Reverse shoulder arthroplasty: is reverse the way forward?

INTRODUCTION

Reverse polarity total shoulder arthroplasty is an innovation primarily designed to treat the rotator cuff-deficient shoulder by increasing constraint and thereby addressing the challenges of pseudoparalysis. Forward elevation can be regained, pain and quality of life can be improved. Recently, there has been an expansion in both the breadth of indications and the volume of surgeries performed. We aim to review current practice and direction of travel.

WHY A 'REVERSE' PROSTHESIS?

The impact of rotator cuff tear arthropathy (CTA) is often significant and disabling. This condition is associated with painful arthrosis of the shoulder in conjunction with instability, which allows the humeral head to escape antero-superiorly. The resulting loss of function in the shoulder is aptly described as 'pseudoparalysis'. Figure 1 shows the normal deltoid function around a shoulder with an intact soft-tissue envelope, and the superior migration that results when the superiorly directed force vector is not neutralised. Conventional anatomical arthroplasty of the shoulder fails to restore function in these patients due to the inadequate stability of the joint around a central point of pivot, combined with an inability of the surrounding muscles to compensate for a weak or torn rotator cuff.

This combination results in a complex and disabling condition that has vexed shoulder surgeons since the early days of development in shoulder arthroplasty systems. A better understanding of shoulder biomechanics and the mechanisms of failure in total shoulder arthroplasty led to the development of reverse shoulder arthroplasty (RSA) designs. While the original indication was CTA, there has been a rapid expansion of indications to include a spectrum of pathologies: proximal humeral fractures and trauma sequelae; massive cuff tears; tumours; primary glenohumeral osteoarthritis (OA); and the revision of failed shoulder arthroplasties.

DEVELOPMENT OF THE REVERSE POLARITY PROSTHESIS

Themistocles Gluck most likely developed a shoulder arthroplasty in the 1800s but did not publish an operation in humans.[1] The first shoulder

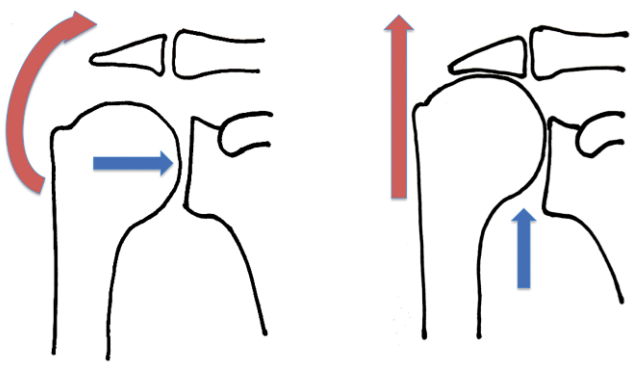

Fig. 1 Proximal migration in cuff tear arthropathy with resulting deltoid dysfunction- schematic



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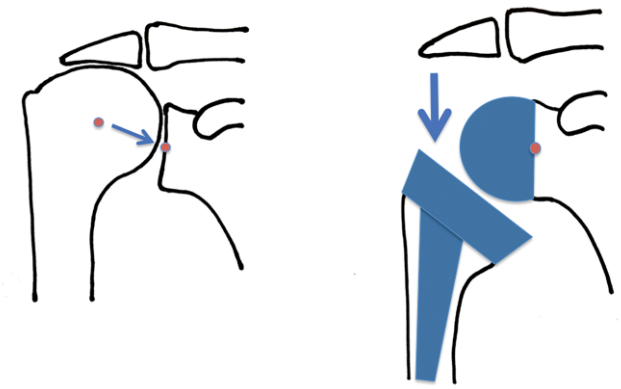

Fig. 2 Medialisation of centre of rotation in reverse shoulder arthroplasty- schematic

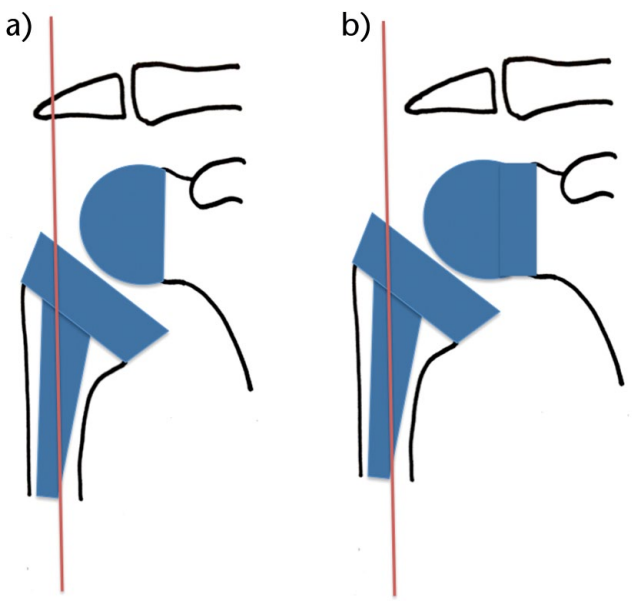

Fig. 3a and 3b Medialised and lateralised designs – schematic

arthroplasty is attributed to Jules Emile Péan in 1893[2] who implanted a platinum and rubber replacement in a shoulder resected for tuberculosis. The early pioneers of modern shoulder arthroplasty including Neer initially employed a humeral hemiarthroplasty. Results were good in terms of pain relief, but Neer identified his results were poorer in terms of strength and range of motion in those with irreparable rotator cuff tears.[3] Failure of the absent cuff to centre the humeral head on the glenoid resulted in defunctioning of the prime movers and greater implant stresses.[4] Superior humeral head migration in these patients was noted by Marmor who proposed adding a glenoid component in a conventional anatomic design to improve constraint and stability.[5] Neer's solution for failure due to instability was to design his Mark I large-head reverse prosthesis, believing that this would preclude the need for a functioning rotator cuff. His design evolutions struggled to maintain a balance of stability and range of motion; the Mark III prosthesis allowed axial rotation of the humeral stem but a high failure rate led to abandonment. Other groups developed reverse polarity shoulders in the 1970s and 1980s, including the Leeds shoulder group,[6] Kessel shoulder group,[7] Bayley-Walker[8] and the Liverpool shoulder group. These early attempts with either conventional anatomic or reverse designs led to high failure rates and poor functional results with loosening of the glenoid component seen due to high implant stresses.

Paul Grammont developed a concept in reverse polarity prostheses which varied from previous designs by focusing on four features:

1. The prosthesis must be inherently stable;
2. The weightbearing surface must be convex and the supported part concave;
3. The centre of rotation must be at or within the glenoid neck; and
4. The centre of rotation must be distalised and medialised.[9]

The movement of the centre of rotation both increases the lever arm of the deltoid and facilitates its function (Fig. 2), with the added advantage of reducing the shearing forces at the glenosphere-bone interface that were responsible for premature failure. While his original system has undergone changes in design, the original principles adopted by Grammont largely underpin all of the present day models of RSA.

CURRENT DESIGN: FEATURES AND BIOMECHANICS

The essential components of current reverse prostheses include a glenoid baseplate fixed to the bony glenoid with a mounted hemisphere called the 'glenosphere', and on the humeral side a stem and a tray with polyethylene insert in a modular fashion. These designs utilise the Grammont principles but it is increasingly recognised that the differing features have particular advantages and disadvantages.[10] Each system may permit positioning of the centre of rotation in the medial or lateral direction (Figs 3a and 3b). Medialised designs decrease baseplate loosening but increase scapular notching, while lateralised designs improve range of motion and

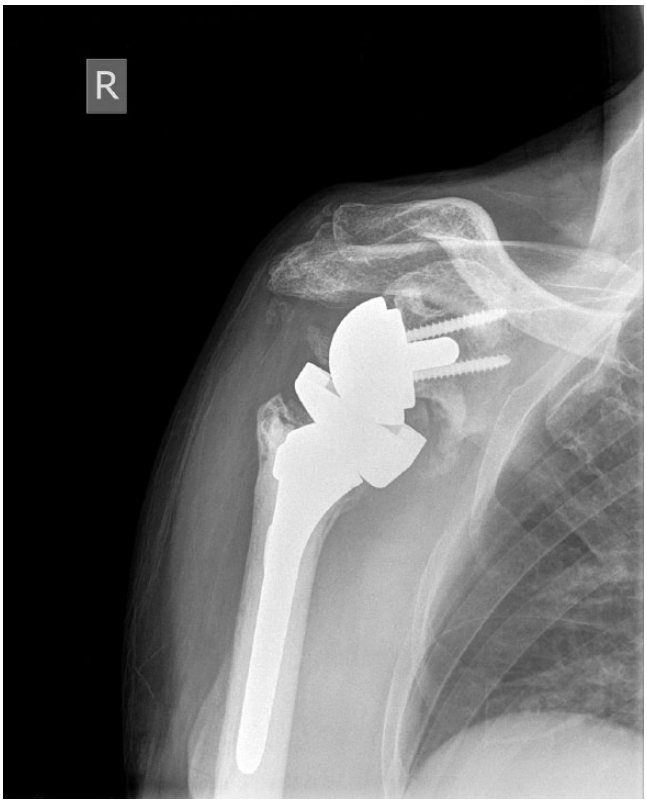

Fig. 4 Glenoid neck notching

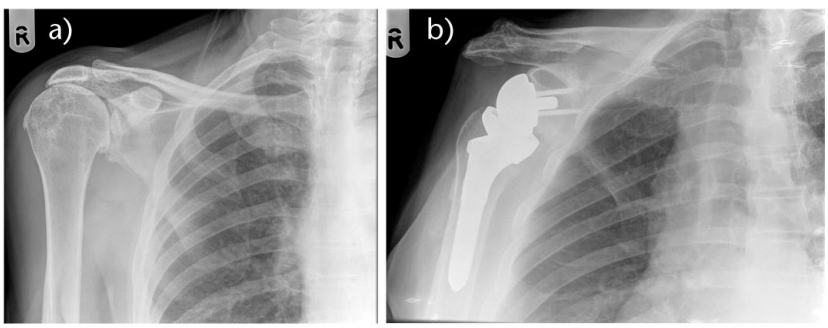

Fig. 5a and 5b Reverse prosthesis for cuff tear arthropathy

Table 1. Top five prostheses in UK Natioanl Joint Registry by frequency of use (13th Annual Report).

Prosthesis	Number in registry
Delta XTEND (DePuy Synthes)	2038
Comprehensive Reverse (Zimmer Biomet)	761
Equinoxe (Exactech)	715
Aequalis (Wright Medical)	659
Lima SMR (Lima Orthopaedics)	545

reduce notching at the expense of increased baseplate stresses and potential failure. Caudal placement of the glenoid baseplate increases range of motion and decreases notching while superior placement and tilt are linked with prosthetic failure. A phenomenon has been identified whereby there is scalloping or notching of the inferior neck of the glenoid. This seems most likely to occur due to impingement of the humeral prosthesis although some surgeons believe polyethylene wear is a significant contributing factor (Fig. 4). There is contrasting evidence regarding the significance of glenoid notching; some studies report a detrimental effect on outcomes while others do not.[11-14] Indeed many shoulder surgeons now accept notching as a routine phenomenon; and the author's own data shows that in the short to medium term scapular notching does not automatically equate to poor clinical outcomes.[15] However, the long term outcomes for this group are obviously unknown and we intend to follow them closely.

Glenoid fixation types have evolved significantly as the generations of prosthesis have developed due to the challenge of resisting the variety of forces placed on the glenosphere-bone interface. Most systems employ a central peg with peripheral screws. Divergent screws, acrylic cement and coatings, including hydroxyapatite and trabecular metal, have all been utilised in current designs to resist better the high torque and shear forces seen at the bone-prosthesis interface. Increased offset-reverse shoulder arthroplasty using bone graft discs (BIO-RSA) has been developed as a concept to lateralise the centre of rotation by augmenting the glenoid while keeping the centre of rotation at the bone-implant interface.[16] This also tensions the cuff without providing a mechanical disadvantage. Modular or platform systems have been introduced that allow for the humeral stem to be retained during revision surgery. This has reduced complications of revision surgery including humeral periprosthetic fracture. Stemless designs have become increasingly popular in the anatomic shoulder arthroplasty market, and some systems are available in a reverse configuration. They allow for the preservation of humeral bone stock, however, studies of their outcomes to date have relatively short follow-ups, and short-term results would suggest that the geometry is acceptable but there is yet to be any meaningful long-term follow-up for these designs.[17]

Augmented glenoid implants to accommodate bone defects and computer navigation to improve the accuracy of positioning of prostheses are now available for use, especially in severe deformity. Screw and glenoid baseplate position is important in RSA to control stability, offset and humeral lengthening, all of which affect stresses at the implant-bone interface. Clinical and cadaveric studies of navigated techniques show improved anatomical implantation accuracy but improved outcomes and reduced complications

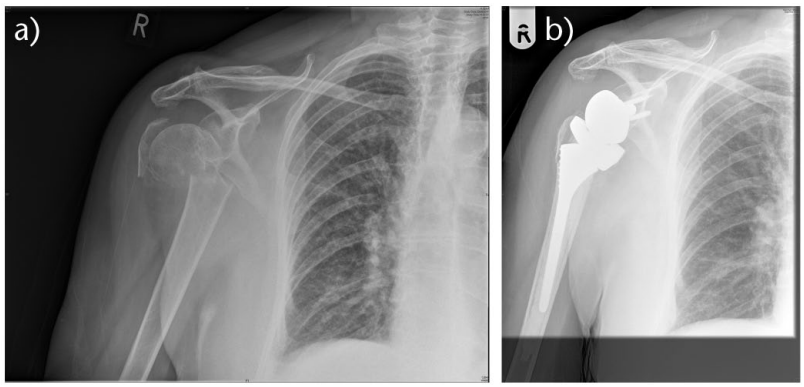

Fig. 6a and 6b Reverse prosthesis for elderly osteoporotic proximal humeral fracture

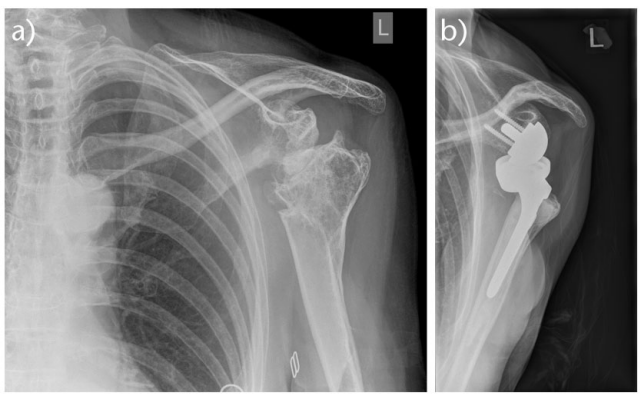

Fig. 7a and 7b Reverse prosthesis for proximal humeral fracture malunion

are not clear, with current studies failing to show a tangible advantage, and long-term analysis is required.[18] As the technology advances, 3D printing may permit and increase the use of true custom prostheses and patient-specific guides, as are evolving in lower limb arthroplasty.

INDICATIONS

Cuff tear arthropathy is a well established indication for RSA, with good results in terms of survivorship and functional outcomes (Figs 5a and 5b).[19] Improved understanding of the prosthetic concept and advances in design have led to an expansion in indications. The threshold for considering RSA has been progressively lowered in elderly patients who may have an intact cuff on ultrasound or MRI but their attenuated cuff tissue is likely to fail early after an anatomic total shoulder arthroplasty. The consequent proximal migration of the prosthetic humeral head places undue stress on the glenoid implant and is referred to as the 'rocking-horse phenomenon'.[20] RSA is also increasingly being considered to be suitable as a primary option in other conditions associated with premature cuff failure such as rheumatoid arthritis and other inflammatory arthropathies.

Massive cuff tears can obviously precede the development of glenohumeral arthrosis; in such cases of pseudoparalysis where the cuff is irreparable, there is increasing evidence of satisfactory outcomes of RSA to treat the functional limitations, although the outcomes are less reliable than in other indications.[21,22]

It is now increasingly accepted that RSA may be used for irreparable acute fractures with tuberosity comminution or those where the humeral head is non-viable,[23] especially in the elderly where this may indeed be more cost effective (Figs 6a and 6b).[24] These have traditionally been treated by hemiarthroplasty following Neer's work in the 1970s.[24] However, the results of hemiarthroplasty are generally considered to be unreliable and a number of factors contribute to this, not least the need for accurate repositioning and healing of the tuberosities to restore function.[26] This requirement for accurate tuberosity restoration seems of lesser importance in RSA where comparative case series suggest that superior outcomes can be obtained.[27] Proximal humeral fracture malunion can also result in unbalanced forces at the glenohumeral joint, compromising potential outcomes of hemiarthroplasty and anatomic total arthroplasty while RSA can be a successful alternative in these cases (Figs 7a and 7b).[28]

RSA has also been advocated for use in shoulders where the rotator cuff is intact but there is severe glenoid bone loss. These glenoids, classified by Walch[29] as type B2 or B3, result in chronic posterior subluxation of the humeral head and would usually be treated by bone grafting and anatomic total arthroplasty. A reverse prosthesis has shown better outcomes in this difficult group by countering troublesome instability.[30]

RSA is increasingly used as the option of choice in the revision of primary hemiarthroplasty or anatomic total prostheses, especially those compounded by bone loss or cuff failure. They can also be of use in reconstruction scenarios following tumour resection.

CONTRAINDICATIONS

Appropriate patient selection is required to obtain optimal results from RSA. Active infection precludes the use of this system as with any other joint arthroplasty, but some of the other contraindications are comparatively more subtle. Deltoid function is critical to success and must be verified in all portions of the muscle. Glenoid baseplate fixation may be compromised by bone loss, which should be identified by pre-operative CT scans for appropriate planning. No lower age limit has been identified outwith the paediatric population but RSA should be used with caution in patients under 65 years of age as the long-term outcomes are uncertain.

The use of RSA where previously a hemiarthroplasty would have been performed is a current subject of discussion. It is important to consider that successive surgeries may reduce glenoid bone stock and hence limit future options. Furthermore, the results of RSA after hemiarthroplasty are thought to be worse than for performing a primary RSA. This is clearly an area in which more work is required and, to a certain extent, longer-term results are needed before a consensus of opinion will emerge.

PATIENT ASSESSMENT AND EXPECTATIONS

As for any intervention, patients must be carefully worked up and counselled about their procedure. This is not dissimilar to any other large joint arthroplasty, and full assessment of the

axillary nerve and deltoid function is mandatory, especially in revision scenarios; any suspicion of dysfunction requires electromyographic examination. While RSA is able to compensate for massive supraspinatus tears, it is not good at restoring external rotation; patients should be counselled to expect this. The natural imbalance between internal and external rotators of the shoulder means that massive tears extending into the infraspinatus and teres minor cannot be compensated for and may require addition of a latissimus dorsi transfer in order to restore external rotation.

The question, "What is a successful outcome in RSA?" is not as easy to answer as it sounds. Overall patient satisfaction with RSA often does not correlate with other outcome measures, even patient-reported ones.[31] Previously high functioning patients suffering trauma may expect their original movement to return but this may not be possible to achieve. Careful counselling is therefore critical.

CURRENT PRACTICE

The UK National Joint Registry (NJR) shows a year-on-year increase in the number of primary RSAs performed, with 798 in 2012 and 2366 in 2015. Equally, the proportion of all primary shoulder arthroplasties which were RSAs increased in the same manner from 31.6% to 45.3%.[32] From the period 2012 to 2015, 1120 out of a total of 6753 RSAs were performed for trauma or trauma sequelae. For acute trauma indications, the median age of patients was 77 years (interquartile range (IQR) 72 to 81, range 51 to 99). For elective indications, the median was 76 years (IQR 70 to 80, range 22 to 96). The remarkable similarity in the medians suggests that the majority of cases are in the 70-to-80 age group for both indications, however, clearly in the elective setting some surgeons are pushing the age ranges although RSA in younger patients remains an indication of great uncertainty. Due to the recent rapid evolution of shoulder arthroplasty design, the NJR is currently unable to examine the effect of different prostheses on outcomes. Equally, there are currently only three years of outcome data showing that 2% of these prostheses have been revised. The first Orthopaedic Data Evaluation Panel (ODEP) data submissions review for shoulder arthroplasties was due to take place in April 2017. Elsewhere, the New Zealand Arthroplasty Registry shows a 93% RSA survivorship at 13 years.[33] Data from the USA show that in 2011 RSA accounted for one third of all shoulder arthroplasties, with one quarter being performed for proximal humeral fractures.[34]

COMPLICATIONS

Complication rates for reverse arthroplasty are decreasing over time, with a recent review showing a fall from 14.7% to 11% between 2006 and 2015.[35] The most common complications suffered by patients post-operatively are instability, periprosthetic fracture, infection, component loosening, neural injury, acromial stress fractures and/or scapular spine fracture, haematoma, deltoid injury, rotator cuff tear and venous thromboembolism.[35]

Instability is the most common complication, usually occurring in the so-called 'at risk position' of adduction, extension and internal rotation, resulting in an anterosuperior dislocation. Risk factors for instability are known to include suboptimal deltoid tension through incorrect technique, deltoid dysfunction from rupture or nerve injury, mechanical impingement and glenosphere size. As with all complications, poor technique can be a contributing factor, and retention of soft tissues, superior glenoid baseplate tilt, or glenoid medialisation, are all associated with dislocations. Glenospheres of increased diameter generally confer increased range of motion prior to impingement.[35]

Glenoid implant loosening has been associated with a superolateral surgical approach, improper technique (including Morse taper complications), superior glenosphere tilt, age < 70 years and female gender.[36,37] Scapular notching is associated with glenosphere failure but has not been shown to be an independent risk factor.[14,35] Humeral implant loosening, however, really isn't much of an issue, with reported rates of only 0.2%.

Infection in RSA has been associated with haematoma formation and the increased dead space compared with anatomic arthroplasty, increased patient age and patients with a previous history of shoulder surgery.[37,38]

Neural injury is more common with RSA than it is with anatomic prostheses, with some studies estimating this as a ten-fold increased risk.[39] This is commonly due to the humeral lengthening, but the threshold of lengthening which precipitates injury is unclear. Moreover, most plexus and nerve palsies are transient.[39,40]

Patient factors are an important predictor of complications, with studies showing an increased length of hospital stay and risk of both surgical complications and prosthetic failure, in terms of dislocation and loosening, in patients with an ASA grade greater than 2.[41]

The learning curve in shoulder arthroplasty has not been studied and the procedure is performed in relatively low volumes. The median number of shoulder arthroplasties per surgeon in the NJR is 13 (IQR 2 to 41) over a four-year period.[32]

As with other large joint arthroplasty, deep infection is a serious complication. Due to their affinity for the skin of the back and axillae, Propionibacterium are often implicated. These are gram-positive rod commensals which inhabit the oily pilosebaceous glands; they are often identified on deep-tissue culture from patients having revision for pain, stiffness or loosening.[42] Their clinical course is often indolent and a variety of virulence factors mean that different strains may behave very differently. Moreover, their location deep within the glands and the relative inefficacy of prophylactic antibiotics means that other prophylactic measures such as meticulous tissue handling and avoiding contact between implant and dermis are recommended.[42]

REVERSE SHOULDER ARTHROPLASTY: A HAMMER FOR ALL NAILS?

With the expansion in indications for RSA and the increasing prevalence of its use, should we be concerned? Rarely in orthopaedics is a wholesale increase in indications seen retrospectively as a wise manoeuvre. A number of issues remain to be resolved which long-term follow-up will either support or refute. One of the major issues that needs resolving is the downward pressure on the age of patients in which RSA is indicated. These higher-demand patients may expect better functional outcomes and greater longevity. In the salvage of trauma in particular, these expectations may not be met, as a good functional outcome in the surgeon's opinion may not match the patient's expectations. The follow-up of RSA case series is naturally short at present, but emerging results suggest compromised function in the medium to long term, possibly due to issues such as 'deltoid fatigue', and caution should be exercised in younger patients.[19,43] The revision rate is also not insignificant in patients under 65 years, with a recent study demonstrating 88% implant survivorship at ten years[44] while others have reported this to be as low as 58%.[45] RSA is widely considered to be a salvage procedure for other failed arthroplasties, but it should be remembered that the current salvage options

for failed RSA remain scarce and more or less limited to a large head hemiarthroplasty.

RSA is currently riding a wave of popularity with shoulder surgeons; increasing use has surpassed that of anatomic arthroplasty following evidence-based recognition among clinicians in the ability of this system to improve quality of life for patients in a range of pathologies. Long-term performance will confirm the success, or otherwise, of this strategy.

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