Since the introduction of reverse total shoulder arthroplasty (RTSA) in 1987 (in Europe) and 2004 (in the United States), the number of RTSAs performed annually has increased. Although the main indication for RTSA has been rotator cuff tears, indications have expanded to include several shoulder conditions, many of which involve dysfunction of the rotator cuff. RTSA complications have been reported to affect 19% to 68% of patients and include acromial fracture, hematoma, infection, instability, mechanical baseplate failure, neurological injury, periprosthetic fracture and scapular notching. Current controversies in RTSA include optimal baseplate positioning, humeral neck-shaft angle (135° versus 155°), glenosphere placement (medial, lateral or bony increased offset RTSA) and subscapularis repair. Improvements in prosthesis design, surgeon experience and clinical results will need to occur to optimize this treatment for many shoulder conditions.

Keywords: reverse total shoulder arthroplasty; indications; contraindications; clinical outcomes; complications

Introduction
Traditionally, anatomical total shoulder arthroplasty (TSA) has been used to treat the shoulder joint with end-stage glenohumeral osteoarthritis (OA) and an intact rotator cuff. However, loosening of the glenoid component remains a common cause of failure after TSA, leading to revision surgery in 0.8% of TSAs per year.1–3 Alternatives to TSA are cup arthroplasty, hemi-arthroplasty (HA) and interpositional allografts with HA. For patients without a rotator cuff or with rotator cuff tear arthropathy, the traditional treatment was HA. Unfortunately, HA for these indications provided unpredictable pain relief and little improvement in range of motion (ROM) or function.4

In the 1970s, Beddow and Alloy were using a prototype reverse shoulder arthroplasty in Liverpool for patients with rheumatoid arthritis but did not publish the results. In 1987, Grammont et al5 introduced the reverse total shoulder arthroplasty (RTSA) to treat rotator cuff tear arthropathy. RTSA was approved by the US Food and Drug Administration in 2004,6 and the number of RTSAs performed annually increased dramatically.7 Approximately 10,000 RTSAs were performed in the USA in 2007, a fivefold increase over 2004. Estimates indicate that 30,000 RTSAs were performed in 2012.7 To assess the contribution of RTSA to overall use of primary shoulder arthroplasty, Jain and Yamaguchi8 used the Nationwide Inpatient Sample from 2009 through 2011. They found that the use of primary shoulder arthroplasty increased significantly during that period, with a major contribution from RTSA, which accounted for 42% of all primary shoulder arthroplasties in 2011.8

Indications and contraindications
Although the most common indication for RTSA is rotator cuff tear arthropathy (Fig. 1), indications have expanded to include several conditions and situations that were difficult to treat with anatomical shoulder arthroplasty, such as acute proximal humerus fracture, chronic locked dislocation, chronic pseudoparalysis caused by irreparable rotator cuff without arthritis, glenohumeral arthritis with severe glenoid bone loss, immunological arthritis with or without associated rotator cuff tears, malunited/nonunited proximal humerus fracture, failed shoulder arthroplasty and tumours.9–13 Many of these conditions involve dysfunction of the rotator cuff. Appropriate candidates for RTSA now include young patients, who have shown...
excellent clinical improvement with high implant surviv- 

Contraindications to RTSA include axillary nerve dam-

Pre-operative deltoid impairment is not an absolute con- 

Patients undergoing RTSA should be aware of its high 

Clinical outcomes according to indication

Rotator cuff tear arthropathy

Several studies have reported results of RTSA in patients 

Pseudoparalysis caused by massive, irreparable rotator cuff 

tear without OA

Acute proximal humerus fracture

HA was traditionally the treatment of choice for three- and 

Because of less than optimal results with this approach, open reduction and internal fixation (ORIF) gained popularity, especially for younger patients. However, the results of both HA and ORIF are unpredictable because of dependence on anatomical tuberosity healing. The complication and failure rates of ORIF to treat shoulder fractures can be high. RTSA may be a more reliable treatment for complex proximal humerus fractures because its functional outcomes appear to depend less on tuberosity healing and rotator cuff integrity (Fig. 3). However, some authors have suggested that tuberosity repair is associated with increased external rotation compared with no

Fig. 1 a) Anteroposterior (AP) radiograph of a shoulder with rotator cuff tear arthropathy showing superior joint space narrowing; b) post-operative radiograph of RTSA.
RTSA can also be a valuable salvage procedure after failed ORIF of a proximal humerus fracture, with a relatively low revision rate. Several studies have reported favourable results of RTSA to treat proximal humeral fractures. Two studies found no significant differences in the clinical results of patients with acute proximal humerus fractures treated with HA or RTSA. However, other authors reported that RTSA appears to achieve better clinical outcomes than HA. Ross et al. reported good clinical and radiographic outcomes of RTSA in elderly patients (mean age 79 years [range, 67 to 90 years]) with three- and four-part proximal humerus fractures and an extremely low complication rate (3.4%) with no dislocations, infections or prosthetic revisions. A recent meta-analysis showed that RTSA may produce more favourable clinical outcomes than HA for treating complex proximal humeral fractures.

Several studies have cautioned that RTSA may not be the optimal treatment for patients with acute proximal humerus fractures. Smith et al. reported that patients treated with RTSA had limited post-operative abduction (approximate range 90° to 100°), and that recovery of external rotation and internal rotation varied widely. Cazeneuve and Cristofari and Bufquin et al. showed various post-operative radiographic findings in patients with acute proximal humerus fractures treated with RTSA, and they cautioned that long-term results are required before RTSA can be recommended as a routine procedure for complex fractures of the proximal humerus in the elderly.

**Malunited/nonunited proximal humerus fracture**

Studies with short-term follow-up have reported high rates of patient satisfaction with RTSA for improving ROM, treating malunited proximal humerus fracture and reducing pain. Boileau et al. recommended the use of RTSA to treat type-4 malunions (severe tuberosity malunion) when a greater tuberosity osteotomy was required. In a retrospective review, Martinez et al. reported improvement in Constant-Murley scores and ROM, as well as a high patient satisfaction rate (86%). Before surgery, patients should be informed that active external rotation might not be restored after RTSA, particularly if an osteotomy of the greater tuberosity is performed. Another approach to patients with painful, malunited proximal humeral fractures is to leave the tuberosities in place and insert the RTSA into the existing anatomy. Willis et al. did not perform a tuberosity osteotomy when placing the RTSA and recommended using the largest possible glenosphere to tension the soft tissue and prevent bony impingement.

Raiss et al. reported on 42 patients treated with RTSA for post-traumatic sequelae of the proximal part of the humerus with malunion of the tuberosities. Of those patients, 43% rated their result as very good, 45% as
good, 10% as satisfactory and 2% as unsatisfactory. Complications were one intra-operative humeral shaft fracture, one traumatic dislocation, one periprosthetic humeral fracture and one aseptic loosening of the humeral and glenoid components. The authors concluded that RTSA is a good treatment option for type-4 proximal humeral fracture sequelae that cannot be treated with anatomical TSA. In a study at the same institution, the use of RTSA for the treatment of nonunion of the surgical neck of the proximal part of the humerus (type-3 fracture sequelae) produced improvement in functional outcome but a high complication rate. Dislocation was the most common complication and was associated with resection of the tuberosities of the proximal part of the humerus, which has been postulated to be necessary to provide a compressive force from the deltoid muscle. Another reason for instability may be the removal of the rotator cuff to gain exposure and place the implants. Therefore, the authors recommended that the tuberosities and the attached rotator cuff should be preserved if possible to reduce the risk of dislocation.

Glenohumeral OA with severe glenoid bone loss

The use of RTSA in patients with severe glenoid bone loss and OA has been reported. There are several classifications of glenoid bone loss that define various defects caused by OA. The most commonly used classification is that of Walch et al: type A2, central bone loss; type B2, posterior bone loss; and type C, severe retroversion of the glenoid (Fig. 5).

Although glenoid bone grafting has been recommended for type-B2 and type-C glenoid wear, it has been shown that use of RTSA without glenoid bone grafting can be successful for patients with severe glenoid bone loss. Excellent results have been reported in patients with OA, an intact rotator cuff and substantial glenoid bone loss treated with RTSA with or without bone grafting (Fig. 6). Long-term follow-up studies are needed before RTSA can be recommended in patients with severe glenoid bone loss.

Chronic locked glenohumeral joint dislocation

Chronic locked glenohumeral dislocation presents many challenges caused by humeral and glenoid bone loss, concomitant soft-tissue contractures and rotator cuff lesions. In these patients the failure rate for TSA has increased, with increasing follow-up because of recurrent instability, glenoid loosening and graft subsidence. Werner et al. reported on 21 patients treated with glenoid bone grafting with RTSA for neglected anterior dislocation with substantial glenoid bone loss at a mean follow-up of 4.9 years (range, 2 to 10 years). They reported an average 45% glenoid bone loss based on glenoid width measurements on pre-operative CT scans or MR images. Outcomes were rated as excellent by ten patients, good by eight patients and fair by three patients.

Rheumatoid arthritis with or without associated rotator cuff tears

The use of RTSA for patients with rheumatoid arthritis has been studied by several authors. Two studies have raised concerns about the high incidence of glenoid base-plate radiographic lucency at follow-up in this patient population. However, excellent to satisfactory results have been reported in up to 95% of patients with rheumatoid arthritis who were treated with RTSA.

Revision arthroplasty

The options for revision surgery after primary shoulder arthroplasty (i.e. HA, resurfacing arthroplasty or TSA) are limited by the challenges of rotator cuff deficiency, glenoid bone loss and soft-tissue contractures. RTSA has solved many of these challenges and produced high patient satisfaction (Fig. 8). However, although some of
the clinical results have been excellent, the use of RTSA in these patients is associated with higher complication and failure rates compared with RTSA for patients without previous arthroplasty.\textsuperscript{78}

The outcomes of RTSA for failed shoulder arthroplasty have been favourable.\textsuperscript{12,13,16,79-81} Levy et al\textsuperscript{12} retrospectively reported on outcomes of 29 RTSAs for the treatment of failed HA performed after proximal humeral fracture. They found significant improvements in the simple shoulder test (SST) and ROM but a complication rate of 28%. Another study of outcomes of RTSA after failed HA in 19 shoulders of 18 patients with glenohumeral arthritis and rotator cuff deficiency reported significant improvement in ROM, with 32% of patients undergoing revision for prosthesis-related complications.\textsuperscript{13} Walker et al\textsuperscript{81} evaluated 24 patients who underwent RTSA after failure of TSA. They found significant improvements in SST scores and ROM but an overall complication rate of 23%. Similarly, Melis et al\textsuperscript{79} studied 34 patients who underwent revision RTSA for failed TSA and found that Constant-Murley scores and the ROM in forward flexion improved significantly. They reported a post-operative complication rate of 30%, and 22% of these patients underwent revision surgery. Patel et al\textsuperscript{80} reported on 28 patients who underwent RTSA for treatment of a failed shoulder arthroplasty (i.e. HA, RTSA or TSA). They reported significant improvements in all outcome measures, including ASES score, University of California Los Angeles score, SST score and the visual analogue scale, with an overall complication rate of 10.7%. Black et al\textsuperscript{16} reported on 32 patients aged younger than 65 years.
REVERSE TOTAL SHOULDER ARTHROPLASTY

treated with RTSA after failed shoulder arthroplasty. Results were compared with those of a similar cohort of 33 patients who underwent primary RTSA. Post-operatively, when comparing primary to revision RTSA, the visual analogue scale and ASES scores were not significantly different, whereas the subjective shoulder value was significantly better for the primary group. Although there were more complications in the revision group (28% versus 18%), the difference was not statistically significant.

Tumours

Several shoulder reconstruction techniques have been reported for patients after wide resection of the proximal humerus and rotator cuff tendons for malignant bone tumours, including allograft, arthrodesis and shoulder arthroplasties. However, a prerequisite for the ability to implant a RTSA in these cases requires preservation of the axillary nerve and deltoid muscle to be successful.

Bonneville et al reported on eight patients treated for malignant tumours of the proximal humerus with transtpheric resection of the tumour and shoulder reconstruction with RTSA. They reported improvement in all outcome scores and concluded that RTSA is an acceptable option to preserve function after resection of a malignant tumour of the proximal humerus.

Complications

Reported complication rates after RTSA are in the range of 19% to 68% and include acromial fracture, haematoma, infection, instability, mechanical baseplate failure, neurological injury, periprosthetic fracture and scapular notching. These rates are influenced by the indications for RTSA and the proportion of revision procedures included in each study. Other factors influencing complication rates include component design and surgeon experience. Wall and Walch reported a 13% complication rate for primary RTSA and a 37% complication rate for revision RTSA. Wierks et al reported 33 complications in 15 patients; the most frequent complications were neuropathy, intra-operative fracture and dislocation, with the primary cause for revision surgery being dislocation. Other authors have reported complication rates as high as 68% for primary RTSA. reported the incidence of complications to be 19% for primary RTSA and 24% for revision RTSA. For revision RTSA, the reported complication and revision rates in a meta-analysis by Zumstein et al were 24% and 10%, respectively. reported overall complication rates of 25% after primary RTSA and 69% after revision RTSA.

Instability

Dislocation after RTSA is a major concern (Fig. 9). The incidence of post-operative instability has been reported to be in the range of 2% to 31%. Patient risk factors for dislocation include body mass index > 30, male sex, previous surgery and subscapularis deficiency. Surgical factors contributing to instability include inadequate soft-tissue and deltoid tensioning, malpositioned implants, mechanical impingement, insufficiency of the subscapularis and use of the deltopectoral approach compared with the anterosuperior approach. The instability rate has also been associated with prosthesis design; prostheses with a head-neck angle of -155° have been shown to have a higher instability rate than those with a more horizontal head-neck angle of 135°.

Teusink et al reported that instability of RTSA often occurs within six months after surgery, with half of cases occurring within three months. When dislocation occurred within three months, a surgical error was considered the most likely cause and closed reduction was typically unsuccessful. Conversely, late dislocation (> 1 year after surgery) can usually be treated successfully with closed reduction.

Infection

Reported rates of infection after RTSA are in the range of 1% to 15%, which is higher than the infection rate after anatomical TSA. In one of the few comparison studies, Barco et al found the infection rate after primary RTSA to be significantly higher than that after primary TSA. In a systematic review including primary and revision RTSA, Zumstein et al reported a mean infection rate of
3.8%, with a higher rate of infection after revision surgery than after primary surgery. In a study of 3906 patients, Richards et al.\textsuperscript{102} reported a sixfold greater risk of infection after RTSA compared with an anatomical TSA. A history of shoulder trauma or failed HA has also been shown in some studies to be a risk factor for infection.\textsuperscript{102,103}

**Scapular notching**

Scapular notching is a complication unique to RTSA, with a reported incidence of 50% to 96% (Fig. 11).\textsuperscript{14,30} Scapular notching typically occurs within six months after surgery and appears to stabilize in most cases.\textsuperscript{104,105} However, some studies report an apparent increase in incidence and severity of notching with increasing follow-up.\textsuperscript{100} The rate of notching in RTSAs with a medialized centre of rotation has been reported to be 47%; however, systematic review has reported rates of up to 97%.\textsuperscript{90} The reported rate of notching when using lateralized RTSAs (4.6%) is significantly lower compared with medialized designs.\textsuperscript{90} The major concern with notching is that it may lead to baseplate failure, but that concern remains controversial (Fig. 12).

Although some authors have suggested an increased risk of baseplate loosening with scapular notching,\textsuperscript{30,106-108} others have not found such a relationship.\textsuperscript{32,92,109-111} The clinical implications of notching are controversial; some authors have reported no associations with clinical outcomes,\textsuperscript{32,110,111} whereas others have reported that high grades of notching may be associated with worse clinical outcomes.\textsuperscript{32,104,110,111} The use of an anterosuperior approach, a high position of the baseplate on the glenoid and superior tilting have all been associated with higher rates of notching caused by mechanical impingement with the arm in adduction.\textsuperscript{110} Eccentric glenospheres with an inferior offset and glenoid components with a more lateral offset (bony or metal) can reduce the risk of notching.\textsuperscript{112,113} Mizuno et al.\textsuperscript{114} analysed the influence of an eccentric glenosphere in 47 consecutive cases compared with an historical group treated by the same surgeon. The rates of notching were not different but the severity of notching was less when using an eccentric glenosphere. Other authors have reported a negligible rate of notching when using an inferior offset component.\textsuperscript{115}
Heterotopic ossification

Heterotopic ossification after RTSA is a relatively common finding of unknown clinical importance.116 In a 164-patient cohort of primary and revision RTSAs, Ko et al116 found an overall rate of heterotopic ossification of the long head of the triceps tendon of 62%. They found that men had a higher rate of heterotopic ossification than women, and that heterotopic ossification was associated with worse post-operative ROM.116 The exact cause of heterotopic ossification in the long head of the triceps tendon after RTSA is unknown. It has been postulated to be caused by releases, traction on the triceps and more extensive exposure of the glenoid than is typically done in anatomical TSA.116

Neurological injury

Neurological injury is a known complication of shoulder arthroplasty of all types, with reported incidence in the range of 1% to 4%.117,118 Nerves from the brachial plexus can undergo stretch injuries at the extremes of motion that occur during intra-operative positioning of the arm.118,119 Brachial plexus palsies have been shown to be more common in RTSA than in TSA, possibly because of the lengthening effect on the arm during RTSA and the need for greater glenoid exposure.120

Scapular fractures

Scapular fractures are a well-recognized complication of RTSA, and they have been reported in 0.8% to 7.2% of cases.121 Postulated causes include excessive tensioning of the deltoid,90 placement of a superior screw in the base-plate122 and stress of the implants on osteoporotic bone.123 Insufficiency fractures of the acromion or displacement of the os acromiale after RTSA can be painful and can limit ROM.90,100,124 Conversely, scapular spine fractures lead to painful dysfunction and may require ORIF.100 Post-operative scapular fractures have been associated with inferior clinical results and increased risk of revision.121 Bilateral scapular fractures125 and clavicle stress fractures126 after RTSA have also been reported.

Conclusions

RTSA has revolutionized the treatment of shoulder disorders that previously had no easy or acceptable solution. Patient satisfaction with RTSA can be high, and most patients experience pain relief and improved function. Although the short-term implant survival rate appears to be acceptable, the long-term results are unknown. RTSA is associated with a higher rate and more diverse spectrum of complications than is desirable. Improvements in prosthesis design, surgeon experience and clinical results will need to occur to optimize this treatment for many shoulder conditions.

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