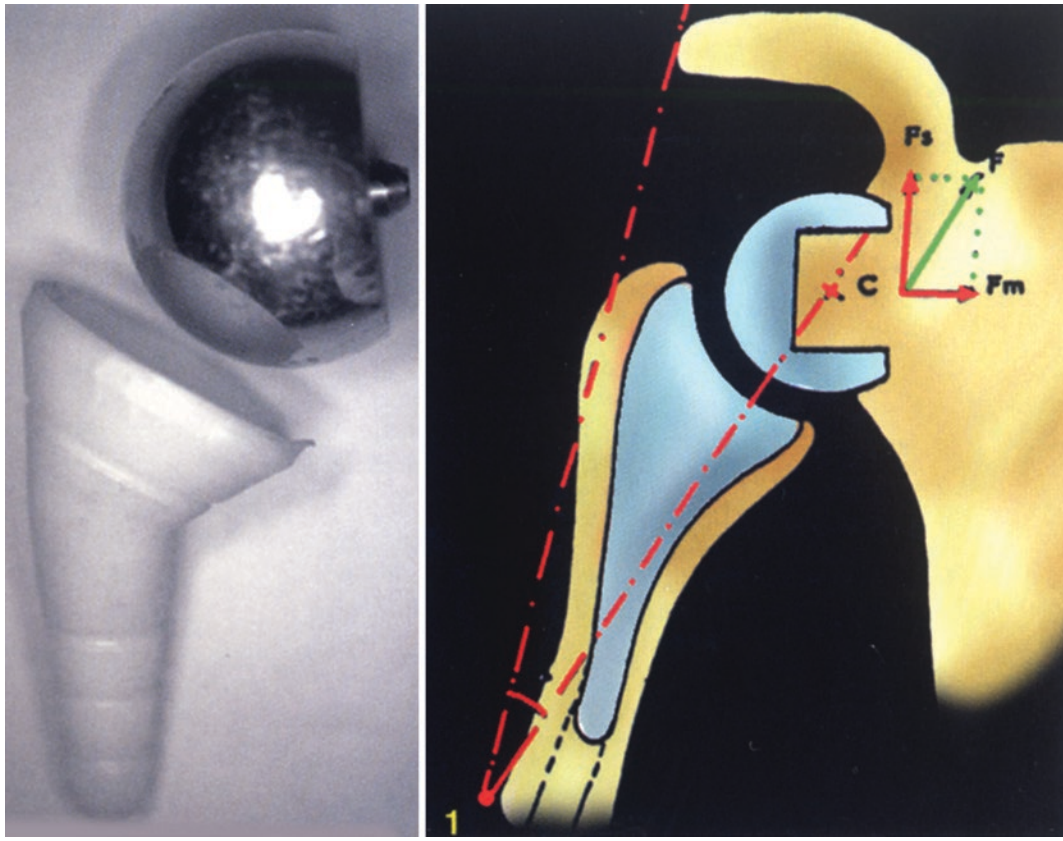


**Fig. 1.12** The first model of Grammont reverse prosthesis named "Trompette," designed by Grammont in 1985 and first implanted in 1986. This prosthesis included a polyethylene humeral component and an alumina ceramic glenoid component with a volume equivalent to 2/3 of a sphere of 44 mm (Reprinted with permission from Boileau P, Walch G, et al. Shoulder Concepts. Reverse Shoulder Arthroplasty. eds. Montpellier: Sauramps Medical; 2016)

failures with the cemented glenoid component, he decided to change the glenoid to an uncemented system fixing the glenoid component with a central peg and some screws of divergent direction to counteract the initial shearing forces [53]. He also abandoned the idea of having two-thirds of a sphere and opted for a design based on half of a sphere in order to place the center of rotation directly in contact with the glenoid surface, decreasing lateral offset at the glenohumeral articulation and thus decreasing shearing forces.

Later, Grammont and his collaborators observed loosening of the cemented large sphere (2/3 of sphere), and they moved to a press-fit glenoid baseplate with a smaller hemisphere [52]. However, some of these early Grammont reverse prostheses are still surviving at more than 15 years of follow-up. Notably, this Trompette prosthesis has been associated only with small and nonprogressive notches on the scapular pillar [52].

### 1.4.2 1991: The Second Model of Grammont's Prosthesis: The Delta III

The Delta III prosthesis came on the market in 1991 and is still available.

The Delta III has five parts: the glenoid baseplate (metaglenoid), the glenosphere, the polyethylene humeral cup, the humeral neck, and the humeral stem (Fig. 1.13a, b).

In the first generation, the metaglenoid was a circular plate with a long and uncemented central

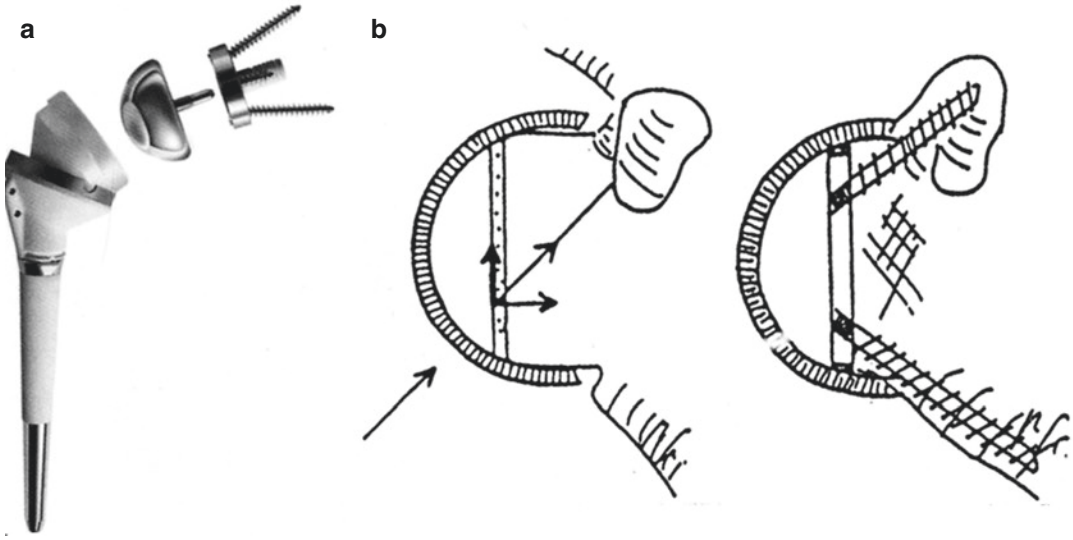


**Fig.1.13** (**a**) The Delta ™ reverse prosthesis has five components: the glenoid baseplate (metaglenoid), the glenosphere, the polyethylene cup, the humeral neck, and the humeral stem. (**b**) The change from a cemented to an uncemented glenoid with divergent screws to resist initial shear forces (Reprinted with permission from Boileau P, Walch G, et al. Shoulder Concepts. Reverse Shoulder Arthroplasty. eds. Montpellier: Sauramps Medical; 2016)

peg. It was fixed with two divergent 3.5 mm screws superiorly and inferiorly in order to resist to the shearing forces at the bone-implant interface. The glenosphere was screwed directly onto the peripheral edge of the plate, but this peripheral screwing was abandoned due to secondary loosening of the screws [20].

In the second generation, the metaglenoid was conical and smooth in the periphery 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 to securely fix the glenosphere with a central screw. The humeral component was a monobloc with a cup of standard thickness [20].

The third generation became available in 1994 with a new humeral component. A diaphyseal stem was screwed on to a metaphyseo-epiphyseal block of one of three available sizes in order to obtain a better fit. The polyethylene cup (a third of a sphere) was fitted over the epiphyseal end, but it was too small and rapidly deteriorated due to medial impingement. The cup was, therefore, replaced by a lateralized cup of 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 [20].

The choice of a large humeral stem came from the idea developed in hip arthroplasty of maximizing the contact area between the stem and the host bone [20].

The Delta III prosthesis (DePuy International Limited, Leeds, England) has been used for the last 20 years worldwide, and its results have been extensively reported [55–60]. In cases of pseudoparalytic shoulders with massive irreparable cuff tears and glenohumeral arthritis, all series have shown a recovery of active abduction of between 120 and 130 degrees.

### 1.4.3 Complications of Grammont Reverse TSA

The persistent problems and high complication rate with this procedure have been described extensively in the current literature with complications including [55, 59–62] hematoma formation [63], infection [55, 59, 63–66], scapular notching [59, 66–68], instability [63, 65, 66], acromial com-

plications [63, 64], glenoid component failures (loosening, disassembly) [10, 28, 35, 59], intraoperative fractures, and neurological complications.

*Deep infection* has been reported in up to 5.1% of primary reverse TSA. This is likely related to the large subacromial "dead space" that allows the formation of a hematoma [69].

*Scapular notching* is a direct consequence of both the absence of a prosthetic neck of the glenosphere and the horizontal orientation of the humeral cup. It is caused by the impingement of the medial aspect of the polyethylene humeral cup on the scapular neck inferiorly but also posteriorly. This repetitive contact can lead to bone loss under the inferior aspect of the glenoid with incidence of up to 50–96% [58, 63, 67, 68] (Fig. 1.14a) and in polyethylene wear (Fig. 1.14b). Moreover, the polyethylene particle disease may cause local osteolysis with progression of the notch [60, 62, 70]. This is supported by the finding of polyethylene particles in the pseudomembrane in the osteolytic area [71].

A series from Nice reported this complication in 74% of cases (45 cases) [55] and another from Sirveaux in 65% (77 cases) [59]. Gerber et al. [72] studied the passive range of motion in prosthesis with superior fixation of the glenosphere. This confirmed previous reports [61, 62] 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.

*Instability*. Proper deltoid tensioning can be another source of complications with inadequate tension leading to instability [69].

*Acromial complications* like fracture are due to the high tensioning of the deltoid [69].

*Glenoid loosening*. Although intraoperative glenoid complications are uncommon, *glenoid loosening* has been observed in up to 4.1% of Grammont reverse prostheses [69].

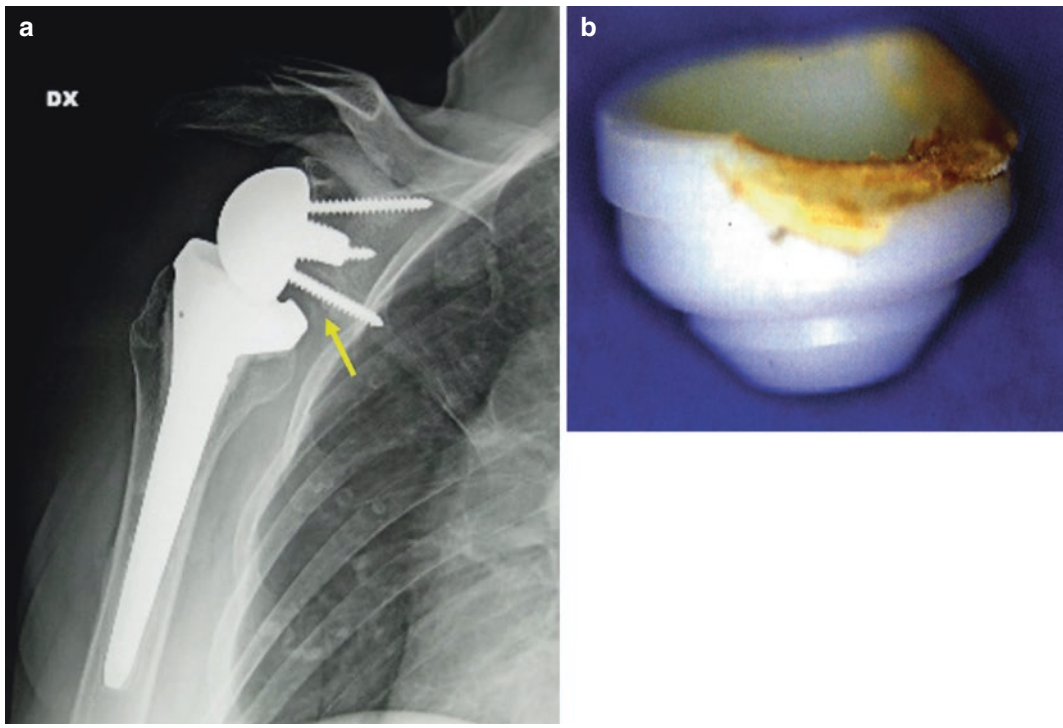


**Fig. 1.14** The scapular notching. (**a**) The yellow arrow shows the scapular notching that results from a mechanical conflict between the medial border of the humeral implant and the inferior rim of the glenoid. This conflict leads to a polyethylene wear of the glenoid component. (**b**) Retrieved glenoid component with polyethylene wear (Reprinted with permission from Boileau P, Walch G, et al. Shoulder Concepts. Reverse Shoulder Arthroplasty. eds. Montpellier: Sauramps Medical; 2016)

A *limited external rotation,* despite the good elevation, achieved by the reverse shoulder prosthesis was reported due to the medialization of the humeral component that increases the medial impingement against the scapula. It also accounts for the medial notch [55, 61, 62].

Moreover, the medialization of the center of rotation reduces the strength of the posterior deltoid fibers. Injury to the suprascapular nerve while fixing the metaglenoid may also be a cause of lack of external rotation [62].

*Limitation of internal rotation* was also noticed. It is caused by the prosthesis design, the medialization that reduces the strenght of the anterior fibers [30], and the state of the subscapularis. Active medial rotation will be improved if part of subscapularis remains intact.

## 1.5 Post-Grammont Reverse Shoulder Arthroplasty

Several new models were developed based on Grammont's principles [64, 73, 74] to overcome all the complications of the previous reverse shoulder prostheses (Table 1.2).

The Tornier Company (Montbonnot-Saint-Martin, France) has developed the Aequalis® reversed prosthesis, based on the biomechanical principles described by Grammont, but with some innovations. The metaglenoid is fixed with divergent locking screws. Wedges and polyethylene cups of varying thickness are used to correct the tension of the deltoid and metaphyseal bone loss. Users of the Delta and Tornier prostheses, following the work of Gerber [72], have recommended that the metaglenoid be implanted lower on the glenoid with a small amount of inferior tilt (Fig. 1.15).

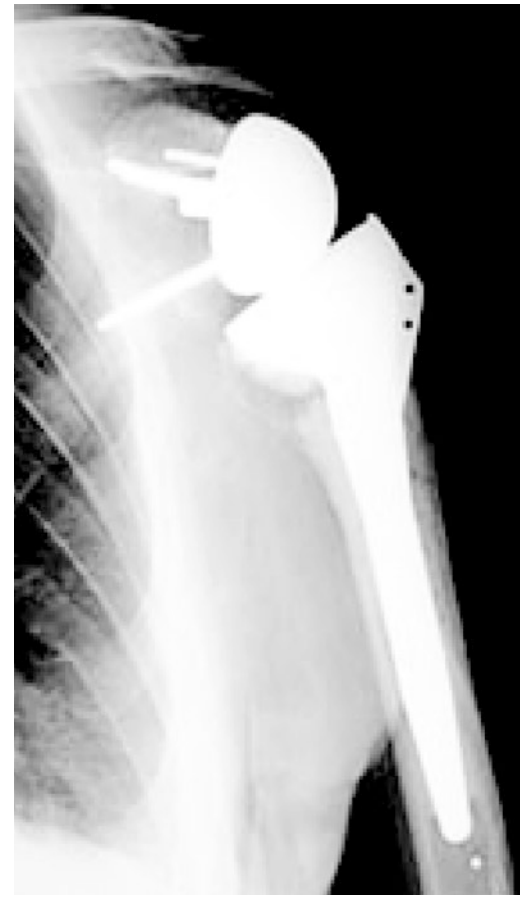

**Fig. 1.15** The Aequalis reversed shoulder prosthesis ™ (Tornier Company, Montbonnot Saint Martin, France). The metaglenoid is fixed with divergent locking screws with inferior tilt (Reprinted with permission from Boileau P, Walch G, et al. Shoulder Concepts. Reverse Shoulder Arthroplasty. eds. Montpellier: Sauramps Medical; 2016)

In *1998*, Frankle designed the reverse prosthesis (ENCORE Medical, Austin, Texas, USA) (Fig. 1.16). It was placed less medially than the Delta, and the center of rotation was closer to its usual anatomical location [64]. In his series of 60 patients with more than 2 years follow-up, less abduction than in the Delta series was observed but with a better range of rotation. However, the design of the glenosphere, which was two-thirds of a sphere, increased shearing of the screwed metaglenoid. Several complications of the glenoid component were noted, including loosening (seven cases) and breakage of the platinum and screws. Frankle's biomechanical studies concluded that a concave metaglenoid was better than a flat one [74].

In *2001*, the Duocentric® reverse prosthesis (Aston Medical) was designed and developed until a third generation based on the "Trompette" and Delta® (DePuy). It was first implanted in 2003. This system was characterized by three main features: spherical inferior overhang to avoid scapular notching, fixation peg of various

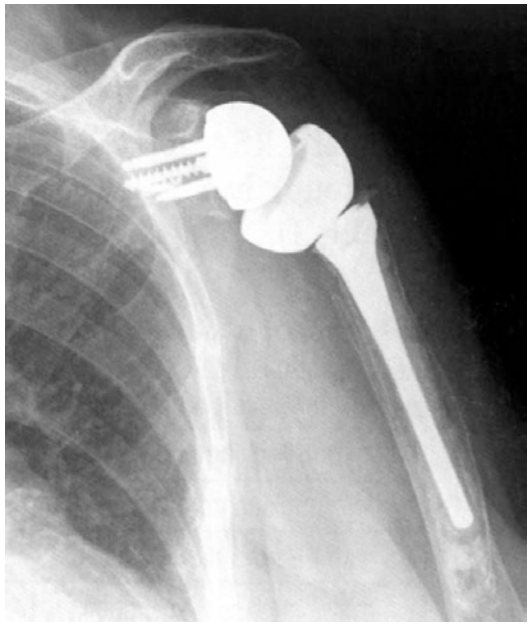

**Fig. 1.16** The Encore reverse prosthesis (Encore Medical, Austin, Texas, USA). The glenosphere is placed less medially than the Delta and the center of rotation is similar to the anatomical position (Reprinted with permission from Boileau P, Walch G, et al. Shoulder Concepts. Reverse Shoulder Arthroplasty. eds. Montpellier: Sauramps Medical; 2016)

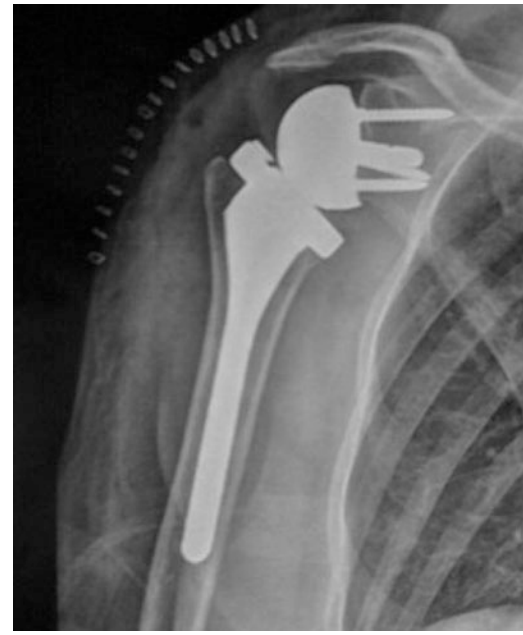

**Fig. 1.17** The Duocentric® reversed shoulder prosthesis with uncemented stem

sizes to preserve the glenoid bone stock, and adjustable length to reinforce the fixation if needed (Fig. 1.17). After more improvements, the Duocentric® Expert reversed prosthesis became available in 2007 [75].

In *2002*, the Universal Arrow System (FH orthopedics, Heimsbrunn, France) was developed in France and became available commercially in Europe. This model was based on Grammont's principles with the center of rotation lying at the level of the glenoid unlike Encore reverse prosthesis. The center of rotation was in the glenoid, and the prosthesis was placed less medially than the Delta prosthesis (Fig. 1.18). Thus, the range of rotation (poor in Grammont's design) was improved, and the risk of medial impingement was eliminated. In addition, the humeral cup had an inbuilt medial notch to avoid friction against the pillar of the scapula. The metaglenoid was concave, adapting to the normal curvature of the glenoid fossa.

De Wilde [73] confirmed that medialization and lowering the implant affect the moment arm of the deltoid and improve the arc of rotation, which is essential in daily activities.

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

In *2003*, Lima Corporate introduced a reverse shoulder prosthesis with a modular shoulder replacement system (SMR™) [76]. This system also allows the conversion to a reverse shoulder arthroplasty without changing the humeral stem, and the glenoid metal back avoids the risk of sacrificing the bone [77]. At a mean follow-up of 32.3 months, all patients improved in terms of range of motion, and no signs of loosening of the implant were reported.

In the SMR Axioma TT Metal Back implant (Lima Corporate SMR™), a wide range of modular pegs are provided to manage bone deficiency. This system is made of a Trabecular Titanium™

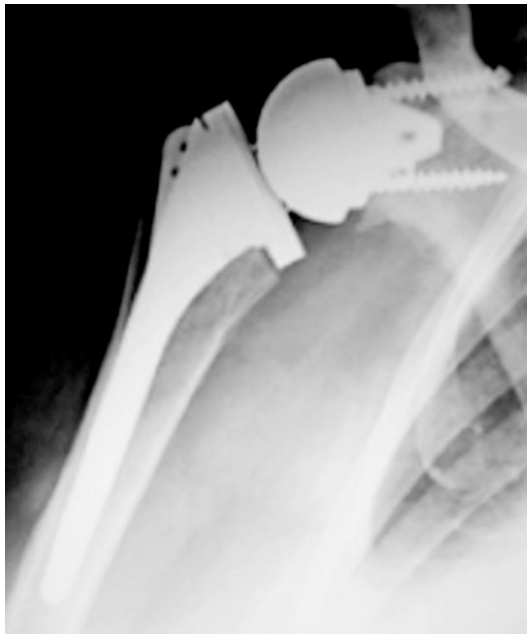

**Fig. 1.18** The Universal Arrow System (FH Orthopedics, Heimsbrunn, France). This prosthesis is placed less medially than the Delta; the center of rotation is in the glenoid unlike Encore reverse prosthesis; the humeral cup has an inbuilt medial notch to avoid friction against the pillar of the scapula

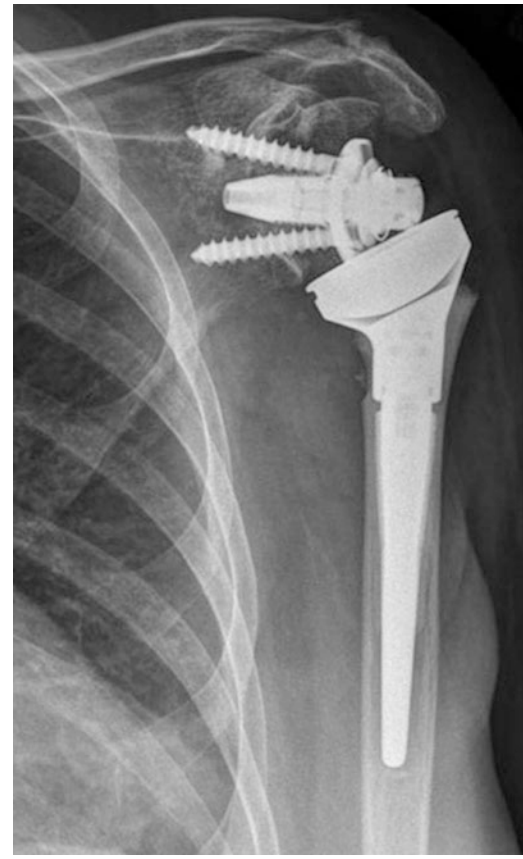

**Fig. 1.19** SMR Axioma TT Metal Back implant (Lima Corporate SMR™). The central peg is made of a Trabecular Titanium™ technology

technology that provides significant osseointegration with high bone ingrowth percentage both in cancellous and cortical bone in sheep model [78] (Fig. 1.19).

In *2012*, Tornier Company designed a new reverse shoulder prosthesis with an onlay design, the Aequalis Ascend™ Flex (Tornier SAS-Wright Medical Inc., Bloomington, MN, USA). It is characterized by a new short, uncemented, and convertible humeral stem to comply with these specifications: bone stock preservation with a short stem, avoiding scapular notching utilizing a 145° angle through a summation of the stem and polyethylene liner angles and making the humeral revision easier. This angle has been shown to minimize scapular impingement while optimizing elevation, internal, and external rotation through virtual implantation studies completed by Tornier, Inc. [79, 80] (Fig. 1.20). Goetzmann et al. presented the preliminary results of 24 reversed shoulder arthroplasty at 2 years of follow-up. The average CS improved from 21 preoperatively to 63 postoperatively ($P < 0.0001$). Anterior active elevation and active external rotation improved from 79° and 10° preoperatively to 139° and 28° postoperatively. The mean active internal rotation improved significantly from the sacrum to L3 ($P < 0.0001$). SSV improved from 34 to 73%. No mechanical complication (migration, fracture, instability, or loosening), loosening, and radiolucent lines around the stem were reported [80].

Recently, new models of reverse shoulder prostheses without stem were proposed.

The TESS (Total Evolutive Shoulder System) (Biomet, Warsaw, IN, USA) has an uncemented glenoid baseplate secured by a full

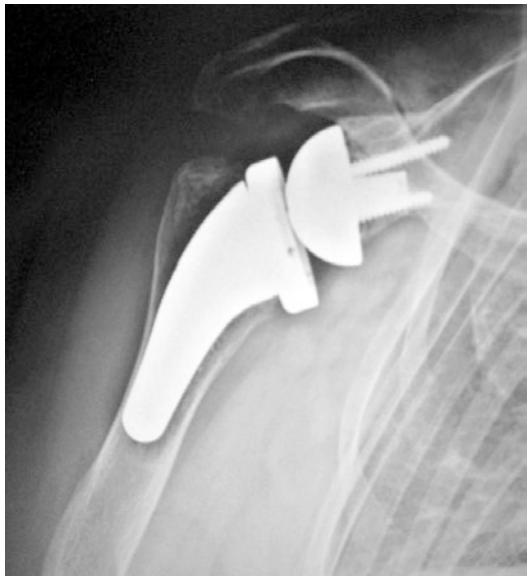

**Fig. 1.20** The Aequalis Ascend™ Flex (Tornier SAS-Wright Medical Inc., Bloomington, MN, USA). This prosthesis has an onlay design and a short, uncemented, and convertible humeral stem to preserve bone stock; 145° angle to avoid scapular notching

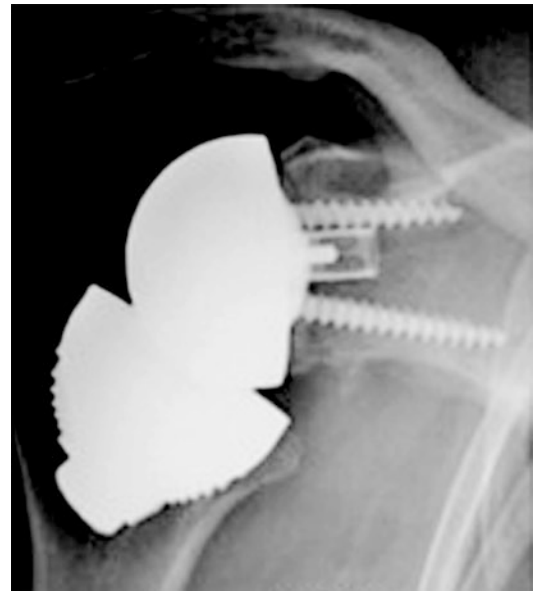

**Fig. 1.21** TESS stemless reverse shoulder arthroplasty. Glenoid baseplate is uncemented and secured by a hydroxyapatite central peg with titanium plasma spray. The humeral implant is based on the anatomic RCo (Reprinted with permission from Boileau P, Walch G, et al. Shoulder Concepts. Reverse Shoulder Arthroplasty. eds. Montpellier: Sauramps Medical; 2016)

hydroxyapatite central peg with titanium plasma spray, as well as two superior and inferior locked screws. The glenosphere is eccentric, with a 3 mm lateralization, and is placed inferiorly. The humeral implant based on the short reverse corolla is an uncemented metaphyseal-epiphyseal implant, made of chrome cobalt, with a titanium plasma spray, and full hydroxyapatite coating. Six wings on the surface of the reverse corolla optimize the rotational stability. Teissier et al. found a significant improvement in pain relief, flexion, abduction, and external rotation, no infections or neurologic lesions, no humeral loosening of the corolla despite the lack of a stem, as well as no component dissociation; scapular notching in medium-term follow-up study was about 19% [81] (Fig. 1.21).

In *2015*, also Lima LTD produces a stemless reverse shoulder prosthesis, the Lima shoulder modular replacement (SMR) stemless shoulder system. This is a convertible system with four parts for anatomic configuration (humeral core component, double male Morse taper, locking screw, and humeral head) and two parts for reverse configuration (humeral core component and reverse liner). The humeral core component is composed of Trabecular Titanium designed for bone ingrowth and is seated by impaction. When utilized in reverse configuration, a metallic reverse liner is impacted into the humeral core component. This metallic liner, manufactured out of CoCrMo, then articulates with an all-polyethylene glenosphere [82].

## 1.6 Indications and Contraindications

Reverse shoulder arthroplasty represents primary indication for elderly patients with cuff tear arthropathy and a cuff-deficient shoulder demonstrating predictable outcomes [58, 83].

As surgeons have acquired more experience, indications have been extended to include revision arthroplasty, proximal humeral nonunion [84], acute fractures [84, 85], pseudo-paralysis due to massive and irreparable cuff tear without arthritis [27, 53, 60], severe fracture sequelae (type 3 or type 4) with tuberosity migration and osteolysis [39, 56, 86], prosthetic revision in a cuff-deficient shoulder [39, 61, 87], and tumor surgery [88, 89].

There are two major contraindications for a reversed prosthesis: a history of previous infection and a nonfunctional deltoid muscle.

As the study of reverse shoulder arthroplasty has advanced and varying systems have developed, vibrant controversies have arisen. Debate exists over the medialization of the center of rotation, with some proposing a more lateral offset pointing to a lower rate of scapular notching and an increase in impingment-free motion [89, 90]. Others suggest notching may also be minimized with appropriate positioning of the more medial glenoid component [68]. These issues require additional high-quality studies and must continue to be explored and debated [91].

## 1.7 Conclusion

The design of the reverse shoulder prosthesis was introduced about 50 years ago, but the initial models, introduced in the early 1970s, failed due to many complications, particularly instability and loosening of the glenoid component. To overcome these concerns, Paul Grammont first introduced two major revolutionary innovations in reverse shoulder prosthesis: a fixed and medialized center of rotation minimizing torque on the glenoid component and a lowered humerus improving the power of the deltoid for elevation/abduction. The pioneering concepts of Grammont and the development of the Delta III prosthesis have been fundamental to all subsequent shoulder arthroplasty systems. After more than 20 years of follow-up of these reverse prostheses, glenoid loosening and impingement of the humeral cup on the scapular neck are still present.

Despite these problems, the Grammont reverse prosthesis is, today, the main available surgical option in severe shoulder pathologies where the rotator cuff and proximal humerus are destroyed or absent and have become an essential part of shoulder prosthetic surgery.

Actually, many designs of reverse shoulder prosthesis have been introduced on the market, all based on the innovative Grammont concepts.

Other studies will be necessary to improve and develop new designs of reverse shoulder prosthesis to minimize the complications associated to these prostheses.

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