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An update on reverse total shoulder arthroplasty: current indications, new designs, same old problems

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- Reverse total shoulder arthroplasty (RTSA) was originally developed because of unsatisfactory results with anatomic shoulder arthroplasty options for the majority of degenerative shoulder conditions and fractures.
- After initial concerns about RTSA longevity, indications were extended to primary osteoarthritis with glenoid deficiency, massive cuff tears in younger patients, fracture, tumour and failed anatomic total shoulder replacement.
- Traditional RTSA by Grammont has undergone a number of iterations such as glenoid lateralization, reduced neck-shaft angle, modular, stemless components and onlay systems.
- The incidence of complications such as dislocation, notching and acromial fractures has also evolved.
- Computer navigation, 3D planning and patient-specific implantation have been in use for several years and mixed-reality guided implantation is currently being trialled.
- Controversies in RTSA include lateralization, stemless humeral components, subscapularis repair and treatment of acromial fractures.

Keywords: acromion fracture; arthroplasty; design; indications; reverse; shoulder; subscapularis repair

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Introduction

The reverse total shoulder arthroplasty (RTSA) was developed in the 1980s as a treatment for rotator cuff tear arthropathy in the elderly.[1] It has demonstrated excellent clinical outcomes and thus has become well-established as the treatment of choice for cuff tear arthropathy. National joint registries have reported 10-year survivorship for the diagnosis of rotator cuff arthropathy of 94.1%.[2] Increasing surgeon experience with the reverse prosthesis has seen a decrease in complications and a change in the indications for surgery.[3] An early expanded indication was primary osteoarthritis with loss of rotator cuff function.[4] Massive irreparable rotator cuff tear without osteoarthritis has also been an accepted indication for a number of years, given numerous studies have reported good functional outcomes.[5] Over the last 10 years the indications for RTSA have seen a huge expansion. The Australian National Joint Registry shows the proportion of primary total shoulder arthroplasty (TSA) cases that are reverses increased from 42.2% in 2009 to 77.9% in 2018.[2]

This review looks at some of the more recent evidence for the following indications: posterior glenoid deficiency with intact cuff, fracture, tumour, revision surgery and in the treatment of younger patients. It also looks at some of the evolutions in design from the classic Grammont prosthesis, new technologies for precise implantation, and some of the controversies including treatment of acromion fractures and repair of subscapularis.

Indications

Posterior glenoid deficiency/wear

There has been an increasing trend towards the use of RTSA in patients with osteoarthritis and an intact rotator cuff, in the presence of posterior glenoid wear and/or humeral head subluxation. Traditionally, posterior glenoid wear has been managed with anatomic TSA and asymmetric reaming, with posterior bone graft or a posteriorly augmented glenoid for larger corrections.[6] Walch et al, however, reported high rates of glenoid loosening following anatomic TSA in a series of 92 patients with biconcave glenoids and primary osteoarthritis.[7] At a mean follow-up of 77 months, glenoid loosening was observed in 20.6%, with a revision rate of 16.3%.

In anatomic TSA in the setting of posterior glenoid deficiency, it is likely the recurrence of humeral head subluxation that leads to early polyethylene wear and glenoid component loosening.[8] This high rate of complications with anatomic TSA has resulted in surgeons considering the use of RTSA. The reverse's semi-constrained design corrects the posterior head subluxation.

Mizuno et al reported excellent clinical outcomes in a series of 27 patients with primary osteoarthritis and biconcave glenoids treated with RTSA, with only one failure at a mean follow-up of 54 months.[9] A retrospective review of 49 shoulders with primary osteoarthritis treated with RTSA similarly demonstrated satisfactory clinical outcomes, with only two failures (both due to infection, 4%), at a mean 7.7 years follow-up.[10] Preoperative glenoid morphology had no influence on outcomes.

McFarland et al also reported on 42 consecutive RTSAs, implanted without bone-grafting using asymmetric reaming, to treat glenohumeral arthritis with severe glenoid bone loss (19 type A2, five B2, and 18 C glenoids) in cuff-intact shoulders.[11] They demonstrated satisfactory clinical function with only one failure (due to baseplate loosening, 2%) at a mean of three years post surgery. Virk et al used posteriorly augmented glenoids for 67 RTSAs in patients with osteoarthritis and posterior glenoid wear (Walch B2, B3, or C glenoid).[12] At a mean follow-up of 40 months (+/- 15.4 months), patients demonstrated satisfactory clinical outcomes with low complications (4.5%) and no aseptic loosening of the baseplate.

Glenoid bone loss resulting in a biconcave (B2) or severely retroverted and dysplastic (C) glenoid should be considerations for use of RTSA.

Fracture

RTSA is an option for treatment of three- and four-part proximal humeral fractures in elderly patients. Poor results following hemiarthroplasty for proximal humeral fractures are well documented and often relate to tuberosity migration with malunion or nonunion.[13,14] A number of recent studies have demonstrated improved clinical outcomes with RTSA compared to hemiarthroplasty.

Meta-analyses comparing RTSA with hemiarthroplasty for the treatment of proximal humeral fractures have demonstrated improvements in clinical outcome scores,[15–17] forward flexion,[15–18] abduction[16] and tuberosity healing.[16,17] Some studies have shown increased complications with RTSA[18] whilst others have shown decreased complications[17] or no difference.[15] A systematic review including 34 trials with 2165 patients, found that RTSA had the highest Constant score and lowest incidence of complications compared to both hemiarthroplasty and surgical fixation, in the treatment of displaced proximal humeral fractures in adults.[19]

One trial randomized 62 patients over the age of 70 years to either RTSA or hemiarthroplasty.[20] They reported significantly higher mean University of California–Los Angeles (29.1 vs. 21.1) and Constant (56.1 vs. 40.0) scores, forward elevation (120.3° vs. 79.8°), and abduction (112.9° vs. 78.7°) in the RTSA group. Six patients in the hemiarthroplasty group were converted to RTSA because of severe pain and limited function. Interestingly, they still had poor function (Constant score mean, 21.8; range, 8–51) after conversion.

A recent randomized trial compared non-operative treatment with RTSA in 59 patients aged 80 years or older with three- and four-part proximal humerus fractures.[21] They reported no difference in clinical outcomes at 12-months between the two groups. It should be noted that this was a population of low-demand patients with multiple comorbidities. Most surgeons would only operate on a patient aged over 80 years if they were high functioning with an elevated quality of life.

A sensible option is a trial of non-operative management with conversion to RTSA for those in whom non-operative treatment fails. A meta-analysis looked at acute versus delayed RTSA for the treatment of proximal humeral fractures in patients over 65 years.[22] They found no differences in forward flexion, clinical outcome scores or all-cause reoperation between the two groups, suggesting that delaying the surgery does not affect the final outcome. However, a study by Mechlenburg et al investigated 837 shoulder arthroplasties for failed non-operative treatment of proximal humerus fracture and found a high revision rate of 7% for hemiarthroplasty and 11% for RTSA. They also found men receiving RTSA had a higher revision rate than men undergoing hemiarthroplasty (Hazard Ratio 6, 95% Confidence Interval 2–19).[23]

There are some inherent fracture patterns, however, that will lead to undesirable sequelae such as malunion, nonunion, avascular necrosis, chronic locked dislocations and post-traumatic arthritis. Martinez et al reported the results of 44 patients treated with RTSA for the sequelae of proximal humerus fractures.[24] This included 16 valgus-impacted malunions, eight locked dislocations or fracture/dislocations with head collapse/necrosis, 14 surgical neck nonunions and six severe tuberosity malunions. The mean Constant score increased from 28 to 58, average anterior elevation increased from 40° to 100° and 86% (38 of 44 patients) were either very satisfied or satisfied. There was, however, a high prosthetic dislocation rate (13.6%).

Raiss et al similarly found a high dislocation rate (34%) in a study of 32 nonunions of the surgical neck treated with RTSA. They also reported similar improvements in Constant score and shoulder mobility.[25] Increased risk of dislocation was associated with intraoperative resection of the tuberosities,[25] so preservation of the tuberosities

should be performed where possible. The mean age of patients was 68 years, with a range from 48 to 83 years.

These studies suggest that RTSA has good clinical outcomes as a treatment for three- or four-part proximal humeral fractures in an elderly population. Where possible in a younger patient, surgical fixation should be attempted. However, reverse TSA offers a satisfactory option for younger patients who present with the sequelae of fractures. The surgeon should be aware of the higher complication rate, particularly dislocations.

Revision

Numerous studies have reported on outcomes for revision of shoulder arthroplasty to RTSA.[26–31] They report satisfactory functional outcomes, but with complication rates as high as 47%.[29] The surgeon should be cautious when interpreting many of these studies as they often group together heterogenous indications for revision as well as different types of prosthetic revision (e.g. hemiarthroplasty, anatomic, reverse).

The most common reason for revision of anatomic TSA is cuff failure.[32] A recent study by Shields and Wiater reported on outcomes of revision of anatomic TSA to RTSA exclusively for rotator cuff failure or component loosening.[33] They matched 35 revision patients with 70 patients undergoing primary RTSA for cuff tear arthropathy. At a mean 50 months follow-up, pain and American Shoulder and Elbow Surgeons scores were similar (p = NS). The revision group had worse subjective shoulder value scores (63 vs. 79; p = 0.002), satisfaction (74% vs. 90%; p = 0.03), and more complications (31% vs. 13%; p = 0.02). They concluded that although function is comparable, one should expect more complications and lower satisfaction.

Recently, Hernandez et al reported on the results of RTSA revision surgery for instability in 62 anatomic TSAs, 13 hemiarthroplasties and 7 RTSAs.[34] The survivorship free from dislocation at five years was 79%, with the hemiarthroplasty conversion group having the highest risk of instability. They also demonstrated decreased pain, improved functional outcome scores and range of motion following revision surgery. Complication rate was reasonably high, with 12 (18%) shoulders requiring repeat revision surgery.

Melis et al reported on 37 consecutive anatomical TSA revised to RTSA for aseptic glenoid loosening/failure.[35] Glenoid bone grafting was performed in 29 cases (78%). The mean Constant score increased from 24 to 55 and active anterior elevation from 68° to 121°. A postoperative complication occurred after revision in 11 patients (30%). Eight patients (21%) needed a subsequent reoperation because of glenoid loosening (n = 3), prosthetic anterior instability (n = 3), and humeral subsidence (n = 2). Wagner et al noted a significantly higher rate of revision in RTSAs with concomitant bone grafting compared to those that did not require bone grafting (24% vs. 7% five-year revision rate) in a series of 143 revision RTSAs.[26]

Many shoulder arthroplasty systems now use a modular humeral stem that can be converted from a hemiarthroplasty or anatomic shoulder replacement to a reverse-compatible stem. Crosby et al, in a multicentre, retrospective analysis of 102 consecutive shoulder revisions, compared 73 shoulders that required exchange of the humeral stem with 29 that had retention of a convertible-platform humeral component.[36] Patients with retention had significantly shorter operative time (mean and standard deviation, 130 ± 48 versus 195 ± 58 minutes) and lower estimated blood loss (292 ± 118 versus 492 ± 334 mL). The rate of intraoperative complications was significantly lower in the retention group (0% versus 15%). Patients with retention also had improved postoperative range of motion (active external rotation, 26° ± 23° versus 11° ± 23° [p = 0.006]; active forward elevation, 112° ± 37° versus 96° ± 33° [p = 0.055]).

These studies demonstrate that RTSA is a good option for the majority of shoulder arthroplasty revisions.

Tumour

Resection of the proximal humerus in the treatment of sarcomas or other neoplasms often includes the tuberosities and rotator cuff to achieve appropriate margins. RTSA is now an option for reconstruction that has demonstrated satisfactory functional outcomes. Some studies have demonstrated equivalent functional outcomes of RTSA for other indications.[37]

Grosel et al reported no early complications in 13 patients who underwent reconstruction with a reverse shoulder megaprosthesis.[38] They recommend RTSA in patients with a life expectancy greater than six months, with good preoperative shoulder function and where preservation of the axillary nerve is planned. Maclean et al reported no revisions or complications at a mean follow-up of 49 months in eight patients who underwent RTSA following oncologic resection.[39] Functional outcomes were not great (mean abduction 62°, Musculoskeletal Tumor Society (MTS) score 60%). De Wilde et al showed excellent functional outcomes (Constant score 76, mean abduction 157°) in 14 patients who underwent RTSA following oncologic resection at a mean 7.7 years follow-up.[37] Three patients (21%) had major complications (two dislocations treated with closed reduction, one infection requiring revision and one aseptic loosening requiring revision). Kaa et al reported on 16 patients who underwent RTSA following oncologic resection at a mean 44 months follow-up.[40] They reported acceptable functional outcomes (mean abduction 78°, MTS 77), but with a similarly high complication rate. Four patients (25%) underwent revision surgery (two aseptic loosening, one

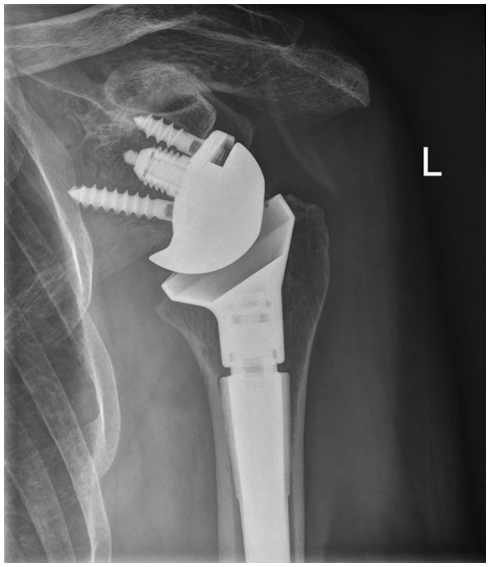

Fig. 1 Traditional Grammont-style prosthesis with medialized glenoid and 155° neck-shaft angle and inlay humeral component. Eccentric glenosphere has been used to avoid notching.

dislocation, one deep infection). Two patients (12.5%) had a perioperative pathological fracture.

The tumours in these studies were primary bone tumours including osteosarcoma, chondrosarcoma, giant cell tumour, and Ewing sarcoma or metastatic disease. Preservation of the axillary nerve and deltoid muscle function is essential for RTSA function and stability.[41] In cases where the deltoid insertion is resected from the humerus, it may be re-attached to the prosthesis with non-absorbable sutures,[40] which may be augmented with an ingrowth surface[38] (e.g. trevira tube).[39] These studies demonstrate that RTSA is a good option for restoration of satisfactory shoulder function following resection for neoplasia. Surgeons need to be cognisant of the high complication rates and need to consider the extent of bone and soft tissue resection, as well as patient function and life expectancy, before undertaking surgery.

Young patients

Greater numbers of RTSAs are being carried out in younger patients (under 60–65 years old). Surgeons have been reluctant to perform RTSAs in young patients due to concerns about longevity of the implant. Clinical results have been shown to deteriorate after six to 10 years.[42,43] High rates of complications have been reported in younger patients.[44] The Australian National Joint Registry (NJR) reports significantly increased revision rates in younger age groups (at seven years: > 75 2.7%; 65–74 3.6%; 55–64 5.7%).[2] Higher rates of revision in younger patients, however, are seen in all types of arthroplasty not just RTSA. Wagner et al reviewed 5494 consecutive shoulder arthroplasties (anatomic, reverse and hemiarthroplasty) performed between 1970 and 2012.[45] They reported a 3% decrease in the risk for revision surgery with every one-year increase in age. Subgroup analysis across the different types of prosthesis showed the same association with age for all.

More recent studies, however, have reported promising outcomes in younger age groups. Ernstbrunner et al reported the results of 20 patients (23 shoulders) with a mean age of 57 years (range, 47–59) at a mean of 11.7 years post surgery.[46] Implant survivorship was satisfactory at 91%, and there was no drop-off in clinical function. A meta-analysis of patients aged < 65 years (mean age, 56; range, 21–65) who underwent RTSA for a failed previous arthroplasty or a cuff-deficient shoulder, included eight articles with a total of 417 patients.[47] The overall complication rate was 17% (range, 7–38%), with the most common complications being instability (5%) and infection (4%). The reintervention rate was 10% at four years, with implant revision in 7% of cases. Clinical outcome measures were highly satisfactory and the authors concluded that RTSA was a reliable procedure in patients aged < 65 years. Goldenberg et al similarly concluded that RTSA is safe and effective in patients younger than 65 years in their recent meta-analysis.[48] They found complication, reoperation, and revision rates were similar to those seen in older patient cohorts with significant improvements in clinical outcome scores up to a mean follow-up of 4.7 years (mean follow-up range, 3.0–7.8 years). Another meta-analysis of RTSA in patients < 60 years similarly demonstrated that early clinical and functional outcomes were favourable, with long-term implant survivorship comparable to older patients.[49]

All these studies confirm that RTSA is a viable option for patients under 60–65 years, and should no longer be reserved for elderly patients.

Design evolution

The medialization seen in the traditional Grammont design RTSA (see Fig. 1) leads to high rates of scapular notching (up to 96% in some series),[50] which may lead to micromotion of the baseplate and glenoid loosening.[51] Numerous studies have demonstrated that increasing grade of notching is associated with worse clinical outcomes (lower Constant scores).[52–55] Excessive medialization may also result in detensioning of any intact cuff, which may lead to instability and weakness in external rotation.

Reverse prostheses have seen a number of evolutions to try to address some of the problems seen with the traditional design. These designs try to provide a more lateralized construct, which may be achieved at the glenoid, the humerus or both.[56]

Lateralization of the glenoid

Lateralization of the glenoid has been shown to decrease scapular notching. A systematic review, including 349 patients from 13 studies, found the incidence of scapular notching to be 5.4% in a lateralized glenoid group compared to 44.9% in a traditional, medialized glenoid group ($p < 0.001$).[57] Furthermore, the lateralized group had increased mean active external rotation (46° vs. 24°, $p < 0.001$). However, the rate of clinically significant glenoid loosening was only 1.8% in the traditional, medialized group compared to 8.8% in the lateralized group ($p = 0.003$). The increase in glenoid loosening may be a result of increased shear forces at the baseplate interface. Biomechanical studies have demonstrated increased micromotion with a lateralized design.[58] Lateralization may be achieved using a prosthesis with a lateralized baseplate and glenosphere design or by bone grafting the glenoid (See Fig. 2).

Zumstein et al, similarly found an increased rate of glenoid loosening with a shoulder prosthesis using a lateralized centre of rotation compared to the traditional Grammont design (5.8% vs. 2.5%, $p = 0.025$).[59] This study, however, only looked at one lateralized prosthesis design. A more recent systematic review of 6583 RTSAs from 103 studies, found only a slight difference in aseptic loosening rates between lateralized and medialized glenoid designs and this was not significant (1.15% medialized vs. 1.84% lateralized).[60]

In another systematic review comparing postoperative outcomes in patients treated with a medialized versus lateralized glenoid prostheses, Helmkamp et al demonstrated an increase in external rotation in the lateralized group (mean 21° vs. 7°).[61] Otherwise, range of motion variables were similar. Lateralization also resulted in decreased scapular notching (4.3% vs. 49%). There were, however, no clear difference between groups in outcome scores.

There is no clear-cut answer on whether a lateralized glenoid is better than medialized. It is a trade-off between the different biomechanical effects. Medialization decreases forces across the glenoid component and creates compressive forces at the bone–implant interface, which may improve glenoid fixation. Lateralization avoids notching and may improve range of motion (particularly external rotation). This ambiguity is perhaps why the focus on lateralization has recently shifted to the humeral component.

Humeral component design

Lateralization on the humerus maintains the decreased torque of a medialized glenosphere/glenoid interface, with the biomechanical advantages that lateralization produces. Modifications to the humeral stem include onlay systems, curved short stems and changes to the neck-shaft angle.

The most widely used neck-shaft angle for RTSA has been 155° (see Fig. 1) for more than 10 years.[4,54,62–66] However, a more horizontal humeral component is biomechanically more likely to impinge on the lateral pillar of the scapula. More recently, implants with neck-shaft angles of 135° and 145° have been developed in an attempt to reduce scapula notching. There are, however, concerns that a reduced neck-shaft angle may lead to a higher dislocation rate.[1,67]

Biomechanical studies have demonstrated increased range of motion with decreasing neck-shaft angle.[68] A lower neck angle increases the range before scapula bone contact occurs and decreases contact area at the inferior scapular neck, indicating that decreased scapula notching would be expected. Decreasing the neck-shaft angle has also been coupled with a change to an onlay proximal interface in some systems (see Fig. 2). The original Grammont prosthesis had an inlay design to increase bony contact with the proximal component. This, however, requires increased reaming of the metaphyseal bone. An onlay proximal interface combined with a curved-stem design preserves proximal bone and the angled cut may be less likely to damage the greater tuberosity and any remaining cuff. It also allows for interchangeability between reverse prostheses with hemiarthroplasty and anatomic TSA. The onlay design results in more lateral displacement of the humerus,[69] which produces increased tensioning of the anterior and posterior rotator cuff and lengthens the deltoid moment arm.[70] A clinical trial comparing RTSAs performed using the onlay, curved-stem prosthesis demonstrated improved external rotation and decreased notching compared to a traditional design.[71] There were, however, increased numbers of scapular fractures with the onlay stems. This increase in scapular fractures has been reported by other authors.[72] Increased deltoid tension secondary to overlengthening the arm has been proposed as a possible causative mechanism.[73] Although prosthesis design has been demonstrated to affect deltoid load, we are unaware of any evidence directly linking deltoid tension to acromion and scapular fractures.[74]

A recent meta-analysis of 2222 shoulders undergoing RTSA (across 38 studies) compared the rate of scapula notching and dislocation between implants with neck-shaft angles of 155° and 135°.[75] Of these, 1762 (79.3%) had implants with a neck-shaft angle of 155°, and 460 had implants with 135° with a lateralized glenosphere. Scapular notching was found to be more common in the 155° group at 16.80% compared to 2.83% in the 135° group ($p < 0.0001$). There was no statistical difference in dislocation rates between the two groups, at 2.33% for the 155° and 1.74% for the 135° group (p = ns). Further studies are needed to compare these neck-shaft angles with and without glenoid lateralization, as lateralization alone has

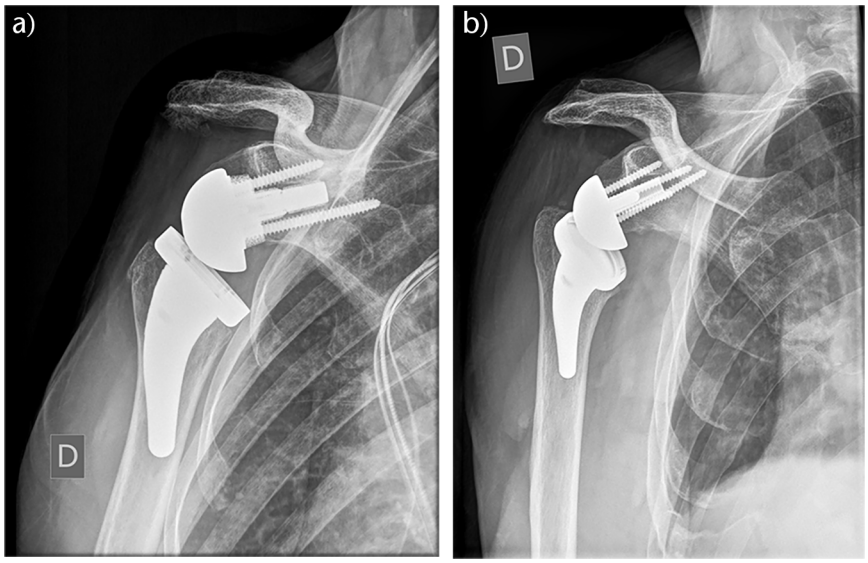

Fig. 2 Lateralized humeral component with 135° neck-shaft angle and onlay design. Lateralized glenoid component with metal augmentation (A) or bone augmentation (B).

been shown to decrease the rate of scapular notching with a 155° prosthesis.[76] Another meta-analysis by the same group also demonstrated increased external rotation with a 135° humeral inclination compared to a 155° prosthesis (33° vs. 25°, $p < 0.001$).[77]

Modified humeral designs with lower neck-shaft angle may reduce scapula notching and increase external rotation without decreasing stability. Further clinical trials are required for this to be definitively proven as well as to investigate the effect on scapula fractures.

Stemless

Stemless total shoulder implants were first introduced to the market in 2004.[78] Around seven different stemless designs (including anatomic and reverse) are available from six implant companies.[79] The two main types of stemless implants are impaction and screw-in. The reported advantages of stemless prostheses include bone preservation, decreased surgical time, lower blood loss, less stress shielding distally, removing the diaphyseal stress riser and less lateralization.[79–87] Disadvantages include dependence on proximal bone stock, increased cost, and reliance on subscapularis repair. There are also concerns regarding proximal bone response to a stemless implant and a lack of high-quality, long-term studies looking at their performance.[88]

Levy et al performed a prospective study of 102 consecutive patients who received cementless RTSA with the Verso implant (Innovative Design, London, UK) with a two- to seven-year follow-up.[89] Seventy-eight patients were female, and the mean age was 74.4 years. Indications for surgery included rotator cuff arthropathy (65), fracture sequelae (12), rheumatoid arthritis (13), failed cuff repair (3), cuff deficiency with a loose prosthesis (3) and acute fracture (2). Patient satisfaction improved with an increase in Subjective Shoulder Value from 8/100 to 85/100. Constant scores improved with 14 to 59 (age and sex adjusted, 86; $p < 0.0001$). All range-of-motion parameters increased – from 47° to 129° in elevation, 10° to 51° in external rotation, and 21° to 65° in internal rotation. Radiographic analysis did not show any lucencies, subsidence or stress shielding, however, glenoid notching was noted in 21 patients.

Teissier et al prospectively analysed 105 RTSAs in patients receiving the Total Evolutive Shoulder System (TESS; Biomet, Warsaw, IN, USA).[90] The mean age was 73 years and mean follow-up time 41 months. Ninety-six per cent of patients reported their satisfaction as good or excellent. Improvement was seen in the Constant score from 40 points preoperatively to 68 points at last follow-up ($p < 0.001$). Mean flexion was 143° (90–170°) and external rotation was 39° (20–70°). Scapular notching was noted in 17 patients.

Von Engelhardt evaluated 67 patients receiving the TESS implant (56 stemless, 11 stemmed) with a mean follow-up time of 17.5 months.[91] A significant improvement in relative Constant (11.3% vs. 78.8%) and Disabilities of the Arm, Shoulder and Hand (DASH) scores (73.7 vs. 31.8) was noted without significant differences between stemless and stemmed. One stemless case was revised due to humeral component loosening and scapula notching was noted in nine cases.

There is limited evidence for stemless humeral components in RTSA, with the majority of studies reporting

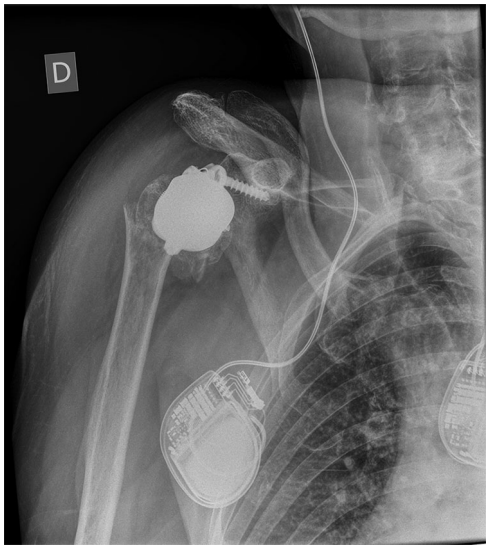

Fig. 3 Stemless design reverse total shoulder arthroplasty (RTSA) with periprosthetic fracture.

short- to medium- term results. Long-term survivorship needs to be determined. There are also complications specific to the design with periprosthetic fractures from impaction onto the lateral cortex being reported (see Fig. 3).

Computer navigation, patient-specific instrumentation and mixed-reality guided implantation

Positioning of the glenoid is an important factor in the functional outcome and survival of RTSA.[92] One of the most common postoperative complications of RTSA is failure of the glenoid component, and glenoid component malposition has been associated with humeral instability, increased stress at the bone–prosthesis interface, early failure and an inferior outcome.[93–96] Poor visualization, complex and variable anatomy, limited bony landmarks as well as abnormal glenoid morphology are just some of the factors that make positioning of the glenoid component technically challenging.[94,97] In recent years, computer navigation (NAV) and patient-specific instrumentation (PSI) have been developed to improve glenoid component positioning in shoulder arthroplasty.[98]

Throckmorton et al performed a study on 70 cadaver shoulders with radiologically confirmed arthritis that were randomized into PSI and standard instrumentation (SI) groups, with 36 anatomic TSAs and 34 RTSAs.[99] The glenoid components in anatomic TSAs with PSI averaged 5° of deviation from the target version and 3° in inclination compared to 8° of version and 7° of inclination in the SI group. This finding was not replicated in the RTSA patients, with no statistical difference in degrees of variation in version or inclination. The number of outliers (defined as version or inclination errors greater than 10° or 4 mm offset error) was improved with statistical significance in the PSI group compared to SI (17% vs. 66%, $p < 0.05$). This finding was replicated by Hendel et al in their study of 31 anatomic TSAs, who also found a reduction in outliers in the PSI group (27% vs. 75%, $p < 0.05$).[100]

Kircher et al performed a prospective, randomized controlled trial of 20 patients with total shoulder arthroplasty for osteoarthritis, with or without glenoid navigation (Nano Station Praxim, Grenoble, France) with a passive optical tracking system for intraoperative navigation).[101] The patients in the navigation group were found to have improved accuracy of glenoid version (measured on axial CT slices) with an average change of retroversion from 15.4° ± 5.8° to 3.7° ± 6.3°, compared to 14.4° ± 6.1° to 10.9° ± 6.8° in the SI group.[101] However, it was noted that operative time was significantly longer in the navigated group at 169.5 ± 15.2 compared to 138 ± 18.4 minutes.[101]

A recent meta-analysis by Burns et al analysed 269 TSAs and RTSAs in 258 patients across nine studies (four controlled and five uncontrolled).[102] They found no significant effect of navigation on version error or inclination error. However, there was a statistically significant improvement in PSI glenoid version error (mean difference –6.3°, 95% CI –0.7° to –11.8°, $p = 0.03$) and inclination error (mean difference –8.2°, 95% CI –2.0° to –14.4°, $p < 0.01$). Although these improvements are encouraging, it is unknown whether they correlate with clinical outcomes.

Another new innovative technology is mixed-reality guided implantation – a form of augmented reality that involves the use of a headset that projects a virtual 3D reconstruction of the scapula that can be manually positioned by the surgeon. Only one case report has been published for RTSA: Gregory et al used a Microsoft HoloLens to perform RTSA in an 80-year-old female with advanced arthritis and Walch A2-type glenoid.[103] Although it is only in its infancy, this technology has immense potential for future surgeons as a practical and educational tool.

Challenges associated with navigation in shoulder arthroplasty are increased operative time, cost, increased labour and aborted use due to malfunction.[98,101] PSI requires the ordering and manufacturing of a custom implant, which also creates a logistical challenge and cost. There are no studies directly comparing navigation with patient-specific instrumentation for shoulder arthroplasty, and the overall cost effectiveness of these technologies has not been researched. While some surgeons choose to use NAV or PSI routinely, there are no absolute indications for the use of either. In our experience, they are useful tools in patients with challenging anatomy, for example severe glenoid bone loss. A study of anatomic TSAs found that patients with greater than 16° of glenoid retroversion benefitted the most from PSI, with regard to accuracy of implantation.[100]

Fig. 4 Radiograph of scapula spine fracture post reverse total shoulder arthroplasty (RTSA) (A). Three-dimensional surgical planning for plate fixation (B). Postoperative radiographs (C).

Controversies

Acromial fracture

Acromial fracture after RTSA is posited to occur because the longer arm length and increased tension of the deltoid muscle transmits higher forces through the muscle origin (see Fig. 4). Additionally, acromial fractures have been associated with osteoporosis, prosthesis design, surgical approach, screw position and length in the glenoid, and technical factors such as deltoid tension.[73,104–107]

The majority of studies looking at this complication report low numbers of between 1 to 25 fractures.[50,104,108–113] One of the largest studies was performed by Teusink et al (n = 1018 RTSAs), who retrospectively reviewed 25 (3.1%) non-operatively managed scapular fractures post RTSA with case controls. The patients were matched 1:4 to a control group, and a higher revision rate was found in the fracture group (8% vs. 2%); however, this was not statistically significant.[113]

Crosby et al reviewed the records of 400 RTSAs and identified 22 cases (5.5%) of acromial fracture, and described three patterns: type I, avulsion fractures of the anterior acromion; type II, fractures to the acromion posterior the acromioclavicular joint; and type III, scapular spine fractures.[104] Eight (2.0%) type I fractures were successfully treated non-operatively. Of the 10 (2.5%) type II fractures, seven were managed operatively with improvement in their symptoms; four (1%) had type III fractures and were all successfully managed operatively.

Levy et al provided an alternative classification of acromial fractures post RTSA, with three types having varying involvement of the deltoid origin.[114] Type I fractures involved a portion of the anterior and middle deltoid origin, type II at least the entire middle deltoid origin and type III the entire middle and posterior origin. In their study of 157 patients with RTSA, 18 acromial fractures were identified and were all managed non-operatively, however, they described a limitation in their functional outcomes.

There have been three recent published meta-analyses looking at acromial fracture post RTSA.[115,116,117], Cho and colleagues reviewed 15 studies (n = 2857 shoulders) with a mean age of 72.9 years and found the incidence of acromial fracture to be 4.0%;[115] 87.7% of acromial fractures were managed non-operatively and 12.3% were managed with surgery, with a union rate of 43.8% and 87.5% respectively. The mean follow-up time was 34 months. Differences were found in the rate of acromial fracture of medial glenoid/medial humeral, lateral glenoid/medial humeral, and medial glenoid/lateral humeral prostheses with rates of 8.4%, 4.0%, and 2.8% respectively.

Patterson et al reviewed 32 studies (n = 3838 RTSAs) with 159 reported acromial fractures – an incidence rate of 4.14%.[116] One hundred and thirty nine patients were treated non-operatively with a sling or brace, and 20 were treated with open reduction and internal fixation. All patients reported inferior functional outcome scores with average Constant and American Shoulder and Elbow Society (ASES) scores of 63 and 57, respectively when compared to their pre-fracture state. They also reported decreased forward flexion (95°) and abduction (76°) after acromial fracture.

King et al performed a systematic review of 90 articles (9048 RTSAs) and found the incidence of acromial and/or scapular spine fracture to be 2.8%.[117] Risk factors for fracture included inflammatory arthritis (10.9%), massive rotator cuff tears (3.8%) and lateralized glenosphere designs (3.8%). The incidence was lowest in acute proximal humerus fractures (0%) and post-traumatic arthritis (2.1%).

These studies establish that acromial fracture has a marked detrimental effect on outcomes following RTSA. Further research is required to determine whether operative or non-operative treatment delivers improved results.

Subscapularis repair

Instability and dislocation are devastating complications following RTSA, and one hypothesized cause is a dysfunctional subscapularis tendon. However, management of the

subscapularis tendon during RTSA is controversial, with conflicting studies reporting the outcomes after repair. A number of studies report a significant increase in dislocation rates when the subscapularis is not repaired.[118–120] Edwards et al evaluated 138 consecutive RTSAs and found subscapularis was repairable in 62 and irreparable in 76. They found all seven dislocations occurred in the irreparable group.[119] Trappey et al retrospectively analysed 284 patients undergoing RTSA (212 primary, 72 revision) and found that patients with an irreparable subscapularis tendon had a higher rate of instability (14 of 123 [11%]) compared to patients with a repairable tendon (1 of 161 [< 1%]).[120] All three studies reported results of RTSA with medializing designs.

More recent studies have not shown any difference between repair and non-repair groups.[4,121–123] Clark et al identified 65 patients who received RTSA with subscapularis repair and 55 without subscapularis repair.[121] Dislocation was noted in two patients in the repair group and three in the non-repair group and was not statistically significant.[121] Friedman et al analysed 340 RTSA patients with subscapularis repair and 251 without repair, and found that there was a dislocation rate of 0% in the repair group and 1.2% in the non-repair group, and this was not statistically significant.[122] Vourazeris retrospectively studied 202 patients undergoing primary RTSA, and found no significant difference in the rate of dislocation in the subscapularis repair group (0% of 86) compared to the non-repair group (2.6% of 118).[123] The study by Clark reflects results of RTSA with increased glenoid-sided lateralization built into the glenosphere, while the latter two studies report results of RTSA designs with humeral-sided lateralization. Modern lateralizing prosthesis designs are reported to decreased instability compared to classic Grammont design by increasing joint-reaction forces and the wrapping angle of the deltoid muscle.[56,124]

A recent meta-analysis by Matthewson and colleagues included 1306 patients post RTSA and found an overall lower dislocation rate when the subscapularis was repaired (OR 0.19, $p < 0.001$), but also found that in patients without repair, a lateralized centre of rotation (COR) resulted in a decreased dislocation rate compared to medialized COR (OR 0.24, $p < 0.001$).[125] Other findings included largely equivalent clinical outcomes between subscapularis repair and non-repair groups after RTSA. However, there is a lack of high-quality studies looking at the effect of subscapularis repair.

It seems that repairing the subscapularis is less important for stability with modern lateralizing prosthesis designs. In non-lateralizing fracture prosthesis we recommend subscapularis and lesser tubercle repair. For elective RTSA, subscapularis repair is recommended as long as its tendon and muscle quality are appropriate, especially in cuff arthropathies. Repairing the subscapularis is reported to have an advantage for active internal rotation,[126] but with a possible drawback of decreased passive external rotation.[127] Subscapularis tendon release and repair should allow for intraoperative external rotation with the arm at side of at least 45°. With modern lateralizing prosthesis designs, we do not recommend tight repairs which have the potential to lead to stiffness and pain, influencing postoperative recovery.[128]

Conclusion

RTSA should be used in the management of posterior glenoid wear, glenoid retroversion and dysplasia, three- and four-part proximal humerus fracture, tumour reconstruction, failed anatomic TSA and is increasingly being used in younger patients. Modern RTSA designs with a lower neck-shaft may reduce scapula notching and increase external rotation without decreasing stability. Further clinical trials are required for this to be definitively proven as well as to investigate the effect on scapula fractures. Similarly, stemless RTSA has promising early results but will require larger, longer-term studies. NAV and PSI have been shown to improve the accuracy of glenoid implantation. Long-term clinical studies or registry results are required to determine whether this is translated to a proven clinical benefit. The cost-effectiveness should also be researched. Acromial fracture after RTSA is estimated to occur in 3–4% of cases and has a marked detrimental effect on outcomes following RTSA. Further research, ideally with randomized clinical trials, is required to determine whether operative or non-operative treatment delivers better results. We recommend subscapularis tendon repair in RTSA with Grammont design for fracture, which we believe to be an important factor in postoperative stability. The effect of subscapularis tendon repair on RTSA dislocation rates of current, lateralizing prosthesis designs should be investigated with high-quality registry data since large numbers are required for adequate statistical power.

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