Evolution of the Reverse Total Shoulder Prosthesis

Reza Jazayeri, M.D., and Young W. Kwon, M.D., Ph.D.

Abstract
Over the last decade, reverse total shoulder arthroplasty has gained significant popularity due to its ability to address difficult reconstructive shoulder problems that could not be adequately treated in the past. The concept of the reverse shoulder prosthesis was introduced in the 1970s, but the initial attempts were associated with high complication and implant failure rates. The pioneering work of Paul Grammont (shifting the center of rotation medially and distally) and the development of the DELTA prosthesis have been fundamental to all subsequent reverse shoulder arthroplasty systems. These semiconstrained prostheses utilize the deltoid to improve function and stability of the shoulder joint by coupling a convex glenoid with a concave humeral component. Modern generations of reverse shoulder prosthesis continue to evolve on the fundamentals of Grammont. Though results of these new prosthesis demonstrate promising outcomes, many controversies and challenges continue to be refined. An historical review of the evolution of reverse shoulder arthroplasty is presented, as well as the currently expanding indications for its application.

S houlder arthroplasty has exponentially evolved as a result of improved understanding of anatomy as well as technological advances in implant design. The treatment of degenerative and traumatic shoulder arthritis in the setting of a functional rotator cuff has been well addressed with the use of an anatomical, non-constrained total shoulder arthroplasty. The introduction of such implants by Charles Neer was a milestone in shoulder arthroplasty; however, solutions to the problem of damaged or absent periarticular structures remained unanswered.7 Subsequently, semi-constrained or constrained implants were attempted in both anatomical and reverse forms, but all early prostheses were unsuccessful, with excessive constraint leading to unacceptable rates of loosening and poor functional results.2,3

In 1985, Paul Grammont introduced a reverse-design prosthesis that replaced the traditional glenoid socket with a “glenosphere” component fixed to the scapular neck. This unique design shifted the center of the glenohumeral rotation medially within the bone of the glenoid. This medialization of the center of rotation in a reverse shoulder prostheses was a key step in overcoming implant loosening, which was the main cause of failure in previous designs. The pioneering work of Paul Grammont and the development of his prosthesis have been fundamental to all subsequent reverse shoulder arthroplasty systems. Since 1985, there have been numerous modifications of the reverse shoulder prosthesis and currently many designs are available that demonstrate good to excellent clinical outcomes. A historical review of the evolution of reverse shoulder arthroplasty is presented, as well as its currently expanding indications.

Historical Review
Dr. Jules Émile Péan was the first to perform a total shoulder replacement, in 1893, for the treatment of tuberculosis at the Hôpital International in Paris.4 This constrained prosthesis was originally inspired by Dr. Themistocles Gluck, a Ro-
manian surgeon in 1890. The humeral stem was made of platinum and leather articulating with a rubber head coated with paraffin. Initial functional results were satisfactory. However, the prosthesis ultimately needed to be removed secondary to recurrent TB abscess.4,5 It was not until the 1950s when Dr. Charles Neer pioneered the first simple, non-constrained humeral prosthesis for the treatment of a humeral head fracture (Neer I). This single-unit prosthesis, which replicated the proximal humerus anatomy, was made of vitallium.6

Modern day total shoulder arthroplasty began, in 1970, with the Neer-II prosthesis (Fig. 1).7 This unconstrained implant required a functional rotator cuff to restore shoulder motion. Though good results were reported in the treatment of conventional shoulder osteoarthritis, these implants had higher failure rates in the cuff-deficient arthritic shoulder. As indications for shoulder arthroplasty widened, Neer considered new designs to address arthritic shoulders with an insufficient rotator cuff. Rotator cuff tear arthropathy, as it was termed by Neer, was characterized by a massive rotator cuff tear with superior humeral head migration and diminished acromiohumeral distance with “femoralization” of the tuberosities and “acetabularization” of the acromion.8

The Reverse Total Shoulder Prosthesis

Early attempts of hemiarthroplasty or bipolar arthroplasty to treat cases of rotator cuff tear arthropathy were unable to consistently alleviate pain and restore function.2 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 weightbearing joints.9,13 Inspired by the success of total hip arthroplasty, several subsequent shoulder implant designs attempted to increase the conformity and constraint of the prosthesis.8 Neer’s first of three reversed glenohumeral articulations Mark I (Fig. 2) included a large anatomical glenoid implant used to stabilize the prosthesis and prevent proximal humeral migration. Such large glenoids, however, presented difficulties in cases with inadequate bone stock and also did not allow reattachment of the rotator cuff. Lack


of a rotator cuff function then led to proximal migration of the prosthesis with eventual superior impingement, glenoid loosening, and poor functional outcomes. The Mark II reverse prosthesis was designed with a smaller “glenosphere” to permit rotator cuff reconstruction. Unfortunately, the smaller radius of curvature limited motion and created over-constraint of the prosthesis. The Mark II and similar implants, including the English MacNab and the DANA shoulder prosthesis, were quickly abandoned, secondary to high rates of loosening of the glenoid component.

The Mark III prosthesis (Fig. 3) was subsequently developed and featured a fixed center of rotation. To limit constraint and to improve range of motion, the new design allowed axial rotation between the humeral stem and the diaphysis. Unfortunately, this prosthesis was also unsuccessful secondary to glenoid loosening. In 1974, Neer abandoned his designs, concluding that constraint alone cannot adequately compensate for a non-functional rotator cuff.

Between 1972 and 1978, over half-a-dozen reverse prosthesis designs attempted various glenosphere modifications and fixation configurations. However, these designs all resulted in catastrophic failure of the glenoid implant. A common design flaw in these prosthesis was glenoid fixation that extended into a laterally projecting neck, which then extended into a lateralized, spherical glenoid component. This placed a significant amount of torque at the scapular fixation site, ultimately leading to loosening and failure.

Grammont Reverse Shoulder Prosthesis
In 1985, Paul Grammont revolutionized shoulder arthroplasty with his concept of medialization and lowering of the center of glenohumeral rotation. The goals of his DELTA (DePuy, Warsaw, Indiana) reverse total shoulder arthroplasty (TSA) prosthesis were to use a semiconstrained ball-and-socket implant to 1. improve stability, 2. compensate for an absent rotator cuff, and 3. decrease the risk of mechanical failure of the glenoid component by medializing the center of rotation of the joint. Grammont’s reverse TSA prosthesis eliminated the neck of the glenoid component and medialized the center of rotation within the glenoid surface. Therefore, forces acting on the neckless prosthesis could pass through the fixed center of rotation and transform the previously shearing torque into compressive forces at the glenoid-bone interface (Fig. 4). In addition, the DELTA (emphasizing deltoid) prosthesis was powered primarily by the deltoid muscle without dependence on a functional rotator cuff. As the center of rotation is medialized and lowered, the deltoid lever arm is increased, its resting tone is higher, and more deltoid muscle fibers are recruited for abduction of the arm.
The first prototype of the Grammont reverse TSA was composed of a cemented glenosphere and an inverted polyethylene humeral stem (Fig. 5). In 1987, the results of this prototype were published in a series of eight patients. All patients were pain free at follow up, but with variable function. The majority of patients had active anterior elevation of 100° to 130°, but three patients demonstrated less than 60° of elevation. These inferior results led to further modifications of the DELTA prosthesis, evolving to the current design.

The DELTA reverse TSA was placed on the market in 1991. Its original design was a monobloc humeral component with a standard cup. The glenoid components included a circular glenoid base-plate with a central peg for press-fit impaction, reinforced with two divergent screws. The glenosphere was then directly screwed onto the peripheral edge of the plate. This design of peripheral fixation proved to be unsuccessful due to early loosening and led to a second generation with a Morse Taper mechanism. In 1994, a third generation design included a diaphyseal stem that was screwed onto a modular metaphyseo-epiphyseal block. Despite these improvements, insufficient size of the polyethylene cup led to medial impingement and rapid deterioration.

Currently, the Delta III prosthesis (DePuy International Limited, Leeds, England) (Fig. 6) has the longest reported outcomes of any reverse shoulder prosthesis. This prosthesis has become a key tool in the armamentarium of shoulder surgeons because it provides a solution to clinical scenarios where few options existed previously. By replacing both sides of the joint, it offers more reliable pain relief compared to hemiarthroplasty. Multiple series of patients with cuff tear arthropathy have demonstrated substantial improvements in Constant scores, average active elevation greater than 110 degrees and good long-term stability. Furthermore, a faster recovery may be achieved as the rotator cuff does need not be protected during the early postoperative period.

Complications of Grammont Reverse TSA

The main complications of reverse total shoulder arthroplasty have included infection, dislocation, intraoperative fractures, brachial plexopathy, acromial stress fractures, glenoid notching, and mechanical failure. 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. Although intraoperative glenoid complications are uncommon, glenoid loosening has been observed in up to 4.1% of Grammont reverse prostheses.
The shift to a medialized center of rotation with a reverse TSA prosthesis is not without its consequences. Scapular notching is a result of contact that occurs in adduction between the medial aspect of the humeral component and the inferior aspect of the glenoid. This repetitive contact can lead to bone loss under the inferior aspect of the glenoid with incidence of up to 50% to 96% reported. The long-term consequences of glenoid notching are unclear, but accelerated polyethylene wear and progressive bone loss are theoretically possible.

Proper deltoid tensioning can be another source of complications, with inadequate tension leading to instability in up to 3.4% of primary cases and high tension leading to fracture of the acromion. Another possible disadvantage of a medial center of rotation may be insufficient tensioning of the posterior external rotators. This may translate into less active motion and more weakness in external rotation.

Modern Reverse Designs

As a result of these experiences, several updated designs of the reverse TSA have been developed and are currently available. Following the recent work of Nyffeler and colleagues, it is now recommended to place the glenoid component at the inferior edge of the native glenoid surface to decrease the incidence of scapula notching. Simovitch and colleagues validated the importance of inferior positioning of the glenosphere in clinical practice and provided rational for designs that place their glenospheres with a small amount of inferior tilt or offset.

The RSP prosthesis (DJO Surgical, Encore Medical, LP, Austin, Texas) places the glenosphere less medial than the DELTA III and the center of rotation closer to its anatomical location. Frankle and colleagues reported their results of 60 shoulders with a minimum two-year follow-up and found significant improvements in pain and function, with a mean active elevation of 105°. However, their complication rate was 17%, with a 12% rate of revision for implant failure. As a result, the RSP was redesigned with improved screw fixation of the glenoid baseplate. Reported outcomes of the second generation in 96 shoulders demonstrated no cases of mechanical failure or notching, with similar improvements in pain and function.

Other innovations in recent designs include various baseplate modifications, altered humeral neck shaft angles, and increased modularity. Biomechanical studies performed by Frankle and colleagues concluded that a concave glenoid baseplate was superior to a flat one. Baseplate fixation methods, including variable angle locking screws and osseo-integrated baseplates, have been developed to improve long-term glenoid fixation. Modular humeral components with wedges and polyethylene cups of varying thickness are also now available to improve the ability to obtain correct deltoid tension.

Expanding Indications

Rotator cuff tear arthropathy is currently the primary indication for a reverse TSA, as this group has demonstrated predictable outcomes. The ideal indication is an older patient with decreased functional demand and preoperative active elevation under 90° with intact deltoid. As surgeons have gained more experience, indications have been expanded to include revision arthroplasty, inflammatory arthropathy with a massive rotator cuff tear, painful and irreparable rotator cuff tears, proximal humeral nonunion or malunion, acute fractures, tumor, and chronic pseudoaplasia without arthritis. At this stage, long-term outcome data on using the reverse TSA for such indications are still lacking.

Conclusion and Summary

The concept of the reverse shoulder prosthesis was introduced in the 1970s, but the initial trials were unsuccessful. The pioneering work of Grammont, in 1985, and the development of the DELTA III prosthesis have been fundamental to all subsequent reverse shoulder arthroplasty systems. Reverse shoulder arthroplasty has emerged as the standard treatment for patients with rotator cuff tear arthropathy, and its use is expanding to include other difficult shoulder problems. However, its application must be tempered by appropriate patient selection in order to minimize the potential for associated complications.

Disclosure Statement

None of the authors have a financial or proprietary interest in the subject matter or materials discussed, including, but not limited to, employment, consultancies, stock ownership, honoraria, and paid expert testimony.

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