Chapter 16
Reverse Shoulder Arthroplasty

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Abstract Severe cuff deficiency and destruction of glenohumeral joint may lead to a painful and pseudo-paralyzed shoulder. In this situation an anatomic total shoulder prosthesis yields a limited clinical result or may even be contraindicated because of glenoid loosening. Early models for reverse shoulder prosthesis were developed to address the drawbacks of conventional shoulder prostheses have failed because of an underlying design flaw. The reverse prosthesis designed by Grammont has introduced new innovations that have led to its success. The Grammont prosthesis imposes a new biomechanical environment for the deltoid muscle to act, thus allowing it to compensate for the deficient rotator cuff muscles. Although new prostheses have been developed to improve on Grammont's original design, they continue to follow Grammont's core principles. Accumulated experience with reverse shoulder arthroplasty has led to expanded surgical indications, including cuff tear arthropathy, massive rotator cuff tears, fracture sequelae, rheumatoid arthritis, acute fractures, tumors or as a revision procedure for failed prostheses. The complication rates has increased with the increasing indications. Longer follow-up studies are required to assess the survival of the prosthesis and the functional performance over time, and it has been recommended to limit its use to elderly patients, basically those aged over 70 years.

Keywords Rotator cuff tear • Prosthesis • Cuff tear arthropathy

16.1 Introduction

The original type of anatomic total shoulder arthroplasty (TSA) was developed by Neer [1], who reported an excellent outcome of TSA for rheumatoid and osteoarthritic shoulders. Conventional arthroplasty was improved by a modular-type prosthesis, which could be separated into humeral and stem parts in 1986 [2].

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A newer type of prosthesis, in which the head–neck angle and offset could be changed according to the presence of anatomic deformities, became available in 1997 [3].

Until March 2014, only anatomic TSA was available in Japan. In this procedure, the deformed joint (up to the humeral head and glenoid) is replaced. This procedure was not suitable for the treatment of glenohumeral arthritis patients with severe cuff function deficiency.

Stanmore TSA has been performed in patients with destructive shoulder and a lack of cuff function as a constrained-type prosthesis [4]. This procedure is no longer in use because of its association with mechanical failure. In the 1970s, reverse shoulder arthroplasty (RSA) was developed as a prosthesis that could be used to replace a destroyed shoulder joint without rotator cuff function [5, 6]. The prosthesis initially had a biomechanical failure, which was caused by the loosening of the glenoid component; however, outcomes are currently satisfactory, and good results have been reported in 89 % of cases since the improvement of the prosthesis [7].

The reverse prosthesis has been allowed in neighboring countries, including South Korea (since 2006), China (since 2008), and Hong Kong (since 2011); thus, its suitability for smaller Asian patients has been proven. RSA has become a standard procedure in shoulder surgery throughout the world. This type of prosthesis has been used in developing countries as well as in advanced countries, with the previous exception of Japan. RSA is indicated for shoulder disabilities in which the patient does not have normal cuff function; however, postoperative complications have been reported to frequently occur in cases in which surgeons fail to properly adhere to the indications and surgical techniques.

RSA was permitted by the Health, Labor, and Welfare Ministry of Japan from April 2014, after the guidelines for the use of RSA were established by the ad hoc committee of the Japan Orthopaedic Association. The guideline describes several points about the use of RSA, including (1) the indications for RSA; (2) complications during and after operations, (3) points to consider for RSA; (3) operating rooms that are suitable for RSA; (4) surgeons who can perform RSA; (5) lecture classes for RSA; and (6) a registration system for RSA. In 2014, 500 RSA procedures were performed in 9 months in Japan. Anatomic TSA is thought to have been performed in fewer than 400 cases during the same period. RSA is currently more popular than anatomic TSA in Japan. This chapter discusses RSA, including the Japanese guideline for its use.

16.2 Development and Characteristics of Reverse Shoulder Arthroplasty

The most remarkable feature of the glenohumeral joint is its ability to precisely stabilize the humeral head in the center of the glenoid while also allowing a wide range of motion. This balance of stability and mobility is achieved by a combination of mechanisms particular to this articulation [8].

A massive cuff tear is required for a diagnosis of cuff tear arthropathy (CTA), but not everyone with a massive cuff tear develops CTA. The exact etiology of CTA is likely multifactorial and can be associated with inflammatory and crystal-induced arthritis [9, 10]. Neer [9] first described the theoretical process that mechanical and nutritional factors might function in the development of CTA. Treatments for CTA have ranged from nonoperative management and glenohumeral arthrodesis to resection arthroplasty and artificial joint replacement. Anatomic shoulder arthroplasty used to be a standard surgical option in the treatment of patients with CTA [1]. Neer determined that the outcomes of unconstrained shoulder arthroplasty were poorer in the case of cuff deficiency.

The anatomic prosthetic replacement has been abandoned because of cuff deficiency, resulting in superior displacement of the humeral component and glenoid loosening [11, 12]. Hemiarthroplasty was observed to provide similar results with respect to pain relief, functional improvement, and patient satisfaction. Shoulders that have undergone hemiarthroplasty gained significantly more active elevation after surgery. Cuff repair was easier when a humeral head prosthesis alone was used because less lateralization of the humerus occurred [12]. However, it has been difficult to predict the outcomes in these patients in terms of mobility and pain relief [13].

Reverse total shoulder arthroplasty (RSA) has become very popular because of its ability to treat patients experiencing severe rotator cuff dysfunction with or without glenohumeral arthritis [14]. An extensive understanding of the shoulder and artificial joint biomechanics makes it possible to accurately design shoulder prostheses.

To address the drawbacks of conventional shoulder prostheses, early models for RSA were developed. However, numerous reverse prosthesis designs of the 1970s resulted in implant breakage and glenoid component loosening because of an underlying design flaw [15, 16].

In 1985, Paul Grammont designed a reverse prosthesis for arthritic shoulders with severe destruction of the cuff, in which standard anatomic prostheses could not be used to restore joint stability and mobility [14, 17]. Boileau et al. [18] explained that the Grammont reverse prosthesis, differing from any previous reverse ball-and-socket design, has introduced two major innovations:

1. In contrast to all previous reverse ball-and-socket prostheses, the Grammont glenoid component is a third of a sphere with a large diameter of 36 or 42 mm and no neck. The back of the glenosphere is in direct contact with the prepared

glenoid surface. This design has the advantage of placing the center of rotation of the joint in contact with the center of the humeral head and provides a fixed center of rotation. Furthermore, the large diameter allows greater range of movement before impingement of the components occurs and provides more stability.

2. The humeral component has a small cup, oriented with a nonanatomic inclination of 155°, that covers less than half of the glenosphere; this has the advantage of lowering the humerus, resulting in overtensioning the deltoid. It allows a greater range of movement to occur before component–bone impingement.

Recently, Berliner et al. [19] reviewed the biomechanics of RSA. Grammont changed the system's center of rotation directly to the bone–implant interface. This design medialized the joint's center of rotation and stabilized the bone–implant interface by converting the shear forces that challenge glenoid fixation into compressive forces [20].

Further, inferior overhang of the glenosphere provides a space between the glenosphere and the scapular neck that may decrease notching. It also creates additional clearance between the greater tuberosity and coracoacromial arch, allowing greater impingement-free range of motion during abduction. The system is designed both to retension and to reposition the deltoid in relation to the joint's center of rotation. A medialized center of rotation increases the deltoid's moment arm by 20–42 % and recruits additional fibers of the anterior and posterior deltoid to serve as abductors (Fig. 16.1) [18, 20, 21] (figure explanation by Kapandji [22] is cited). Compared with native anatomy, the deltoid abduction moment arm in a reverse shoulder has much greater fluctuation peaking at 90° of abduction, the position at which the weight of the arm creates its largest adducting moment [20]. The enhanced torque-producing capacity of the deltoid, particularly in early abduction, may compensate for impairment in the initiation of torque resulting from supraspinatus deficiency. A distalized center of rotation restores tension to a shortened deltoid in the setting of cuff tear arthropathy, effectively improving the muscle's efficacy by approximately 30 % [21]. In addition, distalization of the center of rotation is necessary to provide space for the proximal humerus, allowing less restricted range of motion. Anatomic TSA has a large prosthetic head with a small shallow glenoid. In general, the radius of curvature of the glenoid is at least 5.5 mm longer than that of the humeral component. Grammont's reverse prosthesis, designed with equal radii of curvature, is able to tolerate a joint-reaction force vector of up to 45° [23] whereas the net humeral joint-reaction force vector in conventional total shoulder arthroplasty must be directed within 30° of the glenoid centerline to avoid dislocation [24]. Increased constraint secondary to the deeper and the more conforming concavity of the humeral articular surface prevents glenohumeral translation while providing sufficient stability for functional range of motion. This high degree of intrinsic stability frees the reverse total shoulder prosthesis from dependence on active stabilization by concentric compression and provides a stable fulcrum for the remaining musculature [23]. Total shoulder arthroplasty has a ratio of approximately 1.0 [25, 26], whereas RSA has a stability

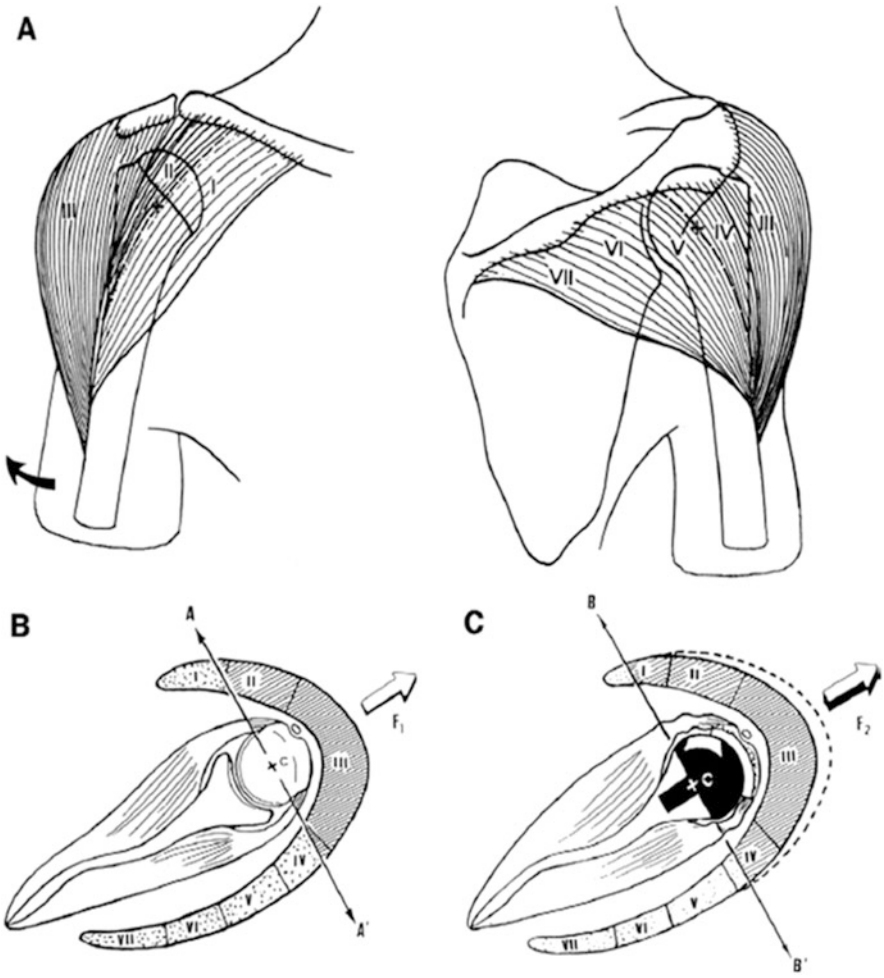

Fig. 16.1 The seven segments of the deltoid, according to Kapandji [22]. (**a**) In a normal shoulder, only the middle deltoid (segment III) and part of the anterior deltoid segment (segment II) can participate to active elevation (**b**). (**c**) After a reverse prosthesis, the medialization of the center of rotation recruits more of the deltoid fibers (segments I and IV) for active elevation. (With permission of Elsevier)

ratio greater than 2.0. With the glenohumeral joint in 90° of abduction, the reverse total shoulder is approximately four to five times more stable than a normal joint and two to three times more stable than an anatomic total shoulder prosthesis [27]. In addition, the net compressive force acting on the glenohumeral articulation is the most important factor of stability [28]. In a reverse shoulder, joint compressive forces are largely produced from deltoid tensioning. Stability also depends on glenoid component positioning.

Although new prostheses have been developed to improve on Grammont's original design, they continue to follow Grammont's core principles [19].

16.3 Indications for Reverse Shoulder Arthroplasty

Reverse shoulder arthroplasty (RSA) was initially recommend only for patients with a combination of disabling glenohumeral arthritis and cuff deficiency. However, clinical success in the restoration of stability, balance, and function has given rise to expanded indications such as a cuff-deficient shoulder without arthritis. With the gradual evolution of the indications, RSA has become an important surgical option in the treatment of a variety of conditions [29].

The Japanese guidelines for RSA list five basic concepts as indications for reverse shoulder arthroplasty (Table 16.1). RSA may be considered when the following conditions are fulfilled. (1) The patient complains of shoulder symptoms caused by irreparable rotator cuff tear associated with pseudo-paresis of anterior elevation and/or abduction in spite of conservative therapy for a certain period of time. Patients with a reparable cuff tear should undergo arthroscopic or open rotator cuff surgery. (2) Degenerative diseases of the shoulder joint, such as cuff tear arthropathy and rheumatoid arthritis, are good conditions for RSA. However, anatomic total shoulder arthroplasty is recommended for the treatment of degenerative disease in patients with intact rotator cuff function (such as patients with primary osteoarthritis of the glenohumeral joint). (3) The strengthening of elevation and pain relief can be achieved, but a full recovery of elevation power is not be expected. Patients with reverse prostheses have reduced strength in comparison to normal patients. This effect is most apparent in external rotation and might explain the clinical outcomes in which a moderately strong relationship is observed. It has been suggested that limited strength is a major factor in reduced range of motion (ROM) [30]. (4) In consideration of the previously reported outcomes, RSA basically should be performed in patients who are older than 70 years. (5) RSA is a final procedure, not a preventive procedure.

Despite demonstrating the early improvement of function and pain, there is limited information regarding the durability and longer-term outcomes of RSA. Survivorship free of revision surgery was 89 % at 10 years with a marked break occurring at 2 and 9 years. Survivorship with a Constant-Murley score less than

Table 16.1 Basic principles for reverse shoulder arthroplasty (RSA) according to the Japanese guidelines for RSA

1. Patients with pseudo-paralysis of the shoulder
2. Degenerative changes in the roentgenographic findings with rotator cuff deficiency
3. The strengthening of elevation and pain relief can be achieved, but the surgeons do not expect a full recovery of elevation power
4. Essentially limited to patients older than 70 years of age
5. A final procedure, not a preventive procedure

30 was 72 % at 10 years with a marked break observed at 8 years [7]. Although the need for revision of reverse shoulder arthroplasty was relatively low at 10 years, the Constant-Murley score and radiographic changes showed deterioration over time. These findings regarding the potential longevity of reverse shoulder arthroplasty are concerning, and caution must therefore be exercised in performing the procedure, especially in younger patients. In consideration of this fact, reverse shoulder arthroplasty has primarily been indicated for patients older than 70 years with symptomatic rotator cuff deficiency, poor function, and pain. The average life expectancy of Japanese individuals in 2014 is approximately 86.83 years in women and more than 80.5 years in males. Japanese individuals have one of the longest lifespans in the world. According to the guidelines, rotator cuff function deficiency and shoulder pain are good indications of RSA when patients are older than 70 years. However, there might be some other indications, including (but not limited to) the salvage of failed total shoulder arthroplasty or the presence of a tumor around the shoulder area.

16.3.1 Absolute Indication

16.3.1.1 Cuff Tear Arthropathy (Hamada Classification [31]: Grade 4, 5)

Cuff tear arthropathy (CTA), a term which was coined by Neer [9] in 1983, describes a state of severe disorganization of the glenohumeral joint following a massive cuff tear. CTA patients are typically elderly and present with a history of long-standing shoulder pain, weakness, decreased active motion, and limited function [32, 33]. CTA occurs in women more frequently than men, and the dominant side is more commonly affected than the nondominant side. Such patients frequently receive multiple injections of corticosteroids and may have undergone one or more surgical interventions. In 1990, Hamada et al. [34] radiographically classified massive rotator cuff tears into five grades. Walch et al. [35] subsequently subdivided grade 4 to reflect the presence or absence of subacromial arthritis and to emphasize glenohumeral arthritis as a characteristic of grade 4.

Hamada et al. [31] examined whether patient characteristics and magnetic resonance imaging (MRI) findings differed between the grades at the initial examination and found that patients with grade 3, 4, or 5 tears had a higher incidence of fatty muscle degeneration of the subscapularis muscle than patients with grade 1 or 2 tears. Currently, the most common indication for a RSA is pain and altered function resulting from glenohumeral arthritis with the compromise of the rotator cuff. When pain or loss of motion is resistant to conservative treatment, alternative treatments should be considered. Arthroscopic debridement or biceps tenotomy may improve pain; however, the results have not been consistent. Glenohumeral arthrodesis may be considered for patients with a nonfunctional deltoid muscle [36]. RSA has become the most common surgical treatment option for patients with

CTA: the ideal candidate for RSA is a CTA patient with severe pain and pseudoparesis [14, 29, 37–39]. The survival rates with the replacement of the prosthesis and glenoid loosening as the end points were 91 % and 84 %, respectively, at 120 months, with a significantly better result demonstrated in shoulders that had arthropathy with a massive rotator cuff tear in comparison to disorders of other etiologies [40].

The presence of a preoperative acromial stress fracture is not considered to be a contraindication to RSA [41]. Boileau et al. [37] suggested that a history of previous infection and a nonfunctional deltoid muscle are two major contraindications to a reverse prosthesis. Gerber also stated that complete axillary nerve palsy is considered a contraindication because of the very high probability of recurrent instability and the minimal potential gain in function [42]. In addition, infection, neuroarthropathy, and substantial glenoid bone erosion or defects are contraindications to RSA.

16.3.1.2 Irreparable, Massive Cuff Tear (Hamada Classification [31]: Grade 2, 3)

Many authors currently define a tear as massive if there is a detachment of at least two complete tendons. The management of patients with irreparable, massive rotator cuff tears in the absence of glenohumeral arthritis remains a challenge for orthopedic surgeons. A variety of arthroscopic treatment options have been proposed for patients with irreparable rotator cuff tears without the presence of arthritis of the glenohumeral joint: these include subacromial decompression [43], simple debridement with a biceps tenotomy [44], partial rotator cuff repair [45], tuberoplasty [46], graft interposition of the rotator cuff [47], superior capsule reconstruction [48], and insertion of a biodegradable spacer [49] to depress the humeral head. In cases of irreparable massive cuff tear with or without glenohumeral pathology, several studies have shown that RSA can predictably restore functions including overhead elevation, improve pain, and increase external rotation, particularly if the patient has a functioning teres minor [38, 40]. Mulieri et al. [50] evaluated the indications for and outcomes of RSA in patients with massive rotator cuff tears but without glenohumeral arthritis. Their indications for RSA include persistent shoulder pain and dysfunction despite the provision of nonoperative treatment for a minimum of 6 months, the presence of at least a two-tendon tear, and Hamada stage 1, 2, or 3 changes in a patient for whom a non-arthroplasty option does not exist. The authors concluded that when non-arthroplasty options have either failed or have a low likelihood of success, RSA provides reliable pain relief and a return of shoulder function in patients with massive rotator cuff tears without arthritis at the time of short- to intermediate-term follow-up examinations.

16.3.2 Relative Indications

16.3.2.1 Complex Three- and Four-Part Proximal Humerus Fractures in Elderly Patients

The use of reverse shoulder arthroplasty is becoming increasingly popular in the treatment of complex three- and four-part proximal humerus fractures in elderly patients [51].

Proximal humerus fractures account for nearly 5 % of all fractures and are increasing in frequency in aging populations. Although three- and four-part fractures and fracture dislocations account for 5 % of all proximal humerus fractures, elderly patients are more prone to sustaining complex fracture patterns in comparison to younger patients [52–54]. Fragility fractures of the proximal humerus are often highly comminuted and displaced and involve poor bone quality, which makes them difficult to treat with open reduction and internal fixation or hemiarthroplasty. Concerns regarding plate osteosynthesis include humeral head osteonecrosis, loss of fixation, and screw penetration through the humeral head. Hemiarthroplasty offers a good solution for irreparable fractures and provides good pain relief; however, the functional outcomes are not always predictable [55]. Hemiarthroplasty outcomes are often bimodal and are divided between excellent and poor outcomes, with the main determinant being the healing of the tuberosities [56]. Consequently, RSA has been advocated for the treatment of complex fractures because the results are often more consistent and predictable [55].

16.3.2.2 Fracture Sequelae of the Proximal Humerus, Including Malunion and Nonunion

Late complications in the proximal humerus, such as malunion, avascular necrosis, and nonunion are frequent and often lead to articular incongruence [57]. Patients can be severely handicapped and may experience considerable pain, stiffness, and important functional impairment. Stiff shoulders with a distorted proximal humerus, soft tissue damage, a scarred deltoid, and rotator cuff tears make shoulder arthroplasty a challenging procedure. The sequelae of a proximal humeral fracture can cause shoulder pain and functional impairment. Hemiarthroplasty or total shoulder arthroplasty are considered after failure of nonoperative treatment [1], although the results have often been poor and unpredictable [58–60]. The procedure is associated with a high risk of complications [57]. The overall results of patients with old trauma are inferior to those that are currently obtained in patients with primary osteoarthritis or with recent four-part fractures who are initially treated with humeral head replacement. In elderly patients in whom there is significant distortion of the proximal humerus, poor bone quality, rotator cuff lesions, or muscle atrophy, reverse shoulder arthroplasty can be proposed instead of

non-constrained arthroplasty. Fracture sequelae of the proximal part of the humerus are challenging conditions, and various treatment options have been described. The nonunion of the proximal humerus can be treated with reverse shoulder arthroplasty. The clinical outcomes of RSA have shown significant improvement [57, 61]. Martinez et al. [62] reported on a case series of 44 patients who underwent RSA for proximal humeral sequelae. The Constant score of the patients improved from 28 to 58 points, the anterior elevation improved from 40° to 100°, and range of external rotation improved from 15° to 35°. The most common complication was prosthesis instability. Zafra et al. [63] reviewed the results of 35 patients who underwent RSA for the treatment of nonunion of a fracture of the proximal humerus. The patients reported a significant decrease in pain, and significant improvements were observed in their flexion, abduction, external rotation, and Constant scores. A total of nine complications were recorded in seven patients including dislocation ($n = 6$). Reverse shoulder replacement may lead to a significant reduction in pain, improvement in function, and a higher degree of satisfaction. However, the rate of complications, particularly dislocation, is high.

16.3.2.3 Rheumatoid Shoulder with Cuff-Function Deficiency

Rheumatoid arthritis represents the majority of inflammatory arthritis cases and affects 1 % of the world's population [64–67]. Furthermore, shoulder symptoms are reported in up to 91 % of patients with long-standing rheumatoid arthritis. A system popularized by Laine et al. [68] categorized rheumatoid arthritis into three stages of disease. Stage II is characterized by a marked limitation in the range of motion and radiographic changes in all cases, with limitations that vary from slight to severe. Stage III disease includes patients in whom the disease has "burned out" and is characterized by severe limitations of movement and radiographic changes, including bone erosion and joint space narrowing. Stage II or III patients in whom the disease shows progression and who have disabling pain should be considered for arthroplasty [69]. The attenuated soft tissue of the rheumatoid shoulder, including the increased frequency of rotator cuff tears, must be considered when planning shoulder arthroplasty. RSA is attractive in patients with end-stage rheumatoid arthritis associated with a massive, irreparable rotator cuff tear (Barlow shoulder arthroplasty [67].

One systemic review showed that the mean increases in Constant score and ASES score after RSA surgery were 42.4 and 54 points, respectively [70]. The mean postoperative forward elevation was 120.6°, with the average increase in elevation being 51°. The mean increase in abduction was 58.5°. Revision surgery was performed for eight prostheses (because of infection in four cases). The authors concluded that RSA appeared to achieve similar results in RA patients to those obtained in patients with massive cuff tears with or without arthropathy.

16.3.2.4 Revision Surgery for Failed TSA

Total shoulder arthroplasty is one of the most effective procedures for relieving pain and improving function. The implant survival of total shoulder prostheses was previously reported to be inferior to that of hemiprostheses [71]. According to the Norwegian Arthroplasty Register, the 5-year survival rates for hemiprostheses and anatomic total prostheses and reverse total prostheses inserted from 2006 to 2012 were 95 % (compared to 94 % in 1994–1999), 95 % (75 % in 1994–1999), and 93 % (91 % in 1994–1999), respectively [72]. The findings indicated that the survival of anatomic total shoulder prostheses has improved. Risk factors for revision include young age, male gender, and shoulder arthroplasty for trauma-related sequelae [73, 74]. Singh et al. [75] examined the factors that were predictive of revision in 2207 patients who underwent total shoulder arthroplasty (TSA) and found that male gender and rotator cuff disease were independent risk factors for revision after TSA. If it is uncertain whether the revision of failed anatomic hemiarthroplasty or total shoulder arthroplasty will preserve or restore satisfactory rotator cuff function, conversion to reverse total shoulder arthroplasty has become the preferred treatment, at least for elderly patients. Wall et al. [76] reported that the postoperative Constant scores of revision arthroplasty patients were significantly worse than those of three other groups of patients (cuff tear arthropathy, massive cuff tear, and primary osteoarthritis). Patients in the revision arthroplasty group also had significantly worse postoperative ranges of elevation in comparison to the other three groups. In addition, the percentage of patients who stated that they were very satisfied or satisfied with the outcome was lower in the revision arthroplasty group than in the other three groups; however, this difference did not achieve statistical significance. A humeral fracture occurred during removal of the primary prosthesis or cement mantle during 13 of the 54 (24.1 %) revision procedures.

16.3.2.5 Primary Osteoarthritis of the Glenohumeral Joint with Glenoid Deformity

Neer et al. [1] observed the existence of posterior glenoid erosion and humeral head subluxation in some cases of primary glenohumeral arthritis and advised that erosion of the eccentric glenoid be corrected at the time of implantation of a polyethylene glenoid. The results of shoulder arthroplasty in the presence of a biconcave glenoid have been analyzed as part of a larger series of shoulders with and without this specific pathology [77, 78]. Humeral head replacement is associated with poor functional results. Levine et al. [79] found that only 63 % of results were satisfactory in patients with posterior glenoid wear. Iannotti and Norris [80] analyzed the influence of humeral head subluxation and posterior glenoid erosion in patients with primary osteoarthritis and found that shoulders with posterior subluxation of the humeral head (as quantified by preoperative axillary radiographs) had lower functional results and more pain regardless of whether the patient underwent

hemiarthroplasty or total shoulder arthroplasty (TSA). Walch et al. [81] reported on 92 TSAs that were performed for B2 glenoids which were reviewed at a mean of 77 months after surgery. Revision surgery was required in 16 % of the cases and glenoid loosening was observed in 21 % of the cases. Mizuno et al. [82] reported the results of 27 RSAs in patients with primary glenohumeral arthritis with a B2 glenoid at a mean of 54 months after surgery. The mean Constant score increased from 31 to 76, and no recurrence of posterior instability was observed.

The B2 glenoid presents a difficult reconstructive problem with high failure rates caused by early glenoid loosening or recurrent posterior instability with the use of anatomic arthroplasty. In particular, unacceptably high rates of complications have been observed in cases where posterior humeral head subluxation is more than 80 % or neoglenoid retroversion is greater than 27° [82]. When posterior erosion cannot be adequately corrected with eccentric reaming, particularly in older patients, primary reverse shoulder arthroplasty may be a more predictable means of addressing bone deficiency and restoring stability.

16.3.2.6 Proximal Humerus Tumors Requiring the Resection of Rotator Cuff Insertions

The proximal humerus is the third most common site for primary bone tumors and soft tissue tumors [7]. Even in cases for which oncological treatment is essential, the preservation of shoulder function is important after a wide resection of the proximal humerus and the rotator cuff tendons. The salvage of limb and shoulder function after proximal humeral resection for tumors still presents a challenge. Several techniques of shoulder reconstruction have been reported, including arthrodesis [83], allograft [84], and massive shoulder arthroplasty [85]. Limb-sparing surgery for tumors of the proximal humerus yield good oncological results, but regardless of the technique that is used, the patients are left with functional impairment of the shoulder, which almost always precludes activities above shoulder level.

Wilde et al. [7] retrospectively reviewed 14 patients who underwent reverse total shoulder arthroplasty for tumors of the proximal humerus; 4 of the patients died, leaving 9 for review. The minimum follow-up period was 0.6 years (mean, 7.7 years; range, 0.6–12 years). At the most recent follow-up examination, the mean active abduction was 157° and the mean functional Constant-Murley score was 76 %. One patient had a deep infection and 1 developed a loose prosthesis; both were treated with single-stage exchange. Their study, with a medium-term follow-up period, suggests that reverse total shoulder arthroplasty is a reasonable option for tumors of the proximal humerus. However, a prerequisite for this therapeutic option is the preservation of the axillary nerve and the deltoid muscle [37].

16.4 Surgical Technique

Preoperative planning is performed using X-ray templates of known magnification in the frontal and sagittal views to determine the implant size and positioning. The use of a computer tomography (CT) scanner is recommended to determine the orientation of the glenoid and bone stock quality. The X-ray templates allow the surgeon to assess the size and the optimal length of the glenohumeral implants and the diameters of the metaphysis, the polyinsert, and the glenoid sphere.

The patient is placed in a beach-chair position with the shoulder positioned sufficiently lateral to allow full arm extension. In every case, general anesthesia with a scalene block or an indwelling scalene catheter is used, and perioperative antibiotics are administered.

Either the deltopectoral or anterosuperior approach can be used. Most surgeons are more familiar with the deltopectoral approach for arthroplasty. The anterosuperior approach is also used for reverse shoulder arthroplasty, which is an intermediate between the transacromial approach originally proposed by Paul Grammont [14] and the anterosuperior approach described by D.B. Mackenzie [86] for shoulder arthroplasty [87]. As an alternative to the deltopectoral approach, the anterosuperior approach has the advantages of simplicity and postoperative stability in cases with massive cuff tears (Fig. 16.2). A deltopectoral approach was found to be much better than an anterosuperior approach in terms of better orientation of the glenoid component, glenoid loosening, inferior scapular notching, and access to the humeral shaft in prosthetic revisions. The transacromial approach is complicated by failure of acromial synthesis [88]. Surgeons must select the approach according to their experience and patient-specific factors. I prefer the deltopectoral approach.

During the procedure, an incision is made from the tip of the coracoid along the deltopectoral groove, slightly lateral to the axillary fold. The pectoralis major is identified. The deltoid and cephalic veins are retracted laterally to open the deltopectoral groove. The coracoid process is identified, and a Hohmann retractor is positioned behind the coracoid. Care should be taken to preserve the origin and insertion of the deltoid. The clavipectoral fascia is incised at the external border of the coracobrachialis. The biceps tendon sheath is opened and extended proximally to the rotator interval. The long head of the biceps is released from the superior attachment to the glenoid and tenodesed to the pectoralis major tendon. The axillary nerve is then identified by digital palpation before opening the subscapularis. When it is intact, the subscapularis is tenotomized close to the musculotendinous junction to repair it in an original position at the end of the procedure. Some previous studies have found that subscapularis repair decreases the rate of instability by creating anterior soft tissue [89], but others did not observe this finding [76, 90].

With the arm externally rotated, an anterior and inferior capsule may be released from the surgical neck of the humerus to the glenoid. With adequate releases, the humeral head can be dislocated into the deltopectoral interval by abduction of the arm and progressive external rotation and extension. In cases of severely restricted

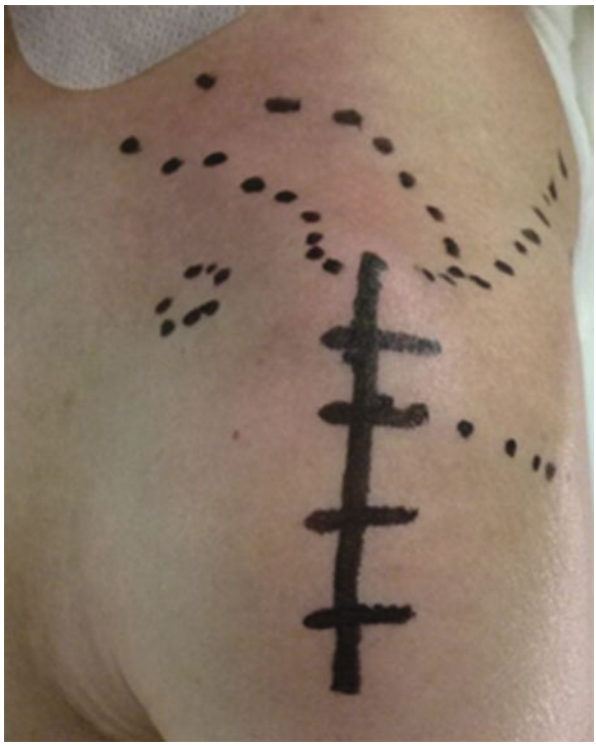

Fig. 16.2 Anterosuperior approach

external rotation, the upper 1 cm of the pectoralis major tendon is released. The joint capsule is split in line with the bicipital groove and extended into the rotator cuff interval. The humeral head is generally deformed, and anatomic reference points may be missing or distorted. Once the retroversion between 0° and 20° has been determined, the head is then resected with an oscillating saw, respecting the greater and lesser tuberosities. After head resection, aggressive removal of osteophytes around the humerus should be performed to improve the range of motion and allow for easier exposure during the remainder of the surgery [91]. Residual posterior osteophytes commonly prevent adequate posterior retraction of the humerus during glenoid preparation.

After retracting the humerus posteriorly, a partial capsulotomy and resection of the remaining glenoid labrum are performed to expose the glenoid. The capsule is released circumferentially. In cases with significant preoperative stiffness, it may be difficult to regain postoperative mobility. Removal of soft tissue adhesions may be required in conjunction with a capsulotomy. A retractor is positioned at the inferior border of the glenoid. The two-pronged retractor is seated at the posterior aspect of the glenoid. Additional retractors are positioned superior and inferior. Glenoid osteophytes are removed to further reveal the anatomic shape. The exact positioning and orientation of the guidewire for the reamer are important (Fig. 16.3). Preoperative planning must ascertain that reaming can be performed without

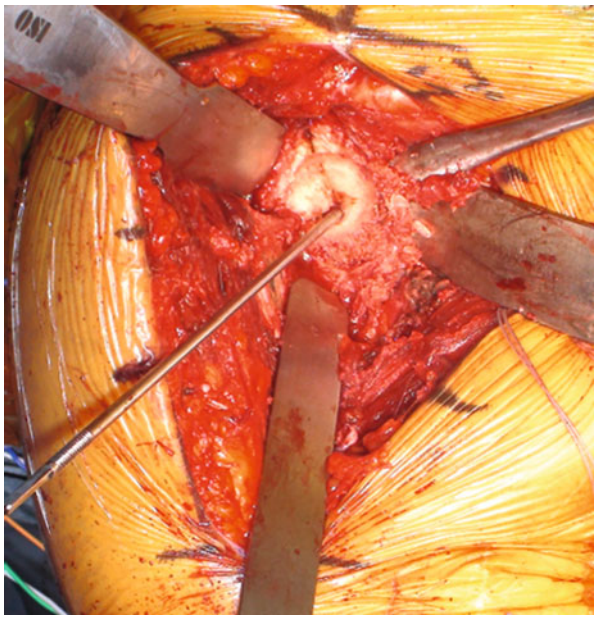

Fig. 16.3 Exposure of glenoid. A guidewire is tilted superiorly

creating glenoid anteversion or retroversion, or a superior glenoid tilt (Fig. 16.4). Compression and locking screws are used to provide stability of the baseplate. To secure fixation, they are anchored in the lateral pillar of the scapula and in the base of the coracoid. An appropriately sized glenosphere is then placed on the baseplate.

Reaming is then performed using a metaphyseal reamer for the metaphysis of the humerus. During this maneuver, the tuberosities may disappear in small patients, as is commonly seen in Japanese females. The diameter of the metaphysis may be too small. The diaphysis of the humerus is manually reamed using cylindrical reamers that progressively increase in diameter. Reaming is complete when the reamer contacts diaphyseal cortical bone. Additional reaming should be avoided to prevent humeral fracture. The last reamer used determines the final implant diameter and length. The assembly of the diaphyseal and metaphyseal components is inserted into the reamed medullary canal. An appropriately thick trial spacer is placed on the metaphyseal component, reduction is performed, and the tension of the deltoid is checked.

The chosen trial insert of the desired thickness is inserted into the trial metaphysis for trial reduction. The humeral trial component is then reduced into the joint to check the deltoid tension, stability, and range of motion. In cases with severe bone defects or inadequate deltoid tension, the final implant is inserted into the canal with appropriate retroversion and a polyinsert with an appropriate thickness. The prosthesis is then reduced using the reducer and the stability is checked. The arm is pulled away from the body after reduction to ensure that there is no pistoning effect. A complete separation of the humeral insert from the glenoid sphere indicates inadequate tensioning of the deltoid. Reverse shoulder arthroplasty

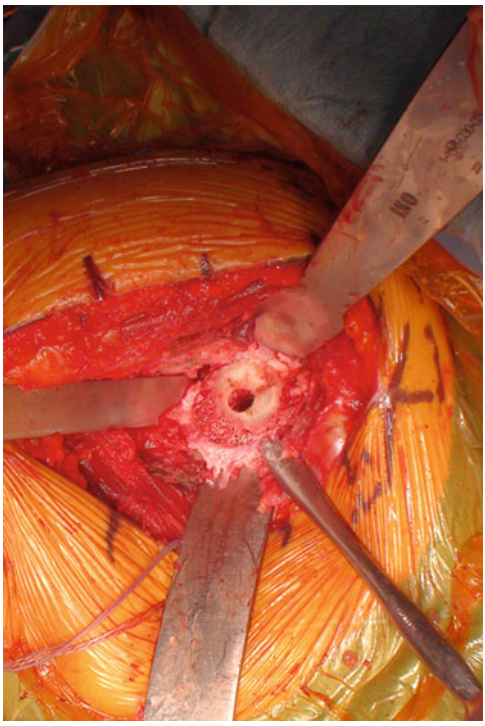

Fig. 16.4 Smile sign. After reaming of glenoid, smile sign should be seen

requires a retensioning of the deltoid to obtain active elevation and stability of the implant.

In patients with a rotator cuff-deficient shoulder, a combined loss of active elevation and external rotation (CLEER) can occur when both the infraspinatus and teres minor muscles are absent. A modified L'Episcopo procedure [latissimus dorsi (LD) and teres major (TM) transfer] is recommended in such cases, because it restores active elevation and external rotation [92].

Abduction of the arm is performed to check that there is no impingement and that the anterior elevation and abduction have been restored. External rotation with the elbow at the side checks for mobility and the risk of subluxation. Internal rotation is performed with the elbow at the side and in abduction. The arm is adducted to check that there is no impingement between the pillar of the scapula and the humeral implant. After reduction, the conjoined tendon should show sufficient muscular tension, which is similar to the deltoid. However, there is no objective and reliable technique that has been described for the preoperative planning of reverse shoulder prosthesis or for the postoperative evaluation of deltoid tension and arm lengthening.

Lädermann et al. [93] described a technique to preoperatively plan adequate deltoid tensioning using radiographs of the contralateral arm, and showed that the arm was lengthened 23 ± 12 mm after reverse shoulder arthroplasty. In cases of postoperative instability, both the humeral and overall arm lengthening were

significantly less. He suggested that subjective intraoperative criteria to evaluate deltoid tension should be replaced by objective measures to prevent insufficient or excessive deltoid tension.

Next, the subscapularis is reattached to the lesser tuberosity. Gerber [42] did not initially repair it, because after RSA it becomes an adductor rather than an abductor, but they found that leaving the subscapularis unrepaired consistently led to an inability of the patient to reach behind their back. Thus, they readapted the subscapularis at the end of the procedure. Edwards et al. [89] found that a subscapularis tendon that cannot be repaired using a deltopectoral approach results in a statistically significant risk for postoperative dislocation, and they suggested that repairing the subscapularis can decrease the likelihood of postoperative dislocation after reverse shoulder arthroplasty.

Finally, the wound is closed over two drains, and the patient is placed in a commercially available shoulder immobilizer. The arm is placed in a brace with the elbow close to the body in neutral or internal rotation postoperatively. A single anteroposterior radiograph of the glenohumeral joint should be taken in the recovery room to assess the immediate postoperative stability and component position and to identify any intraoperative fractures that may have occurred. Passive range of motion (ROM) of the elbow and active and passive ROM of the wrist and hand are permitted the next day. The drains are left in place for 24–48 h. Rehabilitation is performed with passive pendulum exercises five times per day at 5 min per session.

16.5 Activities of Daily Life and Sports After RSA

The main goals of reverse shoulder arthroplasty (RSA) are to obtain relief of pain, regain function, and enhance the quality of life in a patient with cuff function deficiency. Wall et al. [76] reported the clinical outcomes of Grammont-type RSA in 240 cases, and found that patients with primary rotator cuff tear arthropathy, primary osteoarthritis with a rotator cuff tear, and a massive rotator cuff tear without arthritis had the best final outcomes. These three groups did not differ significantly from one another with respect to the postoperative Constant scores, range of motion, or the subjective rating of the outcome. In contrast, the patients in the posttraumatic arthritis and revision arthroplasty groups had significantly worse postoperative Constant scores in comparison with the other three groups. The patients in the posttraumatic arthritis and revision arthroplasty groups also had significantly worse postoperative ranges of elevation in comparison with the other three groups. In addition, the percentage of patients who stated that they were very satisfied or satisfied with the outcome was lower in the posttraumatic arthritis and revision arthroplasty groups (89 %) than in the other three groups (96 %), although this difference did not achieve significance ($p = 0.083$). The postoperative Constant scores were significantly related to the patients' subjective ratings. The postoperative Constant scores were also significantly related to the postoperative active

range of elevation in all the etiology groups. Other reports have shown similar results [37].

In contrast to these reports, Schwartz et al. [94] found that the intraoperative forward flexion was the strongest predictor of the final postoperative ROM, followed by gender and the preoperative ROM. Because intraoperative forward flexion was the most powerful predictor of postoperative motion, the importance of trying to attain additional soft tissue release in the operating room cannot be overstated. It has been suggested that a limited active ROM of reverse shoulder prostheses is related to a lack of strength.

Alta et al. [30] identified correlations between the clinical outcome scores (Constant-Murley, DASH, and Simple Shoulder Test score) and the abduction and external rotation torque values, which supports that impaired shoulder strength is likely one of the causes of active ROM limitations. The functional outcome is probably not determined by simple ROM ranges alone, but also by the actual capacity for material handling in elevated and axially rotated arm positions.

In our experience, some patients treated with RSA recovered more rapidly than our expectation in terms of the pain and active range of motion (Fig. 16.5). We have never experienced such rapid patient recovery after rotator cuff surgery or artificial joint surgery. Although the patient expectations after anatomic TSA and RSA relate to sustained improvements in pain, function, and motion, the time necessary to reach these goals is unclear. Levy et al. [95] evaluated the time needed to achieve a plateau in maximal improvement after both TSA and RSA, and found that those treated with TSA can anticipate a more consistent and effective recovery of pain, function, and shoulder rotation. Patients receiving RSA can expect a variable length of recovery, with greater improvements in forward elevation and abduction.

Although patients can raise their arms over their heads after this procedure, significant concerns exist regarding the limitations that a RSA prosthesis places on internal rotation (IR), and the concomitant difficulty with activities of daily living, specifically perineal care [96]. Surgical treatment for bilateral, symptomatic CTA with an RSA prosthesis was thought to result in unsatisfactory outcomes and dysfunction in activities in daily living because of patient difficulty with internal rotation [96]. Patients require internal rotation of the shoulder in abduction to reach their back pocket, perform perineal hygiene, wash their back, and so on. Stevens et al. [96] found that perineal care is not a problem for most patients after bilateral RSA; all patients were able to perform perineal hygiene, and their patients experienced a median improvement in the IR of three vertebral levels on each side at final follow-up, although this was not significant. In many patients with a massive rotator cuff tear, the external rotation is restricted by a torn infraspinatus tendon preoperatively. Although Werner et al. [38] found that external rotation decreased from 17° to 12° after RSA, Wall et al. [76] and Rhee et al. [97] reported that the external rotation remained unchanged after RSA. Further, Rhee et al. [97] compared outcomes after a humeral component retroversion of 20° with 0° during RSA for cuff tear arthropathy, and no significant difference was seen in the ROM. However, they observed a better result for back washing and fastening a bra in the back when the retroversion was 0°.

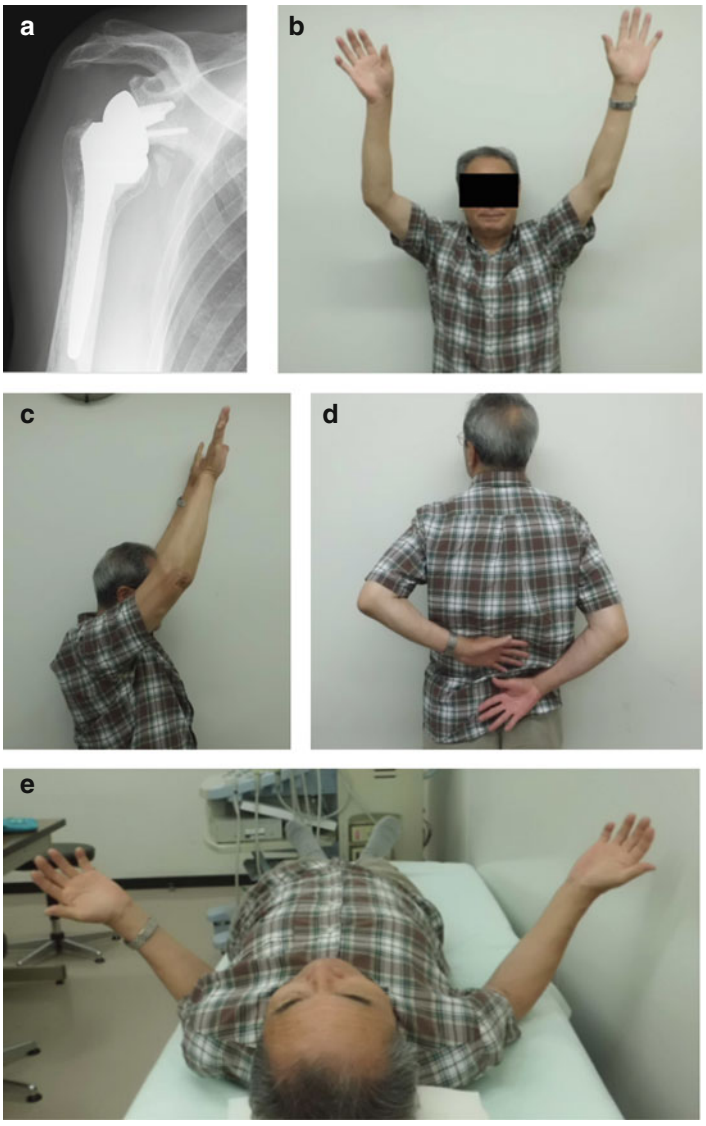

Fig. 16.5 Images obtained after reverse shoulder arthroplasty for cuff tear arthropathy. (**a**) Anteroposterior (AP) radiograph shows humeral and glenoid implants in place. Clinical photographs show postoperative active range of motion in abduction (**b**), forward elevation (**c**), internal rotation (**d**), and external rotation (**e**)

A major component of an improved quality of life after RSA is the ability to resume activities that were not possible or accomplished with difficulty before shoulder replacement surgery. Advances in RSA, creating early positive outcomes, have heightened the patients' expectations for a return to their previous levels of

activity. Several recent studies have shown that most patients maintain their athletic participation after hip or knee arthroplasty [98, 99], but much less is known about the activity level after shoulder arthroplasty. With the support of the American Shoulder and Elbow Surgeons and the European Society for Surgery of the Shoulder and Elbow, an online survey was performed in 2010 [100]. The survey indicated that 56 % of shoulder surgeons permitted patients to proceed to their maximum allowed activity level after 5–7 months after RSA, 22 % allowed this level of activity 2–4 months after, and an additional 20 % required at least 8 months before this level of activity was allowed. The restrictions after RSA were much more conservative than those after hemiarthroplasty and TSA. Jogging/running, walking, stationary bicycling, and ballroom dancing were allowed. Numerous other low-impact activities, such as hiking, golf, table tennis, and cross-country skiing, were allowed with experience. Surgeons were undecided about doubles tennis, bowling, downhill skiing, and rowing, among other activities. Numerous activities were not allowed, including all those not allowed with TSA, as well as singles tennis, football (soccer), weightlifting, basketball, and track and field. Surgeons are advised to select older patients with lower demands.

The surgeon recommendations on the restrictions after RSA are largely anecdotal; generally, low-demand activities are accepted, but it is recommended that high-demand activities be avoided for concerns over implant loosening or failure. Seventy-eight patients (average age, 73 years) after RSA were assessed to define the patient-reported activities following RSA [101]. A significant proportion of patients continued to perform medium- (gardening, leaf raking, lawn mowing) or high-demand activities (snow shoveling, wheelbarrow use, dirt shoveling) following RSA. These findings are similar to those for other types of shoulder arthroplasties. Barns et al. [102] reported that 18 of 78 patients with RSA (23.1 %) returned to 24 different high-intensity activities, such as hunting, golf, and skiing; 38 patients (48.7 %) returned to moderate-intensity activities, such as swimming, bowling, and raking leaves; and 22 patients (28.2 %) returned to low-intensity activities, such as riding a stationary bike, playing a musical instrument, and walking. Four patients played golf before and after RTSA, but neither of the two patients who played tennis before RTSA were able to do so after the surgery. Simovitch et al. [103] reported that 95 % of their 40 patients with RSA were able to return to sports at the same level as before surgery or at a higher level, and only 13 % reported increased pain from playing their sport after undergoing an RSA. They therefore concluded that RSA in senior athletes can be safely performed with good clinical results, and that no prominent mode of mechanical or clinical failure has been identified based on a short-term follow-up.

16.6 Complications of Reverse Shoulder Arthroplasty

Accumulated experience with RSA has led to expanded surgical indications, including rotator cuff arthropathy [14, 18, 29, 38, 39], massive rotator cuff tears [38, 40, 50], fracture sequelae [57, 61], rheumatoid arthritis (RA) [70], acute fractures [51], tumors, or as a revision procedure for failed anatomic or reverse prostheses [104]. Although the complication rates vary widely because of the differences in what is considered to be a complication, the number has increased with the increasing indications, with reported rates ranging from 10.8 % to 68 % [29, 76, 88].

Kemptom et al. [105] reviewed an initial series of 200 reverse total shoulder arthroplasties performed by a single surgeon to characterize the early complication-based learning curve for RTSA to determine the types and severity of complications most affected by surgeon experience; they found that the early complication-based learning curve for reverse total shoulder arthroplasty is approximately 40 cases. There was a trend toward more complications in revision versus primary reverse total shoulder arthroplasty and more neuropathies in revisions. Walch et al. [29] compared two consecutive series of 240 RSA procedures to evaluate if the increase in surgeon experience modified the rate of complications. The postoperative complication rate decreased with increased experience (from 19 % to 10.8 %), with dislocation cases showing a reduction from 7 % to 3.2 % and infection cases showing a reduction from 4 to 0.9 %. However, the number of nerve palsies increased. The rate of glenoid notching remained stable, but the severity of notching decreased. The problem and complication rates differed among the different etiologies, and were both twice as common in the revision patients as in the combined primary arthroplasty group [106]. Surgeons must be aware that these patients may have neurological injury, infection, inferior scapular notching, instability, and so on.

16.6.1 Hematoma

The design of the RSA provides a large, empty subacromial space; in an early series, hematoma formation was the most frequently reported complication [38]. Sonography is most commonly used postoperatively to demonstrate the presence of a hematoma. Previous studies have indicated that a hematoma occurs in 1–20 % of patients following RSA [37, 38, 107], whereas a postoperative hematoma occurs in 0.3 % following anatomic TSA [108]. The placement of the glenosphere more inferiorly increases the acromiohumeral distance and increases the subacromial space. Hematoma was higher in failed rotator cuff repair, revision of anatomic prosthesis, and revision of reverse prosthesis [109].

To treat postoperative hematoma, Gerber [42] made the following recommendations: (1) draining should be allowed for 24–48 h, (2) a sling should be used

postoperatively, (3) the arm may be used for activities such as brushing the teeth or eating, and (4) sling use should be discontinued after 4–6 weeks.

16.6.2 Neurological Injury

Neurological injury after shoulder arthroplasty has been reported and is transient in most cases [29, 42, 110, 111]. Clinical and subclinical neurological injury after reverse shoulder arthroplasty (RSA) may jeopardize the functional outcomes because of the risk of irreversible damage to the axillary nerve. It may be attributed to intraoperative traction, manipulation of the arm, retractor placement, or relative lengthening of the arm [111]. Lynch and Cofield et al. [112] observed that the presumed mechanism of injury was traction on the plexus occurring during the operation in most cases. The prognosis for neurological recovery was usually good [29, 42, 111]. In addition, neurological injury after total shoulder arthroplasty did not interfere with the long-term outcome of the arthroplasty itself [112]. During exposure of the glenoid, the humerus is posteriorly retracted, externally rotated, and abducted, which may accentuate the traction across the brachial plexus; this places excessive traction on the axillary nerve, in particular.

Walch et al. [29] reported that neurological complications increased from three (1.5 %) in the first cohort to eight (3.6 %) in the second, five of which persisted at follow-up. Of the three cases with transient nerve palsies, one involved the axillary nerve with sensory and motor deficits confirmed by EMG, which resolved in 5 months without sequelae; one had paresthesia in the ulnar nerve distribution, which resolved in a few weeks; and one involved partial sensory and motor dysfunction of the median, ulnar, and radial nerves, which also disappeared in a few weeks without sequelae. Of the five cases with persistent neurological deficits, three had dysesthesia of the fourth and fifth fingers, and one had recurrent median nerve paraesthesia corresponding to carpal tunnel syndrome.

Subclinical neurological lesions after reverse shoulder arthroplasty are common, mainly those involving the axillary nerve. One of the major reported risk factors is postoperative lengthening of the arm. Lädermann [110] observed subclinical postoperative electromyographic changes in 9 of 19 shoulders, with most involving the axillary nerve; 8 resolved in less than 6 months. In the anatomic shoulder arthroplasty group, a brachial plexus lesion was evident in 1 of 23 shoulders. The prevalence of acute postoperative nerve injury was significantly higher in the reverse shoulder arthroplasty group. The mean lengthening of the arm after reverse shoulder arthroplasty was 2.7 ± 1.8 cm compared with the normal, contralateral side. Arm lengthening with a reverse shoulder arthroplasty may be responsible for these nerve injuries.

Marion et al. [113] undertook a simple anatomic study using fresh human cadavers to assess the macroscopic effects on the axillary nerve when lowering the humerus was performed during RSA implantation, and measured the effects of a lateralization of the humerus on the axillary nerve. When the humerus was lowered,

clear macroscopic changes appeared below the middle of the glenoid. With regard to the lateralization of the humerus, a macroscopic study and measurements confirmed the absence of stretching of the nerve in those positions. Lowering of the humerus below the equator of the glenoid changes the course and tension of the axillary nerve and may lead to stretching and irreversible damage, compromising the function of the deltoid.

16.6.3 Infection

Postoperative infection is a devastating complication that can follow a total joint arthroplasty. Infection is a relatively common complication associated with RSA, with a reported incidence of approximately 1–10 % [76, 107, 111, 114, 115]. Patients undergoing primary RSA had a six times greater risk of infection compared with patients undergoing primary TSA [115]. However, Florschütz et al. [116] reported that of 814 primary TSA performed, deep periprosthetic infections were confirmed in 16 shoulders. Infections occurred in 6 TSAs and 10 RSAs, with no significant difference among the prosthesis types. Morris reported that the greatest risk factors for infection after RSA were a history of a prior failed arthroplasty and age younger than 65 years [117]. RSA-related infection is generally the result of the formation of a hematoma caused by to the presence of a large amount of dead space and the revision setting after multiple prior surgeries. In a retrospective multicenter study, Jacuot et al. [118] reported that infections were largely caused by coagulase-negative staphylococci and *Propionibacterium acnes* in 32 cases. Implant revision (one- or two-stage) led to better functional results than implant removal, with similar healing rates. Revision of the implant preserves the shoulder function, with no higher rate of residual infection compared with implant removal.

Preventative measures are absolutely necessary to decrease the overall rate of periprosthetic joint infection following RSA procedures [119] (Table 16.2). These strategies are best understood and employed when the risk factors are divided and tackled on three fronts: host, operating room environment, and surgical variables. Similar to other joint arthroplasty procedures, the intraoperative strategies for preventing infection include perioperative administration of intravenous antibiotics; adequate skin preparation; appropriate use of gowns, gloves, and antibiotic cement; limiting OR traffic; and selection of the optimal method of wound closure. Preoperative antibiotic administration decreases the rate of infection following surgical procedures.

Appropriate preoperative antibiotics are administered within 1 h of the incision, and they are mandatory for prophylaxis. Antibiotic prophylaxis can be delivered through antibiotic-impregnated bone cement. In the Finnish Arthroplasty Register, Jämsen et al. [120] found that the combined use of systemic antibiotic prophylaxis and antibiotic-impregnated bone cement lowered the rate of infection (0.68 % of

Table 16.2 Indications for RSA according to the Japanese guidelines for RSA

A. Absolute indications
1. Cuff tear arthropathy (Hamada classification, grade 4, 5)
2. Irreparable, massive cuff tear (Hamada classification, Grade 2, 3)
B. Relative indications
1. Complex three- and four-part proximal humerus fractures in elderly patients
2. Fracture sequelae of the proximal humerus, including malunion and nonunion
3. Rheumatoid shoulder with cuff function deficiency
4. Revision surgery for failed TSA
5. Primary osteoarthritis of the glenohumeral joint with glenoid deformity
6. Proximal humerus tumors requiring the resection of rotator cuff insertions

32,918 knees) more than the use of systemic antibiotics alone (1.05 % of 6,550 knees).

Propionibacterium acnes infection is a significant problem after shoulder surgery [118, 121]. Residual *P. acnes* is found on the skin up to 29 % of the time immediately after surgical skin preparation, and in 70 % of dermal biopsy specimens [122]. These residual bacteria may be one source of infection. Recently, Sabetta et al. [122] reported that the application of topical benzoyl peroxide with chlorhexidine for skin preparation is an effective way to reduce *P. acnes* on the skin at the beginning, and importantly, at the end, of a surgical procedure.

As with other types of joint arthroplasty, infection is diagnosed based on a combination of symptoms, laboratory tests, and findings on physical examination, such as a draining sinus, radiologic evidence of loosening of the prosthesis, radioisotope scanning, and analyses of intraoperative specimens [123]. The management of deep sepsis in RSA involves increased concerns about bone loss compared to traditional TSA [124]. Acute infection can be managed with irrigation, debridement, and polyethylene exchange. Chronic infection is best managed with two-stage revision. Stage one consists of hardware removal, irrigation and debridement and the placement of an antibiotic spacer, followed by a minimum 6-week course of parenteral antibiotics. During stage two, prosthesis reimplantation is performed, but should be deferred until all cultures and blood test results are negative. There is some evidence to suggest that chronic infections can be managed with a one-stage exchange involving irrigation and debridement, reimplantation, and parenteral antibiotics [111, 123, 125]. Beckman et al. [125] retrospectively reviewed 11 consecutive patients with an infected reverse shoulder prosthesis treated by a one-stage revision. All but one patient was considered to be free of infection after one-stage revision after a median follow-up of 24 months, and without antibiotic treatment for a minimum of 6 months. They concluded that a one-stage revision arthroplasty reduces the cost and duration of treatment.

16.6.4 Scapular Notching

The most common problem observed in the radiologic findings was scapular notching, which was noted in approximately 49.8–96 % of patients with a Grammont-type prosthesis [38, 76, 88, 126]. Scapular notching, which is a defect of the bone in the inferior part of the glenoid component, is caused by direct mechanical collision of the superomedial part of the humeral implant against the pillar of the scapula. Particulate polyethylene debris may aggravate inferior notching and lead to osteolysis. Impingement-free range of motion in all planes is essential [111]. In one study, 34 of 77 shoulders had inferior scapular notching, 23 had posterior notching, and 6 had anterior notching. The angle between the glenosphere and the scapular neck, as well as the craniocaudal position of the glenosphere, were highly correlated with inferior notching [127]. Inferior placement of the baseplate on the glenoid plate has been shown to prevent the occurrence of notching and also improve the range of motion [128].

In patients with a Grammont-style prosthesis in which the center of rotation of the glenosphere is on the face of the glenoid, the overall incidence of notching is high [18, 38, 76, 111, 127]. Several authors have recommended inferior placement of the Grammont-style glenosphere relative to the glenoid face to reduce the risk of notching [18, 38, 76, 111, 127].

Impingement may contribute to prosthetic instability, unexplained pain, and long-term loosening. The current prosthetic designs attempt to alleviate this conflict. Some authors lateralize the center of rotation [39, 42], which increases the tilting forces at the interface but also increases the impingement-free ROM. In patients with laterally offset glenospheres, the incidence of scapular notching has been reported to be between zero and 13 % [39, 106, 107, 111]. Zumstein et al. [106] reported that notching is a problem associated with RSA, but not a complication. They defined a problem as an intraoperative or postoperative event that was not likely to affect the patient's final outcome, including radiographic scapular notching, hematomas, heterotopic ossification, algodystrophy, phlebitis, intraoperative dislocations, intraoperative cement extravasation, or radiographic lucent lines of the glenoid.

16.6.5 Periprosthetic Fracture

Intraoperative periprosthetic fractures are common in patients who undergo RSA and can be challenging to manage [111]. Meticulous attention should be paid to prevent intraoperative glenoid fractures, especially when handling the glenoid baseplate reamer and when reaming the osteoporotic glenoid surface. An uncemented glenoid baseplate is used in all RSA systems. The baseplate is attached using a variably sized central screw or post. Wierks et al. [129] recommended reaming the glenoid with a reamer of an appropriate size for the baseplate by hand,

because they experienced nondisplaced fractures of the glenoid when using a pneumatic power drill because of its high torque. When a glenoid fracture occurs, the surgeon should consider the company-dependent strategy to achieve rigid fixation again. Frequently, the proximal humerus is osteopenic and easy to break. Careful attention should therefore be paid when preparing the humerus. Wierks et al. [129] initially prepared the proximal humerus before inserting the glenoid baseplate and experienced a high number of rim fractures in the proximal humerus with this sequence. They subsequently recommended that the glenoid component be inserted first, followed by preparation of the proximal humerus and insertions of the humeral component.

16.6.6 Dislocation

One of the most common complications limiting the outcomes of RSA is postoperative instability. In the literature, the reported rates of instability range from 2.4 % to 31 % [130]. The direction of instability is usually anterior, occurring following extension, adduction and internal rotation. The stability in RSA is dependent on adequate soft tissue tensioning. Surgical factors related to the prosthesis design, such as the glenosphere offset and size, humeral neck–shaft angle, and polyethylene thickness and constraint, have been shown to affect the tensioning and stability. There are also surgical techniques that have been shown to alter the stability by increasing the length of the arm and consequently the deltoid muscle tension, such as the level of humeral osteotomy, offset placement of the humeral socket and the baseplate position on the glenoid.

Compared with the deltopectoral approach, the anterosuperior approach has the advantages of providing better postoperative stability in cases with massive cuff tears [87]. In the deltopectoral approach, Edwards et al. [89] quantified the risk of postoperative dislocation after reverse total shoulder arthroplasty in patients with a subscapularis tendon that was irreparable at the time of surgery. Seven postoperative dislocations occurred; all dislocations were in patients whose subscapularis was irreparable. Dislocations were more likely to occur in patients with complex diagnoses, including proximal humeral nonunion, fixed glenohumeral dislocation, and failed prior arthroplasty. They concluded that an irreparable subscapularis tendon at the time of RSA using a deltopectoral approach results in a statistically significant risk for postoperative dislocation. Chalmers et al. [131] reported that atraumatic instability occurred in 11 patients (incidence, 2.9 %) treated with RSA before 3 months post surgery. The most commonly associated factors were a body mass index (BMI) greater than 30 kg/m^2, male gender, subscapularis deficiency , and previous surgery; in these patients, they use an abduction orthosis. Closed reduction alone was successful in 44 % of cases. Five of the 11 RSAs required polyethylene exchange. Teusink et al. [94] experienced 21 patients with dislocation after RSA, and the average time from surgery until the first dislocation event was 200 days. All dislocations were anterosuperior dislocations. Of these, 62 %

occurred within the first 90 days postoperatively. After an average follow-up of 28 months, 62 % of these shoulders remained stable, 29 % had required revision surgery, and 9 % remained unstable.

16.6.7 Scapula Fractures

Fractures around the acromion are a known complication of reverse total shoulder arthroplasty, and have occurrence rates between 0.9 % and 7.2 % based on the literature [37, 132–135]. A fulcrum in RSA is provided by an appropriately tensioned deltoid, which actively elevates the upper arm and stabilizes the prosthesis. The acromial origin of the deltoid is important in deltoid tensioning and in the ultimate performance of the implant. Fractures of the acromion commonly occur as a result of a preexisting acromial lesion, overtensioning of the deltoid, or osseous fatigue from the loading of an osteopenic acromion [23]. Acromion wear of the shoulder, as seen in cuff tear arthropathy, may have a deleterious effect on the acromion, such as thinning, fatigue failure or fragmentation. Osteoporosis is a significant risk factor for scapular fractures after RSA [135]. Fractures that disrupt the appropriate tension of the deltoid may lead to deleterious consequences for the function of the implant. Teusink et al. [136] found that the incidence of scapular fractures after RSA was 3.1 %. Postoperative scapular fractures may occur at any point postoperatively; an increasing incidence is likely as longer follow-up becomes available. This complication leads to inferior clinical results compared with controls. However, patients show improvement compared with their preoperative measurements, even after longer-term follow-up. Scapular fractures after RSA can be treated either surgically or nonsurgically.

In most cases, the fractures can be treated without surgical intervention. After conservative management, most patients who had an acromial fracture returned to a functional level that was comparable to that achieved before fracture [137]. Crosby et al. [132] proposed a classification system based on the relationship of the fracture to the acromioclavicular joint. They showed three discrete patterns of scapula fractures: avulsion fractures of the anterior acromion (type I), fractures of the acromion posterior to the acromioclavicular joint (type II) and fractures of the scapular spine (type III), and they suggested that type I fractures have a high likelihood of symptom relief. For type II fractures, they recommend acromioclavicular joint resection if the joint is stable, but open reduction internal fixation if it is unstable. They believe type III fractures are best treated with open reduction internal fixation.

Otto et al. [135] advocated a different classification system for postoperative acromial fractures. Type I included fractures through the midpart of the acromion, involving a portion of the anterior and middle deltoid origin. Type II were defined as fractures involving at least the entire middle deltoid origin with a portion, but not all of, the posterior deltoid origin. Type III fractures involved the entire middle and posterior deltoid origin, similar to the acromial base fracture. Once an acromial

fracture was identified clinically, patients were managed with a shoulder immobilizer for 6 weeks and were instructed to limit activity to pendulum shoulder exercises. After this nonsurgical regimen, significant improvements in the range of motion were seen for all measured movements for the type II group, for there were no improvements in the movements for the type I group, and there were only improvements for external rotation for the type III group. No good or excellent results were observed for type III fractures.

Although postoperative fracture of the acromial spine has a significant effect on the patient outcome [132, 135]. Walch et al. [138] reported that patients with *os acromiale* had a statistically superior mean Constant score when compared to normal subjects after RSA. A significant difference was also found for the activity and mobility portions of the Constant score, but there were no differences in the pain, strength, active elevation or subjective satisfaction. They concluded that acquired and congenital preoperative lesions of the acromion, such as os acromiale, are not a contraindication for RSA.

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