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SHOULDER ARTHROPLASTY (G ATHWAL, SECTION EDITOR)

Expanding roles for reverse shoulder arthroplasty

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Abstract Since its introduction in the USA in 2003, reverse total shoulder arthroplasty (RTSA) has been used with increasingly frequency as surgeons have observed the remarkable improvement in pain, range of motion, and function associated with this implant. RTSA was initially used exclusively for elderly, low demand individuals with end-stage rotator cuff tear arthropathy. However, RTSA is now being increasingly successfully employed for the management of irreparable rotator cuff tears, glenohumeral osteoarthritis with an intact rotator cuff, acute proximal humerus fractures, the sequelae of proximal humerus fractures, neoplasms of the proximal humerus, inflammatory arthropathy, young patients and failed anatomic total shoulder arthroplasty and hemiarthroplasty. While long-term outcomes are pending, short- and mid-term follow-up results suggest that in experienced hands, RTSA may be a reasonable treatment for many previously difficult to treat pathologies within the shoulder.

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Introduction

While anatomic total shoulder arthroplasty (TSA) has predictably good long-term results in glenohumeral osteoarthritis [1], TSA fails rapidly in the presence of rotator cuff dysfunction due to superior edge loading, the "rocking horse glenoid" phenomenon, and accelerated glenoid loosening [2]. There has thus always been interest in an alternative prosthesis that can provide pain relief, range of motion, function, and longevity in the absence of a functional rotator cuff. While several reversed polarity shoulder prostheses were developed historically [3], none achieved predictably good outcomes until Paul Grammont developed his design in 1985 [4]. Although widely used in Europe subsequently, this style of reverse total shoulder arthroplasty (RTSA) implant was not approved by the Food and Drug Administration until 2003 [4]. Since then, this prosthetic design has achieved widespread usage and acceptance [5]. The principles of the design include a semi-constrained, reverse polarity articulation with a medialized center of rotation to reduce shear forces on the baseplate, and distalization of the humerus to optimize deltoid lever arm [4]. While subsequent designs have been slightly altered [6], many of the overall principles remain constant. The reversed polarity and constrained design provide a stable fulcrum to allow the deltoid to elevate the humerus in the absence of the rotator cuff [7]. Thus, the RTSA can achieve excellent pain relief and predictably restores active forward elevation (AFE), even in pseudo-paralytic patients [7]. A recent study

even demonstrated that 85 % of patients who undergo RTSA are able to return to recreational athletic activities [8].

Initially, the RTSA was indicated for elderly, low-demand patients with rotator cuff tear arthropathy and glenohumeral arthritis with rotator cuff deficiency [6, 9–11]. However, as surgeon experience with the prosthesis has grown, surgeons have observed the predictable improvements in pain, range of motion, and function provided by the prothesis [12]. In addition, while early reports described high complication rates [13, 14], as surgeon experience has grown, more recent studies have demonstrated the vast majority of complications to be minor, with major complications being infrequent [15–18]. The procedure has also been demonstrated to be cost-effective [19•]. Surgeons have thus expanded indications [18, 20] to include a variety of pathologies such as irreparable rotator cuff tears [21], glenohumeral osteoarthritis with an intact rotator cuff [22], acute proximal humerus fractures [23], the sequelae of proximal humerus fractures [24], neoplasms of the proximal humerus [25•], inflammatory arthropathies [26, 27], young patients [28•, 29], and failed TSA and hemiarthroplasty (Table 1) [34, 35]. Indeed, the expansion of RTSA indications has been sufficiently large to lead to substantial increases in the overall incidence of shoulder arthroplasty [5, 36–38]. The purpose of this review is to discuss the expanding role of RTSA within shoulder surgery.

Massive, irreparable rotator cuff tears without glenohumeral degeneration

Massive, irreparable rotator cuff tears have traditionally presented a treatment challenge for shoulder surgeons. Outcomes with arthroscopic debridement [39], partial repair [40], and tuberoplasty [41] are unpredictable. Traditionally, TSA fails rapidly due to accelerated glenoid loosening [2]. While tendon transfers can be successful, they are only indicated in very specific, infrequently encountered, clinical scenarios [42]. RTSA has thus become a popular option in this clinical setting [20, 21, 28•, 43]. In the largest described series for this specific indication, Mulieri and colleagues presented a series of 72 shoulders that underwent RTSA for a massive irreparable rotator cuff tear without degenerative changes within the glenohumeral joint and noted significant improvements in range of motion (mean final AFE of 134°), functional outcomes (mean final American Shoulder and Elbow Surgeons score [ASES] 75.4), and pain (mean final visual analogue score for pain of 1.9), with a 20 % complication rate and a 10 % revision rate at 54-months mean follow-up [21]. Several more recent series including heterogeneous cuff-deficient indications have confirmed these results [28•, 43]. Collectively, these authors have concluded that RTSA provides a reliable surgical option in this patient population [21, 28•, 43].

While one comparative study suggested that RTSA may provide more improvement in AFE, strength, and functional outcome scores than TSA, in this study, these procedures were performed for different indications and thus these results may not be directly comparable [44] Other comparable studies suggest outcomes between TSA and RTSA to be similar, although RTSA consistently provides inferior rotational motion, particularly internal rotation [17, 45, 46]. Other authors have argued that in patients with pre-operative external rotation lag signs, post-operative active external rotation can be improved with the addition of a latissimus dorsi transfer [47].

Glenohumeral osteoarthritis with an intact rotator cuff

Because of the propensity for the late development of rotator cuff dysfunction after TSA [48, 49], RTSA has been considered as an option in select patients with glenohumeral osteoarthritis and intact rotator cuff [22]. In particular, RTSA could be considered in elderly patients with imaging demonstrating

Table 1 Representative Outcomes from recent series of RTSA performed for indications other than rotator cuff tear arthropathy or a massive irreparable rotator cuff tear

Outcomes of reverse shoulder arthroplasty for alternative indications

Author	Year	Indication	*N*	F/U, years	AFE	ASES	Constant	Complications	Re-operations
Mizuno [30]	2013	Glenohumeral OA	27	4.5	152°	NA	76 %	15 %	4 %
Sebastiá-Forcada [31•]	2014	Acute PHFx	31	2.4	120°	NA	56 %	6 %	3 %
Raiss [32•]	2014	Sequelae of PHFx	32	4.0	110°	NA	46 %	41 %	28 %
De Wilde [33]	2011	Tumor	14	7.7	157°	NA	76 %	21 %	14 %
Patel [34]	2012	Revision arthroplasty	31	3.4	108°	66	NA	10 %	10 %
Young [26]	2011	Inflammatory arthritis	18	3.8	139°	NA	65 %	33 %	0 %
Muh [28•]	2013	Mixed (Young patients)	67	3.1	134°	72.4	NA	15 %	11 %

Unless otherwise specified, results are displaced as arithmetic means

N number of shoulders, *F/U* length of follow-up, *AFE* active forward elevation, *ASES* American Shoulder and Elbow Surgeons Score, *NA* not available, *OA* osteoarthritis, *PHFx* proximal humeral fractures

an intact rotator cuff but with clinical suspicion for rotator cuff dysfunction, as evidenced by loss of AFE or weakness in external rotation. These patients may have limited preoperative strength and limited post-operative rehabilitation potential within the rotator cuff. No published series are available to date to review outcomes for this patient population.

RTSA is more commonly used in for glenohumeral osteoarthritis with an intact rotator cuff when fixation of the glenoid component is questionable. Steen and colleagues performed a retrospective cohort analysis of 24 consecutive patients who underwent RTSA for glenohumeral osteoarthritis with an intact rotator cuff due to improper glenoid trial seating or persistent posterior subluxation. These patients were matched with 96 patients who underwent TSA. No differences in range of motion, standardized functional outcomes, or revision rates were demonstrated between groups, although radiographic loosening of the glenoid component was more common in the TSA group. However, RTSA was over $7,000 most expensive than TSA due to the cost of the implant. From these results, the authors concluded that if the surgeon is in doubt with regards to the outcome of a TSA due to the glenoid component, conversion to an RTSA is a reasonable option [22].

In particular, recently, some authors have advocated that RTSA may be preferable in the setting of a biconcave, retroverted glenoid, classified as the "B2 glenoid" within the Walch system [50]. In a retrospective case review, Walch and colleagues analyzed 92 TSAs performed for a B2 glenoid at a mean follow-up of 77 months and observed a 21 % rate of glenoid loosening, which was positively correlated with posterior wear and subluxation [51]. Chin and colleagues confirmed these findings, demonstrating 48 % glenoid component radiolucencies at mean 60-months follow-up in 37 B2 glenoids that underwent TSA [52]. Mizuno and colleagues analyzed 27 RTSA performed for a glenohumeral osteoarthritis with an intact rotator cuff in the setting of a B2-type glenoid with a mean follow-up of 54 months, finding significant improvement in range of motion (mean final AFE of 152°) and functional outcomes (mean final Constant score of 76 points), with a 15 % complication rate and a 4 % re-operation rate [53•]. Based upon these results, some authors have advocated that the RTSA should be the preferred treatment in the setting of an advanced B2-type glenoid deformity [51, 53•, 54].

Acute proximal humerus fractures

RTSA is increasingly being used as an acute treatment for proximal humerus fractures [37, 38, 55, 56]. Bufquin and colleagues performed prospective cohort study of 43 patients who underwent RTSA as the acute treatment of a three- or four-part proximal humerus fracture with a reasonable of motion (final mean AFE of 97°), functional outcomes (final mean Constant score of 66 %), and a 21 % rate of major complications (complex regional pain syndrome, neurologic injuries, and instability) [57]. Ross and colleagues performed a retrospective review of 29 shoulders that underwent RTSA for three- or four-part proximal humerus fractures with a mean follow-up of 55 months with excellent pain relief, range of motion (mean final AFE 130°), and functional outcomes (mean final ASES 89), and with a 3 % complication rate and a 0 % reoperation rate [58•]. Sebastiá-Forcada and colleagues performed a prospective, randomized clinical trial comparing 31 patients who underwent hemiarthroplasty and 31 patients who underwent RTSA for complex proximal humeral fractures in patients over the age of 70, finding significantly better AFE, University of California-Los Angeles Scores, and Constant scores in the RTSA group. In the RTSA group, there was only a single re-operation, while in the hemiarthroplasty group 19 % of the patient required later conversion to RTSA, which unfortunately did not improve their outcomes to the those observed with primary RTSA [31•].

Several systematic reviews have also been performed [59, 60]. Gupta and colleagues performed a systematic review comparing open reduction and internal fixation, hemiarthroplasty, and reverse total shoulder arthroplasty in the treatment of acute proximal humerus fractures. While outcomes with all functional outcomes scores were better in open reduction and internal fixation were better than RTSA, RTSA provided a lower re-operation rate (12.7 vs. 5 %) [60]. RTSA also avoids outcome heterogeneity related to tuberosity nonunion and resorption, which is common with hemiarthroplasty. Ferrel and colleagues also performed a systematic review but specifically examined RTSA and hemiarthroplasty, finding that RTSA provided improved AFE, but at the expense of decreased external rotation and a higher complication rate as compared to hemiarthroplasty [59]. Overall, these results suggest that RTSA is a promising new option for acute proximal humerus fractures. The common complications related to tuberosity healing seen with hemiarthroplasty for acute proximal humerus fractures are less frequent and have a less deleterious effect on functional outcomes following RTSA. Hopefully, future prospective randomized clinical trials will compare non-operative treatment, open reduction and internal fixation, and RTSA to allow a better understanding for how RTSA best fits into current treatment paradigms.

Sequelae of proximal humerus fractures

A variety of complications can be encountered in the treatment of proximal humerus fractures, including post-traumatic arthropathy, screw perforation of the chondral surfaces due to humeral head collapse, avascular necrosis, tuberosity nonunion, tuberosity malunion, tuberosity resorbtion, rotator cuff dysfunction, rotator cuff tears, malunion of the head to the

shaft, nonunion of the head to the shaft, and the development of intractable stiffness [9, 24, 32•, 61, 62•]. Prior to the development of the RTSA, these complications, collectively referred to as "fracture sequelae", were often difficult to treat, especially because they occur in combination not infrequently (Fig. 1). As a result, many surgeons have incorporated RTSA into their treatment algorithm for this challenging patient population [9, 24, 32•, 61, 62•].

Boileau and colleagues first subdivided fracture sequelae into four types and reported poor outcomes with hemiarthroplasty for surgical neck nonunions and severe tuberosity malunions, both of which required tuberosity osteotomy to gain access to the canal, and suggested that RTSA may be a better option for these patients [24]. Boileau and colleagues then first reported outcomes of the RTSA in this setting in five elderly patients who had failed either conservative treatment or percutaneous pinning due to the development of nonunion or malunion of the tuberosities, nonunion of the surgical neck, osteonecrosis, and pre-existing glenohumeral degeneration in the setting of a massive rotator cuff tear. RTSA provided significant improvement in range of motion (mean final AFE 123°), functional outcomes (mean final Constant 61), with a 20 % complication and reoperation rate [9]. The authors concluded that while the outcomes are not as predictable as RTSA for the indication of rotator cuff tear arthropathy, RTSA was a good option for this patient population. More recently, Raiss and colleagues performed a retrospective review of 32 patients who underwent RTSA for the treatment of a surgical neck nonunion with mean follow-up of 4 years, finding significant improvements in range of motion (mean final AFE 110°) and functional outcomes (mean final Constant 47), but with a 41 % complication rate, a 34 % dislocation rate, and a 28 % reoperation rate [32•]. The authors attributed the high rate of instability with routine resection of tuberosities as part of their surgical approach and advocated retention and fixation of the tuberosities to avoid this issue [32•]. Hattrup and colleagues reported 20 patients with mean follow-up of 44 months who underwent RTSA for proximal humeral malunion (69 %) and osteonecrosis (15 %) describing excellent pain relief, significant improvement in range of motion (final AFE 137°), and functional outcomes (mean final ASES 65), and a 19 % complication rate and a 10 % revision rate [61]. Hussey and colleagues reported upon 19 patients who underwent RTSA as revision of a failed open reduction and internal fixation due to osteonecrosis (26 %), intra-articular hardware perforation (21 %), and nonunion (32 %) with a mean follow-up of 36 months and found significant improvement in pain, range of motion (mean final AFE 101) and functional outcomes (mean final ASES 50), although with a 26 % complication rate and a 21 % revision rate [62•]. Similar to other authors, these surgeons advised that RTSA performed for sequelae of proximal humeral fractures can provide considerable improvement in pain, motion, and function but that patients must be counseled that major complications and re-operations are frequent and surgeons should be aware that the procedure is technically demanding [62•].

Neoplasms of the proximal humerus

Resection of the proximal humerus, including the attachment of the rotator cuff, is occasionally necessary to achieve clean margins and obtain local oncologic control. In these settings, patients had traditionally undergone fibular autografting, proximal humeral replacement with a hemiarthroplasty, or bulk proximal humeral osteochondral allografting, with mixed functional results [63]. Because RTSA is less reliant upon the rotator cuff, some tumor surgeons have begun reconstructing proximal humeral resections with an RTSA [25•]. King and colleagues recently reported upon the outcomes in two patients who underwent allograft prosthetic composite with a long-stemmed RTSA and a proximal humeral allograft for reconstruction after resection of an osteosarcoma in one patients and chondrosarcoma in the other patient. Although both patients developed nonunions at the junction of the native humerus and the allograft, with revision fixation at long-term follow-up both patients had excellent range of motion and functional outcomes [25•]. De Wilde and colleagues reported mid-term outcomes (mean follow-up 7.7 years) in 14 patients who underwent of RTSA for proximal humeral tumors, finding excellent range of motion (mean abduction 157°), and functional outcomes (mean Constant score 76 %), although 21 % of patients developed major complications and 14 % required component revision [33]. Kaa and colleagues reported 16 patients who underwent RTSA for resection of a sarcoma or metastasis, with mixed results due to a high complication rate, with a 30 % infection rate, a 20 % prosthetic loosening rate, and a 10 % instability rate [64]. The authors concluded that this procedure offers superior functional results to the hemiarthroplasty alternative but that caution should be employed given the high complication rate [64]. As experience with these reconstruction techniques increases, RTSA will likely be used increasingly for this indication.

Failed TSA and hemiarthroplasty

While anatomic total shoulder arthroplasty (TSA) has predictably good long-term results in glenohumeral osteoarthritis [1], by 15-years follow-up, 55–63 % of patients have developed moderate to severe proximal humeral migration denoting rotator cuff dysfunction [49, 65–67], which predisposes them to glenoid loosening [65, 67]. Glenoid loosening remains the most common indications for TSA revision [68]. In these cases, loosening of the glenoid component also often involves

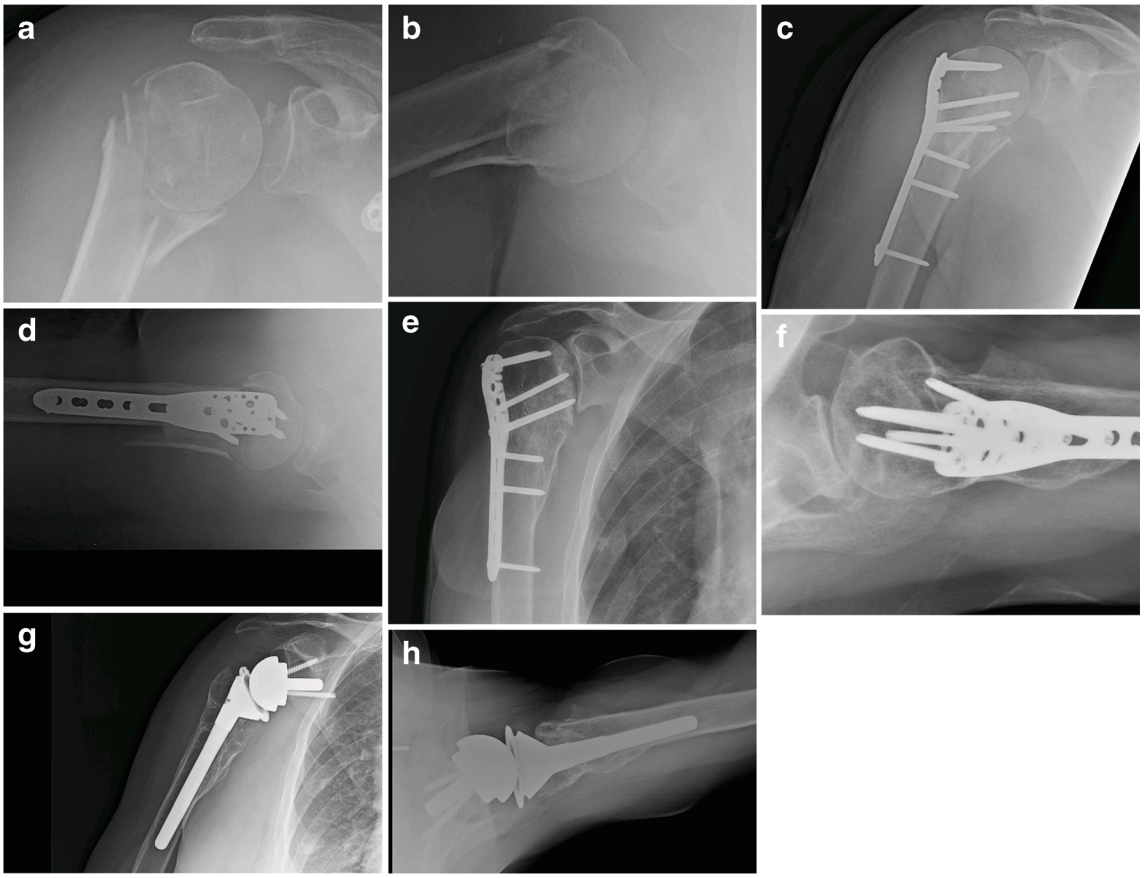

Fig. 1 This 62-year-old female sustained a 4-part proximal humerus fracture (Grashey anteroposterior and axillary radiographs shown in **a** and **b**), underwent open reduction and internal fixation with fibular strut allografting (**c**, **d**). Two-and-a-half years later, the patient presented with increasing pain. On examination the patient was found to have 80° active forward elevation and weakness in all planes of the rotator cuff. Radiographs (**e**, **f**) demonstrated avascular necrosis and glenoid osteophyte formation and an ultrasound demonstrated a full thickness anterosuperior rotator cuff tear. The patient underwent removal of hardware and reverse total shoulder arthroplasty (**g**, **h**) with restoration of range of motion

significant glenoid bone loss that may be difficult to reliably reconstruct with a TSA glenoid component. Prior to widespread use of the RTSA, revision shoulder arthroplasty was thus often plagued by limited range of motion and functional outcomes. Boileau and colleagues first reported upon the use of RTSA for revision arthroplasty in 19 cases, most (84 %) for failed hemiarthroplasties performed for proximal humeral fractures with significant improvements in range of motion (mean final AFE 113°) and functional outcomes (mean final Constant 46), but with a 47 % complication rate and a 42 % revision rate [9]. Patel and colleagues reported upon 31 patients who underwent RTSA for a failed arthroplasty, of which 35 % were for rotator cuff insufficiency, 19 % for instability, 19 % for revision from a spacer placed for periprosthetic sepsis. At a mean follow-up of 41 months, the patients had significantly improved pain, range of motion (mean final AFE 108°), and functional outcomes (mean final ASES 66), and with a 10 % complication rate and a 6 % revision rate [34]. Walker and colleagues reported upon 22 patients who underwent RTSA as a revision of a failed TSA, 86 % of which were for an unstable TSA, with significant improvements in pain, range of motion (mean final AFE 130°), and function (mean final ASES 68), with a 23 % complication rate and a 0 % revision rate [35]. Most recently, Wagner and colleagues reported 41 patients followed for a mean of 3.1 years who underwent RTSA as a revision from a prior arthroplasty with concomitant glenoid bone grafting for implant instability (44 %), glenoid loosening (24 %), and for revision from a spacer placed for periprosthetic sepsis (20 %). While patients experienced significant pain relief, improvement in motion, and improvement in function, the authors noted a 24 % component revision rate at 5-year follow-up and also noted a significantly higher rate of revision when RTSAs with concomitant bone grafting were compared to those that did not require bone grafting [69•]. These authors, similar to previous authors, reported that RTSA can provide satisfactory outcomes in the setting of revision arthroplasty, but that re-operation and component failure remain common even in experienced hands.

Inflammatory arthropathy

Patients with inflammatory arthropathy frequently have severe osseous deformity, glenoid bone loss, and concomitant or impending rotator cuff dysfunction, which makes RTSA an attractive option in this patient population [18, 26]. In a recent series in which surgical indications were compared between the first 240 RTSAs and the most recent 240 RTSAs performed at a single center, with increasing experience the RTSA was performed with increasingly frequency for rotator cuff tear arthropathy and rheumatoid arthritis and decreasing frequency for revision shoulder arthroplasty [18]. Young and colleagues published the only dedicated series the authors are aware of on the use of the RTSA in the setting of rheumatoid arthritis. They reported upon 18 RTSAs with a mean follow-up of 3.8 years who experienced significant improvements in pain, range of motion (mean final AFE 139°), and function (mean final Constant 74). However, a 22 % rate of intraoperative or post-operative fracture was noted. While no patient required a revision, the authors advocated caution in this patient population as the periarticular osteopenia leads to frequent iatrogenic periprosthetic fracture [26].

Younger individuals

While RTSA has been demonstrated to be successful in elderly individuals, many of the pathologies best addressed by RTSA, including massive, irreparable rotator cuff tears, failed TSA and hemiarthroplasty, and sequelae of proximal humeral fractures, also occur in younger individuals. These patients have often represented a particularly difficult-to-treat patient population for shoulder surgeons. Select authors have thus begun to use RTSA in patients under the age of 60 in these scenarios [28•, 29]. Sershon and colleagues performed a short-term (2.8-years mean follow-up) retrospective review of 36 shoulders in patients under the age of 60 that underwent RTSA for failed rotator cuff repairs (33 %), proximal humeral fracture sequelae (31 %), failed prior arthroplasty (14 %), sequelae of prior glenohumeral instability (11 %), and rotator cuff tear arthropathy (11 %). These authors reported significant improvements in range of motion (final mean AFE of 121°) and functional outcomes (final mean ASES score of 65.8). The major complication rate was 17 %, of which 11 % of patients required re-operation, and 25 % of patients were counted as failures due to ASES scores below 50. The authors concluded that while good outcomes can be achieved in young patients who undergo RTSA, the prognosis remains guarded and patients must be counseled that major complications are common [29]. Muh and colleagues performed a short-term (37-months mean follow-up) multicenter retrospective review of 67 patients under the age of 60 (mean age of 52.2) who underwent RTSA for a massive, irreparable rotator cuff tear (43 %), rotator cuff tear arthropathy (16 %), and failed prior arthroplasty (13 %), with 67 % of the entire patient population having had prior surgery. These authors reported very similar results, with 81 % satisfaction, significant improvement in range of motion (final mean AFE of 134°), functional outcomes (final mean ASES of 72.4), a 15 % major complication rate, and an 11 % reoperation rate. These authors also arrived at a similar conclusion, that RTSA can be successful in younger patients but that it would be employed with caution because a it is associated with a higher failure rate and lower satisfaction rate than RTSA performed for rotator cuff tear arthropathy in elderly individuals [28•].

Conclusion

As experience has grown with RTSA and the predictable pain relief and restoration of active forward elevation it provides for elderly, low-demand patients with end-stage rotator cuff tear arthropathy, this procedure has been performed with growing frequency for an increasingly broad range of indications. Recent publications have described success using the RTSA for irreparable rotator cuff tears, glenohumeral osteoarthritis with an intact rotator cuff, acute proximal humerus fractures, the sequelae of proximal humerus fractures, neoplasms of the proximal humerus, inflammatory arthropathy, younger individuals, and failed anatomic total shoulder arthroplasty and hemiarthroplasty. While complication rates are considerable and in many of these settings outcomes are inferior to those observed when RTSA is performed for rotator cuff tear arthropathy, RTSA can provide pain relief, restoration of range of motion, and good functional outcomes for a wide variety of pathologies that were previously surgically difficult to treat reliably. The long-term survivorship of the implant has not yet been described, but short- and mid-term follow-up results suggest that these results are durable.

Compliance with ethical standards

Conflict of interest Peter N. Chalmers declares that he has no conflict of interest.

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Human and animal rights and informed consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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