Radiological changes, infections and neurological complications after reverse shoulder arthroplasty related to different design types and their rates: Part II

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- Early reported complication rates with the Grammont-type reverse shoulder arthroplasty (RSA) were very high, up to 24%.
- A ‘problem’ is defined as an intraoperative or postoperative event that is not likely to affect the patient’s final outcome, such as intraoperative cement extravasation and radiographic changes. A ‘complication’ is defined as an intraoperative or postoperative event that is likely to affect the patient’s final outcome, including infection, neurologic injury and intrathoracic central glenoid screw placement.
- Radiographic changes around the glenoid or humeral components of the RSA are very frequently observed and described in the literature.
- High complication rates related to the Grammont RSA design led to development of non-Grammont designs which led to a dramatic fall in the majority of complications.
- The percentage of radiological changes after RSA is not negligible and remains unsolved, despite a decrease in its occurrence in the last decade. However, such changes should be now considered as simple problems because they rarely have a negative influence on the patient’s final outcome, and their prevalence has dramatically decreased.
- With further changes in indications and designs for RSA, it is crucial to accurately track the rates and types of complications to justify its new designs and increased indications.

Keywords: infection; intraoperative cement extravasation; neurologic lesion; problems; prosthesis design

Introduction

Initial complication rates of the original Grammont-type prosthesis were reported at up to 24%.¹–³ With the expansion of indications for reverse shoulder arthroplasty (RSA), the complication rates increased,⁴ which led to development of improved non-Grammont designs which led to a dramatic fall in the majority of complications.⁵

Complications after RSA can be divided into mechanical and radiographical types. We are grateful to the editors of EFORT Open Reviews for allowing us to present an overview divided into two parts. The Part I ‘Mechanical complications and fractures after reverse shoulder arthroplasty related to different design types and their rates’ has been published in this issue.⁶ The goal of this second part is to review reported radiological complications, infection and neurologic injury related to the use of RSA and to analyse their occurrence based on the various prosthetic designs used. Rarer complications, such as intraoperative cement extravasation and intrathoracic central glenoid screw, will also be discussed.

Humeral radiolucency and loosening

Humeral radiolucent lines are assessed in seven zones according to the classification of Gruen et al.⁷ adapted to the shoulder, and are classified according to width (< 2 mm or > 2 mm). Zone 1 is the area surrounding the greater tuberosity located at the superolateral part of the stem. Just below it are zone 2 and zone 3 placed on the lateral side of the stem in sequential order until the tip of the stem. Below, zone 4 is located on either side of the humerus. Zone 7 is the area surrounding the calcar on the superomedial part of the stem, whereas zone 5 and zone 6...
are located on the medial side of the stem in sequential order between zone 4 and zone 7 (Fig. 1).\(^8\) Loosening is defined as displacement of the humeral component in the period between the initial postoperative radiograph and the most recent follow-up, or if radiolucencies > 2 mm are present in more than three zones.\(^8\)

Mélis et al published a multicentre study that specifically evaluated radiological changes in 68 Grammont-style RSAs with minimum eight-year follow-up. They reported radiolucent lines around the humeral stem in 57% of shoulders,\(^8\) which were evaluated according to the Gruen et al classification adapted to the shoulder.\(^7\) They were more frequent with cemented components in zones 1, 2, 3, 4 and 6, equally distributed in zone 5, whereas in zone 7 they were significantly more common in uncemented RSAs. Radiolucent lines, which were more common in cemented stems, were located in the proximal zones and did not appear to progress towards loosening of the component at ten years of follow-up.\(^8\) Other authors haven’t reported humeral stem failures using a lateralized glenosphere at short and medium-term follow-up.\(^9\) In a recent meta-analysis, Shah et al reported a pooled mean incidence of radiolucent lines around the humeral component in 12% (2419 RSAs analysed), a pooled mean incidence of humeral component loosening of 1.4% (3817 RSAs analysed), and a pooled mean revision rate for humeral component loosening of only 1.3% (782 RSAs analysed).\(^4\)

Stress shielding

Stress shielding has rarely been reported in regard to different designs of RSA (Fig. 3). Denard et al performed a multicentre study with a minimal follow-up time of two years where they compared functional outcomes and stress shielding of RSA between cement or press-fit fixation using a standard-length humeral stem with a proximal medializedateral taper designed for proximal fixation.\(^12\) They found that proximal lateral stress shielding was more common...
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in the press-fit group (68%) than in the cemented group (25%). Proximal medial changes were frequent in both groups, which could be related to the component design; as the taper design might achieve some press-fit fixation even with the cemented fixation, which would result in partial stress shielding. The changes observed were minor and there were no cases of tuberosity resorption or loosening. Mélis et al compared 34 press-fit RSA to 34 RSA with cement fixation at a minimum eight years of follow-up. Proximal cortical thinning was observed in 47% of the press-fit stems and in only 5.9% of cemented stems. Partial or complete greater tuberosity resorption was observed in all press-fit stems and in 69% of cemented stems, while lesser tuberosity resorption was present in 76% and 45%, respectively. Radiographic signs of stress shielding, that were present especially with press-fit components, were associated with increasing relative stem diameter, which was greater in press-fit stems, and did not affect stability.

Raiss et al analysed radiographic stress shielding findings in 77 RSA short-stemmed press-fit humeral stems with a minimum follow-up of two years. They found signs of stress shielding in 35% of stems, which in 17% were high adaptive changes. The high adaptations were associated with a higher filling ratio and cortical contact of the stem, which is in line with the study by Mélis et al. They concluded that surgeons should try to achieve the minimal required canal filling with these type of implants in order to minimize radiographic changes. Harmsen and Norris observed proximal stress shielding in 98% of cases at minimum two-year follow-up in 232 RSAs using a standard length stem designed for diaphyseal fixation. These findings warrant further long-term studies to compare the method of fixation for humeral stem used in RSA in order to determine the likely different patterns of stress shielding based on stem design. Celik et al have reported that three-dimensional computerized tomography (CT) volumetric filling ratio enables early identification of patients with a short stem implant at risk for stress shielding compared to the plain radiographs, and could prove valuable in improving humeral stem designs.

Glenoid radiolucency, loosening and migration

Any radiolucent lines around the glenoid screws, around the peg or below the baseplate are classified according to their width (< 2 mm or > 2 mm). Loosening is considered to be present if the glenoid component has migrated, as demonstrated by shift, tilt or subsidence, or if complete radiolucent > 2 mm is present in each zone.

Mélis et al reported radiolucent lines around the glenoid component in 16% of cases but no loosening. Recently, Lignel et al published a multicentre study, which included 513 patients with RSA with lateralized glenoid implants performed after proximal humerus fracture, where 25% of patients had at least a five-year follow-up. They reported a 1.8% rate of migration of the glenoid implant (Fig. 4) and 12.2% rate of loosening, defined as stage 3 or 4 notching or full radiolucent line under the baseplate. Superior tilt of the glenoid component, a short peg and an intraoperative fracture represent risk factors for loosening. In the aforementioned systematic review on studies between 2010 and 2019 by Shah et al the pooled mean incidence of radiolucent lines around glenoid component was 7.7% (1336 RSAs analysed), whereas loosening was present in 2.3%. They reported a higher reported rate of radiolucent lines but significantly lower rates of loosening compared to systematic review published in 2011 by Zumstein et al, who included studies published between 1985 and 2008, and whose rates were 2.9% and 3.5%, respectively.

Fig. 3 Immediate postoperative (A) and one-year follow-up (B) of a left reverse shoulder arthroplasty. Observe the proximal bone resorption. Source: From wiki.beemed.com, with permission.

Fig. 4 Superior migration of the glenoid component of a right reverse should arthroplasty. Source: From wiki.beemed.com, with permission.
This notable decrease in the rate of glenoid loosening could be ascribed to significant advancement in biomaterials. Lateralized RSA designs have increased loads transferred to the bone–prosthesis interface, which led to higher rates of loosening with initial designs. However, introduction of locking-screw technology, hydroxyapatite coating and increased size (i.e. 5 mm vs. 3.5 mm) of peripheral screws have significantly diminished the rate of baseplate loosening in specific lateralized RSA design. Lopiz et al published a retrospective radiographic evaluation of 105 Grammont-style glenoid components with minimum five-year follow-up. They demonstrated that a considerable number of RSA show radiographic findings around the glenoid component at five years, with 37.1% exhibiting minor changes (affecting one or two screws) and 8.6% exhibiting major changes (affecting three or more screws or the central peg). Their findings account for an aseptic loosening rate of the glenoid component at 4.8%. Like Lignel et al, they showed that superior tilt of the glenoid component is a risk factor for radiolucent lines as well as for aseptic loosening, which is in agreement with previous theoretical observations that superior tilt increases shear forces on the glenosphere. Superior approach limits exposure of the inferior rim of the glenoid and thus prevents the adequate inclination of the glenoid component, therefore predisposing to superior tilt of the glenoid component and increasing the risk of radiolucent lines or notching. Lopiz et al concluded that there has been significant improvement regarding the percentage of radiological changes observed of the glenoid in RSA over the years, probably as a result of non-Grammont designs with improved biomechanics, acquired experience by the surgeons and improved knowledge of optimal glenoid component positioning.

**Bone spurs and heterotopic ossification**

Bone spurs at the inferior glenoid or heterotopic ossifications (Fig. 5) after RSA are a relatively common finding of unknown clinical importance. Shah et al and Zumstein et al have reported limits exposure of the inferior rim of the glenoid in RSA over the years, probably as a result of non-Grammont designs with improved biomechanics, acquired experience by the surgeons and improved knowledge of optimal glenoid component positioning.

**Infection**

The incidence of infections after primary RSA is reported in the literature to be between 1% and 15%. Zumstein et al reported in their systematic review an average heterotopic ossifications are: the extent of surgical release of soft tissues like the release of the triceps tendon in the superolateral approach, cemented implants, fracture (remaining fractured bone debris or possible migration of malpositioned tuberosities could act as a confounding factor in radiological evaluation), standard glenosphere, Delta III prosthesis, use of bone graft, and RSA combined with cerclage for complex proximal fracture with extension to diaphysis. Protective factors for heterotopic ossifications are: female sex, left shoulder, eccentric glenosphere, Lima and Delta Xtend prosthesis. As described by other authors, the presence of heterotopic ossification could be a by-product of a chronic foreign-body reaction of the capsule. Heterotopic ossification could be found distal to the glenoid and could limit range of motion. It is largely a benign and non-progressive condition that does not require additional treatment and has no long-term clinical consequences. The exception is rarely encountered grade 2 heterotopic ossifications which has a negative effect on the shoulder function during its development. Importantly in heterotopic ossifications a very high degree of suspicion for infection is necessary since the evidence associating heterotopic ossification to infections (particularly with Cutibacteria) is accumulating. Incidence of different radiological changes after RSA reported by different authors is summarized in Table 1.
infection rate of 3.8%, which included primary and revision RSA, with a higher rate in revision surgery.3 The infection rate reported in a more recent systematic review by Shah et al was 2.4% for primary RSA cases.4 Although the reported prosthetic joint infection rate is significantly lower than that in Zumstein et al,3 it is still higher than that for anatomic shoulder arthroplasty.28 Factors that might explain the higher rate of RSA infection are increased implant surface, large subacromial dead space caused by the ball-and-socket configuration, common postoperative haematoma, extensive surgical dissection, patients with compromised general health and numerous previous procedures.4,29

Risk factors for prosthetic joint infection of the shoulder can be divided to patient and treatment factors. Patient factors are male sex, younger patient,28 smoking,30 hepatitis C, HIV, Parkinson’s disease and those dependent on haemodialysis.31–34 In the majority of studies, diabetes has not been correlated with an increased risk of prosthetic joint infection.35 It is unclear whether body mass index is a risk factor, as the current studies have reported mixed findings.36,37 There is strong evidence associating hip and knee prosthetic joint infection with either diabetes or high body mass index (BMI). It is thus to be expected that shoulder infection incidence is also increased in these conditions.38 Patients with transplanted organs and lifelong immunosuppressant therapy can be successfully treated with a primary implant. There are no large studies on this matter but, in a small study, Hatta et al have not shown an important problem with shoulder prosthetic joint infection in patients with transplanted organs.39

Regarding treatment factors, associations include prior non-arthroplasty shoulder surgery,40 a history of steroid injection within three months prior to arthroplasty,41 proximal humerus fracture,42 revision shoulder arthroplasty,43 perioperative blood transfusion,44 and postoperative therapeutic anticoagulation.45 Thus, the broad indications for RSA and the design might explain the higher prosthetic

### Table 1. Incidence of different radiological changes after RSA reported by different authors

| Author & year of publication | Follow-up | Number of shoulders and type of RSA | Humeral radiolucency/loosening | Glenoid radiolucency/loosening | Humeral subsidence | Stress shielding | Bonne spurs/heterotopic ossification |
|------------------------------|-----------|-----------------------------------|-------------------------------|-------------------------------|--------------------|----------------|--------------------------------------|
| Mélis et al, 2011*           | Minimum 8 years | 68 Grammont RSA – 34 C and 34 UC components | 57%/0% Radiolucent lines > 2 mm in width in more than three zones: 11.8% C vs. 5.8% UC stems. | 16%/0% | 8.8% in C and 2.9% in UC stems | Proximal cortical thinning: 5.9% C vs. 47% UC stems. Greater tuberosity's partial or complete resorption: 69% C vs. 100% UC stems. Lesser tuberosity’s partial or complete resorption: 45% C vs. 76% UC stems | NS/0% BS and/or HO: 75% |
| Shah et al, 2020* (included studies between 2010 and 2019)* | Average 3.2 years | 1336 for GR, 3995 for glenoid loosening, 3817 for HL, 5529 for HO | 12%/1.4% | 7.7%/2.3% | N/A | N/A | HO: 0.8% |
| Zumstein et al, 2011* (included studies between 1985 and 2008)* | Minimum average 2 years | 782 | N/A/1.3% | 2.9%/3.5% | N/A | N/A | HO: 0.8% |
| Lignel et al, 2018* | Average 55 months | 513 RSA with laterlzed glenoid implant | N/A | N/A/1.8% cases of migration and 12.2% of potential cases of loosening | N/A | N/A | BS: 43.9% |
| Lopiz et al, 2021* | Minimum 5 years | 105 Grammont-style RSA | N/A | 37.1% minor changes and 8.6% of major changes of GR. Loosening 4.8% | N/A | N/A | N/A |
| Tross et al, 2020* | Minimum 1 year | 139 UC short stems RSA | N/A | 11% | N/A | N/A | N/A |
| Denard et al, 2020* | Minimum 2 years | 93 UC vs. 26 C standard length stems RSA | N/A | N/A | N/A | Proximal lateral stress shielding: 25% C vs. 68% UC stems Calcar osteolysis: 58 C vs. 43% UC stems | N/A |
| Harmsen et al, 2017* | Minimum 2 years | 232 standard length stems RSA | N/A/0 | 11% | N/A | N/A | N/A |

Note. RSA, reverse shoulder arthroplasty; C, cemented; UC, uncemented; BS, bone spur; HO, heterotopic ossification; GR, glenoid radiolucency; HR, humeral radiolucency.

*Systematic review.

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The most commonly identified organism is *Cutibacterium acnes* (former name *Propionibacterium acnes*) which has low virulence and is normally found in the highest concentration on the chest and back region. Nelson et al published a systematic review in 2016 and showed that *Cutibacterium acnes* was found in 38.9% of all shoulder prosthetic joint infection followed by *Staphylococcus aureus* at 14.8% and *Staphylococcus epidermidis* at 14.5%. Shoulder prosthetic joint infection due to *Cutibacterium acnes* presents with an indolent nature, slow progress, mild pain or stiffness, whereas an infection with a more virulent *Staphylococcus aureus* may present with more pronounced symptoms of redness, swelling, drainage and systemic symptoms. In 2018, the International Consensus Meeting on Musculoskeletal Infection proposed recommendations for the diagnosis and management of periprosthetic infections of the shoulder. Currently, the perioperative antibiotic of choice in shoulder arthroplasty is Cefazolin, which should be applied intravenously 30–60 minutes prior to incision in a dose of 2 grams. The 2018 International Consensus Meeting concluded that postoperative antibiotics are not necessary, but that, if administered, they should not be continued beyond 24 hours postoperatively. Proven and suspected infections should be revised operatively.

For early and late acute shoulder prosthetic joint infection a debridement with implant retention is the treatment of choice. Current literature shows that one-stage revision may be better than two-stage revision due to lower re-infection and complication rates, if it is possible to radically debride the joint. Pellegrini et al concluded that a definitive antibiotic spacer could be used in low-demand, elderly patients with a contraindication for an additional operation. A 12-week antibiotic treatment is advisable in shoulder prosthetic joint infection starting with an initial IV period and including rifampicin, in the case of debridement and retention of the prosthesis or one revision for staphylococcal shoulder prosthetic joint infection. Chronic suppressive antibiotic therapy in select patients with retained components or failed previous treatment might also be useful. There are many dilemmas that remain unresolved regarding the shoulder prosthetic joint infection. The decrease in RSA infection rates as reported by Shah et al and Zumstein et al is unlikely to be associated with the difference in prosthetic design but is probably related to other factors such as...
as improved surgical technique and experience. Further high-level studies specific to the shoulder are needed to improve our current understanding.

**Neurological lesion**

**Prevalence**

Clinical neurological lesions after RSA, which most commonly affect the axillary nerve, are rarely reported, and Shah et al published their overall incidence at 0.6%. The Grammont design (0.9%) had a significantly increased neurological injury rate compared to all other designs combined (0.1%). Primary RSA (0.4%) had a statistically lower rate of neurological injury compared to revision cases (1.1%). The subtotal of modern designs (0.4%) had a lower rate of neurological lesions compared to findings by Zumstein et al (1.2%).

The location of the deltoid impairment can be anterior (group 1), anterior and middle (type 2) or global (type 4) (Fig. 7). They might be more common in RSA than in anatomic total shoulder arthroplasty due to the lengthening of the upper limb during RSA, the need for a greater glenoid exposure and trauma cases (Fig. 8). Subtle neurological lesions discovered by intraoperative neuromonitoring or postoperative electromyographic changes appear to be more common than clinical neurological lesions as they have been reported in up to 63% of patients. Even though neurological injuries are transient and rare, they might affect the clinical outcome by decreasing the deltoid strength caused by axillary nerve injury, which may also lead to surgery, either neurolysis or removal of the baseplate screw.

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**Fig. 7** The deltoid impairment due to neurological lesion can be classified according to its location and extent: type 1 (A) corresponds to an impairment localized anteriorly, type 2 (B) an anterior and middle one, and type 4 (C) is a global impairment. Source: From wiki.beemed.com, with permission.

**Fig. 8** Lateral (A and C) and superior (B and D) views of right and left shoulders. Note the gross atrophy of the right anterior deltoid (type 1). Source: From wiki.beemed.com, with permission.
Aetiology

Neurological injury during or after RSA implantation may be a consequence of surgical dissection, vessel injury, intraoperative positioning of the upper extremity, compression secondary to haematoma or retractor inter-scalene brachial plexus block and lengthening of the arm. Implanting the RSA can endanger the axillary nerve because of its nearby course to the humeral metaphysis (mean distance of 8.1 mm) and the inferior glenoid rim (mean distance, 13.6 mm). Routine palpation and visualization of the axillary nerve during RSA has been suggested in order to avoid its injury. Although, Librizzi et al reported a low incidence of partial temporary isolated axillary nerve injury when the nerve has not been exposed intraoperatively. Additionally, superior and posterior axillary nerve injury when the nerve has not been exposed might prove beneficial in lowering the rate of neurological injury. Cadaveric studies have shown that measurement might raise the incidence of postoperative neurological injury. Consequently, strategies have been devised to restrict upper-extremity lengthening in RSA. If there is a high risk of dislocation, such as in revisions or proximal humeral bone loss, larger-diameter glenoid components, a superior approach and bony or prosthetic lateralization of the glenosphere are advised for use to prevent excessive tension. However, if the lengthening is expected to be over four centimetres based on the preoperative planning, Nagda et al propose to use intraoperative nerve monitoring.

Intrathoracic central glenoid screw

An unusual and previously unreported complication was published just recently by Frandsen et al, who described a complication of RSA in which a long central baseplate screw was oriented through the scapula, subscapularis fossa, chest wall and all the way into the thoracic cavity. This case shows that entering the thoracic cavity is indeed possible when longer than usual screws are used to fix the baseplate of RSA. It demonstrates the significance of knowledge of the glenoid anatomy and screw orientation, particularly in cases of advanced glenoid deformity. Especially if the glenoid is retroverted and the baseplate is placed at right angle to the face of the eroded glenoid, the central screw points towards the thorax. Surgeons should be aware of this potential life-threatening problem when they are dealing with a type B2, B3 or C glenoid and using long screws: the most common lengths of the central screw are 25–35 mm (Fig. 9). Surgeons should be cautious of a baseplate screw longer than 40 mm. The risk of this injury is not related to prosthetic design.

Intraoperative cement extravasation

Cement extrusion has been an unusual complication after RSA (Fig. 10). It has been well reported after hip arthroplasty, but not as much after shoulder arthroplasty. The tip of the humeral stem lies in immediate proximity of the spiral groove, where the radial nerve lies. Cement extravasation in this region could lead to the thermal injury of the radial nerve due to the cement polymerization. Levy et al...
described a case of radial nerve injury after RSA revision.\textsuperscript{88} Most commonly, cement extravasation occurs due to cortical perforation or fracture. Its increased risk is associated with aggressive reaming, endosteal notching and cortical thinning close to the distal end of the prosthesis.\textsuperscript{89,90} Sherfey et al\textsuperscript{91} proposed hand-reaming of the humeral canal in order to avoid a fracture. Initial treatment of radial nerve injury consists of observation for three to four months for incomplete lesions or lesions in continuity. Electrodiagnostic studies are useful for monitoring the evidence of recovery and to establish the extent of the nerve injury. Failed recovery after six months after surgery is an indication for surgical treatment.\textsuperscript{92} Successful removal of the cement causing radial nerve palsy has been previously reported. The risk of this injury is not correlated to prosthetic design.

**Difference in complication rates and types depending on RSA design**

The impact of specific RSA designs is described in Table 2. The comparison between the results published by Zumstein et al\textsuperscript{3} (included studies between 1985 and 2008) and Shah et al\textsuperscript{4} (included studies between 2010 and 2019) is noted in Table 3.

**Conclusion**

Our review of the recent literature on the topic of RSA and its complications shows that the percentage of radiological changes after RSA is not negligible and remains
unsolved. However, such changes should be now considered as simple problems because they rarely have a negative influence on the patient’s final outcome and their prevalence has dramatically decreased. Also there has been a considerable decrease in the majority of complications over the years, probably as a result of modifications in the design, materials, biomechanics of the prosthesis, recommendations related to positioning and the experience in RSA implantation acquired by the surgeons. With further changes in indications and designs for RSA, it is crucial to accurately track the rates and types of complications to justify its new designs and increased indications.

**Table 2. Difference in complication rates depending on specific reverse shoulder arthroplasty (RSA) design**

| Implant design type       | Effect on the complication rate                                                                 |
|---------------------------|--------------------------------------------------------------------------------------------------|
| Glenoid Lateral offset    | An eccentric glenosphere is a protective factor for heterotopic ossification, whereas a standard glenosphere is a risk factor for heterotopic ossification.17 |
| Inferior tilt             | Placing the glenoid baseplate in 10 degrees of inferior inclination in order to avoid superior inclination decreases the likelihood of radiolucent lines15,16 |
| Varus neck-shaft angle    | The use of a 135 degree neck-shaft angle lowers the incidence of neurologic injuries compared to 155 degree Grammont-style RSA.82 |
| Humerus Polyethylene      | Repetitive contact between polyethylene and bone may result in polyethylene wear debris, chronic inflammation and osteolysis,24 radiolucency around the glenoid component,29 presence of an inferior bone spur and ossification in the glenohumeral space.7 |
| Onlay vs. inlay stem       | Onlay stem increases distalization, which leads to increased stretch on the axillary nerve and risk of nerve injury.79,80,83 |
| Press fit fixation vs.     | Radiolucent lines are more frequent in cemented humeral components and are most commonly found in the proximal zones of the stem. They did not appear to progress towards loosening of the component at ten years of follow-up.7 Proximal stress shielding is more common in press-fit stems.7,11 |

**Table 3. Differences in complication rates between results published by Zumstein et al (included studies between 1985 and 2008) and Shah et al (included studies between 2010 and 2019)**

| Complication type               | Complication rate published by Zumstein et al | Complication rate published by Shah et al |
|--------------------------------|-----------------------------------------------|-------------------------------------------|
| Radiolucency humerus/loosening | N/A/1.3%                                      | 12%/1.4%                                   |
| Radiolucency glenoid/loosening | 2.9%/3.5%                                     | 7.7%/2.3%                                  |
| Infection                      | 3.8%                                          | 2.4%                                      |
| Neurological lesion            | 1.2%                                          | 0.6%                                      |

**ICMJE CONFLICT OF INTEREST STATEMENT**

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**REFERENCES**

1. Lädermann A, Denard PJ, Tirefot J, Collin P, Nowak A, Schwitzguebel AJ. Subscapularis- and deltoid-sparing vs traditional deltopectoral approach in reverse shoulder arthroplasty: a prospective case-control study. J Orthop Surg Res 2017;12:112.
2. Walch G, Bacle G, Lädermann A, Nove-Josserand L, Smithers CJ. Do the indications, results, and complications of reverse shoulder arthroplasty change with surgeon’s experience? J Shoulder Elbow Surg 2017;26:1470–1477.

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3. Zumstein MA, Pinedo M, Old J, Boileau P. Problems, complications, reoperations, and revisions in reverse total shoulder arthroplasty: a systematic review. J Shoulder Elbow Surg 2011;20:146–157.

4. Shah SS, Gaal BT, Roche AM, et al. The modern reverse shoulder arthroplasty and an updated systematic review for each complication: part I. JSES Int 2020;4:929–943.

5. Wright MA, Murthi AM. Offset in reverse shoulder arthroplasty: where, when, and how much. J Am Acad Orthop Surg 2021;29:89–99.

6. Nabergoj M, Denard PJ, Collin P, Trebše R, Lädermann A. Mechanical complications and fractures after reverse shoulder arthroplasty related to different design types and their rates: part I. EFORT Open Rev 2021;6:1097–1108.

7. Gruen TA, McEive GM, Amstutz HC. ‘Modes of failure’ of cemented stem-type femoral components: a radiographic analysis of loosening. Clin Orthop Relat Res 1979;141:17–27.

8. Mélis B, DeFranco M, Lädermann A, et al. An evaluation of the radiological changes around the Grammont reverse geometry shoulder prosthesis after eight to 12 years. J Bone Joint Surg (Br) 2011;93-B:1240–1246.

9. Frankie M, Siegal S, Pupello D, Saleem A, Mishell M, Vasey M. The reverse shoulder prosthesis for glenohumeral arthritis associated with severe rotator cuff deficiency: a minimum two-year follow-up study of sixty patients. J Bone Joint Surg (Am) 2005;87-A:1697–1705.

10. Bogle A, Budge M, Richman A, Miller RJ, Wiater JM, Voloshin I. Radiographic results of fully uncemented trabecular metal reverse shoulder system at 1 and 2 years’ follow-up. J Shoulder Elbow Surg 2015;22:620–625.

11. Tross AK, Lädermann A, Wittmann T, et al. Subsidence of uncemented short stems in reverse shoulder arthroplasty: a multicenter study. J Clin Med 2020;9:3362.

12. Denard PJ, Haidamous G, Gobezie R, Romeo AA, Lederman E. Short-term evaluation of humeral stress shielding following reverse shoulder arthroplasty using press-fit fixation compared with cemented fixation. J Shoulder Elbow Surg 2020;29:906–912.

13. Raiss P, Schnetzke M, Wittmann T, et al. Postoperative radiographic findings of an uncemented convertible short stem for anatomic and reverse shoulder arthroplasty. J Shoulder Elbow Surg 2019;28:715–723.

14. Harmsen SM, Norris TR. Radiographic changes and clinical outcomes associated with an adjustable diaphyseal press-fit humeral stem in primary reverse shoulder arthroplasty. J Shoulder Elbow Surg 2017;26:1589–1597.

15. Celik H, Chauhan A, Flores-Hernandez C, D’Lima D, Honecke H. Three-dimensional volumetric filling ratio predicts stress shielding in short-stem anatomic total shoulder arthroplasty. J Am Acad Orthop Surg 2020;28:1047–1054.

16. Lädermann A, Schwitzguebel AJ, Edwards TB, et al. Glenoid loosening and migration in reverse shoulder arthroplasty. J Bone Joint Surg (Br) 2019;101-B:461–469.

17. Lignel A, Berhouet J, Loirat MA, et al. Reverse shoulder arthroplasty for proximal humerus fractures: is the glenoid implant problematic? Orthop Traumatol Surg Res 2018;104:773–777.

18. Lopez Y, Galan-Olleros M, Rodriguez-Rodriguez L, Garcia-Fernandez C, Marco F. Radiographic changes around the glenoid component in primary reverse shoulder arthroplasty at mid-term follow-up. J Shoulder Elbow Surg 2021;30:e378–e391.

19. Gutiérrez S, Walker M, Willis M, Pupello DR, Frankie MA. Effects of tilt and glenosphere eccentricity on baseplate/bone interface forces in a computational model, validated by a mechanical model, of reverse shoulder arthroplasty. J Shoulder Elbow Surg 2012;20:732–739.

20. Laver L, Garrigues GE. Avoiding superior tilt in reverse shoulder arthroplasty: a review of the literature and technical recommendations. J Shoulder Elbow Surg 2014;23:1582–1590.

21. Verhofste B, Decock T, Van Tongel A, De Wilde L. Heterotopic ossification after reverse total shoulder arthroplasty. J Bone Joint Surg (Br) 2016;98-B:1215–1221.

22. Simovitch RW, Zumstein MA, Lohri E, Helmy N, Gerber C. Predictors of scapular notching in patients managed with the Delta III reverse total shoulder replacement. J Bone Joint Surg (Am) 2007;89-A:588–600.

23. Garofalo R, Brody F, Castagna A, Cuccarelli E, Krishnan SG. Reverse shoulder arthroplasty with glenoid bone grafting for anterior glenoid rim fracture associated with glenohumeral dislocation and proximal humerus fracture. Orthop Traumatol Surg Res 2016;102:989–994.

24. Garofalo R, Flanagan B, Castagna A, Lo EY, Krishnan SG. Long stem reverse shoulder arthroplasty and cerclage for treatment of complex long segment proximal humeral fractures with diaphyseal extension in patients more than 65 years old. Injury 2015;46:2379–2383.

25. Nyffeler RW, Werner CM, Gerber C. Biomechanical relevance of glenoid component positioning in the reverse Delta III total shoulder prosthesis. J Shoulder Elbow Surg 2005;14:524–538.

26. Carson DA. An infectious origin of extraskeletal calcification. Proc Natl Acad Sci USA 1998;95:7846–7847.

27. Rosteius T, Rausch V, Pätzholz S, et al. Incidence and risk factors for heterotopic ossification following periprosthetic joint infection of the hip. Arch Orthop Trauma Surg 2019;139:1307–1314.

28. Richards J, Inacio MC, Beckett M, et al. Patient and procedure-specific risk factors for deep infection after primary shoulder arthroplasty. Clin Orthop Relat Res 2014;472:2809–2815.

29. Contreras ES, Frantz TL, Bishop JO, Cveticanovich GL. Periprosthetic infection after reverse shoulder arthroplasty: a review. Curr Rev Musculoskelet Med 2020;13:757–768.

30. Hatta T, Werthel JD, Wagner ER, et al. Effect of smoking on complications following primary shoulder arthroplasty. J Shoulder Elbow Surg 2017;26:1–6.

31. Bala A, Penrose CT, Vissagiu JD, et al. Total shoulder arthroplasty in patients with HIV infection: complications, comorbidities, and trends. J Shoulder Elbow Surg 2016;25:1971–1979.

32. Burrus MT, Werner BC, Cancienne JM, Gwathmey F, Brockmeier SF. Shoulder arthroplasty in patients with Parkinson’s disease is associated with increased complications. J Shoulder Elbow Surg 2015;24:1881–1887.

33. Cancienne JM, Kew ME, Deasey MJ, Brockmeier SF, Werner BC. Dialysis dependence and modality impact complication rates after shoulder arthroplasty. J Shoulder Elbow Surg 2019;28:671–677.

34. Cancienne JM, Dempsey UJ, Holzgreve R, Brockmeier SF, Werner BC. Is Hepatitis C infection associated with a higher risk of complications after total shoulder arthroplasty? J Shoulder Elbow Surg 2016;25:775–782.

35. McEvany MD, Chan PH, Prentice HA, Paxton EW, Dillon MT, Navarro RA. Diabetes disease severity was not associated with risk of deep infection or revision after shoulder arthroplasty. Clin Orthop Relat Res 2009;477:1538–1546.

36. Kunutsor SK, Barrett MC, Whitehouse MR, et al. Incidence, temporal trends and potential risk factors for prosthetic joint infection after primary total shoulder and elbow replacement: systematic review and meta-analysis. J Infect 2020;80:426–436.
36. Theodorou A, Krishnan J, Aromataris E. Risk of complications in patients who are obese following upper limb arthroplasty: a systematic review and meta-analysis. Obes Rev Clin Pract 2020;14:9–26.

38. Eka A, Chen AF. Patient-related medical risk factors for periprosthetic joint infection of the hip and knee. Ann Transl Med 2015;3:233.

39. Hatta T, Statz JM, Itoi E, Cofield RH, Sperling JW, Morrey ME. Shoulder arthroplasty in patients with immunosuppression following solid organ transplantation. J Shoulder Elbow Surg 2020;29:44–49.

40. Florschütz AV, Lane PD, Crosby LA. Infection after primary anatomic versus primary reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2015;24:1296–1301.

41. Werner BC, Cancienne JM, Burrus MT, Griffin JW, Gwathmey FW, Brockmeier SF. The timing of elective shoulder surgery after shoulder injection affects postoperative infection risk in Medicare patients. J Shoulder Elbow Surg 2016;25:390–397.

42. Lung BE, Kaniyia S, Bisogno M, Komatsu DE, Wang ED. Preoperative indications for total shoulder arthroplasty predict adverse postoperative complications. JSES Open Access 2019;3:99–107.

43. Morris BJ, O’Connor DP, Torres D, Elkousy HA, Gartsman GM, Edwards TB. Risk factors for periprosthetic infection after reverse shoulder arthroplasty. J Shoulder Elbow Surg 2015;24:161–166.

44. Everhart JS, Bishop JY, Barlow JD. Medical comorbidities and perioperative allogeneic red blood cell transfusion are risk factors for surgical site infection after shoulder arthroplasty. J Shoulder Elbow Surg 2017;26:1922–1930.

45. Cancienne JM, Aowalale JT, Camp CL, et al. Therapeutic postoperative anticoagulation is a risk factor for wound complications, infection, and revision after shoulder arthroplasty. J Shoulder Elbow Surg 2020;29:S67–S72.

46. Nelson GN, Davis DE, Namdari S. Outcomes in the treatment of periprosthetic joint infection after shoulder arthroplasty: a systematic review. J Shoulder Elbow Surg 2016;25:1337–1345.

47. Boisrenoult P. Cutibacterium acnes prosthetic joint infection: diagnosis and treatment. Orthop Traumatol Surg Res 2018;104:S19–S24.

48. Garriguès GE, Zmitowski B, Cooper AM, Green A, Group ICMS. Proceedings from the 2018 International Consensus Meeting on Orthopedic Infections: the definition of periprosthetic joint infection. J Shoulder Elbow Surg 2019;28:58–512.

49. McNally M, Sousa R, Wouthuyzen-Bakker M, et al. The EBIS definition of periprosthetic joint infection. J Bone Joint Surg [Br] 2021;103-B:18–25.

50. Trebse R, Roskar S. Evaluation and interpretation of prosthetic joint infection diagnostic investigations. Int Orthop 2021;45:847–855.

51. Weigelt L, Plate A, Stadler L, et al. Alpha-defensin lateral flow test does not appear to be useful in predicting shoulder periprosthetic joint infections. Int Orthop 2020;44:1023–1029.

52. Dilisio MF, Miller LR, Warner JJ, Higgins LD. Arthroscopic tissue culture for the evaluation of periprosthetic shoulder infection. J Bone Joint Surg [Am] 2014;96-A:1752–1758.

53. Lappner PLC, Hynes K, Sheikh A. Capsular needle biopsy as a pre-operative diagnostic test for peri-prosthetic shoulder infection. Shoulder Elbow 2019;11:191–198.

54. Renz N, Cabric S, Morgenstern C, Schuetz MA, Trampuz A. Value of PCR in sonication fluid for the diagnosis of orthopedic hardware-associated infections: has the molecular era arrived? Injury 2018;49:806–811.

55. Anagnostopoulos A, Bossard DA, Ledergerber B, et al. Perioperative antibiotic prophylaxis has no effect on time to positivity and proportion of positive samples: a cohort study of 64 Cutibacterium acnes bone and joint infections. J Clin Microbiol 2018;56:e00157–17.

56. Bedencič K, Kavčič M, Faganeli N, et al. Does preoperative antimicrobial prophylaxis influence the diagnostic potential of periprosthetic tissues in hip or knee infections? Clin Orthop Relat Res 2016;474:258–264.

57. Pérez-Prieto D, Portillo ME, Puig-Verdier I, et al. Preoperative antibiotic prophylaxis in prosthetic joint infections: not a concern for intraoperative cultures. Diagn Microbiol Infect Dis 2016;86:442–445.

58. Wouthuyzen-Bakker M, Benito N, Soriano A. The effect of preoperative antimicrobial prophylaxis on intraoperative culture results in patients with a suspected or confirmed prosthetic joint infection: a systematic review. J Clin Microbiol 2017;55:2765–2774.

59. Duvall G, Kaveeshwar S, Sood A, et al. Benzyl peroxide use transiently decreases Cutibacterium acnes load on the shoulder. J Shoulder Elbow Surg 2020;29:212–216.

60. Stull JD, Nicholson TA, Davis DE, Namdari S. Addition of 3% hydrogen peroxide to standard skin preparation reduces Cutibacterium acnes-positive culture rate in shoulder surgery: a prospective randomized controlled trial. J Shoulder Elbow Surg 2020;29:212–216.

61. Moroder P, Trampuz A, Scheibel M. Propionibacterium: we found it, now we have to deal with it: commentary on an article by Jason E. Hsu, MD, et al. ‘Single-stage revision is effective for failed shoulder arthroplasty with positive cultures for Propionibacterium’. J Bone Joint Surg [Am] 2016;98-A:1112.

62. Hsu JE, Gorbaty JD, Whitney JJ, Matsen FA III. Single-stage revision is effective for failed shoulder arthroplasty with positive cultures for Propionibacterium. J Bone Joint Surg [Am] 2016;98-A:2047–2053.

63. Pellegrini A, Legnani C, Macchi V, Meani E. Management of periprosthetic shoulder infections with the use of a permanent articulating antibiotic spacer. Arch Orthop Trauma Surg 2018;138:665–669.

64. Zimmerli W, Trampuz A, Ochsner PE. Prosthetic-joint infections. N Engl J Med 2004;351:1645–1654.

65. Renz N, Trampuz A, Zimmerli W. Controversy about the role of rifampin in biofilm infections: is it justified? Antibiotics (Basel) 2021;10:165.

66. Zimmerli W, Sendi P. Role of rifampin against Staphylococcal biofilm infections in vitro, in animal models, and in orthopedic-device-related infections. Antimicrob Agents Chemother 2019;63:e01746-18.

67. Achermann Y, Kusejko K, Aunon A, et al. The impact of surgical strategy and Rifampin on treatment outcome in Cutibacterium periprosthetic joint infections. Clin Infect Dis 2020.

68. Lädermann A, Lübbeke A, Mélis B, et al. Prevalence of neurologic lesions after total shoulder arthroplasty. J Bone Joint Surg [Am] 2011;93-A:1288–1293.

69. Lenoir H, Dagneaux L, Canovas F, Waizenegetter T, Pham TT, Chammas M. Nerve stress during reverse total shoulder arthroplasty: a cadaveric study. J Shoulder Elbow Surg 2017;26:323–330.

70. Parisien RL, Yi PH, Hou L, Liu X, Jawa A. The risk of nerve injury during anatomical and reverse total shoulder arthroplasty: an intraoperative neuromonitoring study. J Shoulder Elbow Surg 2016;25:1122–1127.

71. Barco R, Savvidou OD, Sperling JW, Sanchez-Sotelo J, Cofield RH. Complications in reverse shoulder arthroplasty. EFORT Open Rev 2017;12:70–80.

72. Collin P, Matsukawa T, Denard PJ, Gain S, Lädermann A. Pre-operative factors influence the recovery of range of motion following reverse shoulder arthroplasty. Int Orthop 2017;41:2135–2142.
73. Merolla G, Wagner E, Sperling JW, Paladini P, Fabbri E, Porcellini G. Revision of failed shoulder hemiarthroplasty to reverse total arthroplasty: analysis of 157 revision implants. *J Shoulder Elbow Surg* 2018;27:75–81.

74. Black EM, Roberts SM, Siegel E, Yannopoulos P, Higgins LD, Warner JJ. Failure after reverse total shoulder arthroplasty: what is the success of component revision? *J Shoulder Elbow Surg* 2015;24:1908–1914.

75. Lädermann A, Stimec BV, Denard PJ, Cunningham G, Collin P, Fasel JH. Injury to the axillary nerve after reverse shoulder arthroplasty: an anatomical study. *Orthop Traumatol Surg Res* 2014;100:105–108.

76. Leschinger T, Hackl M, Buess E, et al. The risk of suprascapular and axillary nerve injury in reverse total shoulder arthroplasty: an anatomic study. *Injury* 2017;48:2042–2049.

77. Cazeneuve JF, Cristofari DJ. The reverse shoulder prosthesis in the treatment of fractures of the proximal humerus in the elderly. *J Bone Joint Surg [Br]* 2010;92-B:335–339.

78. LiBrizzi CL, Rojas J, Joseph J, Bitzer A, McFarland EG. Incidence of clinically evident isolated axillary nerve injury in 869 primary anatomic and reverse total shoulder arthroplasties without routine identification of the axillary nerve. *JSES Open Access* 2019;3:48–53.

79. Hart ND, Clark JC, Wade Krause FR, Kissenerth MJ, Bragg WE, Hawkins RJ. Glenoid screw position in the Encore Reverse Shoulder Prosthesis: an anatomic dissection study of screw relationship to surrounding structures. *J Shoulder Elbow Surg* 2013;22:814–820.

80. Marion B, Leclère FM, Casoli V, et al. Potential axillary nerve stretching during RSA implantation: an anatomical study. *Anat Sci Int* 2014;89:232–237.

81. Kim HJ, Kwon TY, Jeon YS, Kang SG, Rhee YG, Rhee SM. Neurologic deficit after reverse total shoulder arthroplasty: correlation with distalization. *J Shoulder Elbow Surg* 2020;29:1096–1103.

82. Wagner ER, Muniz AR, Chang MJ, et al. Neuroapraxia and early complications after reverse shoulder arthroplasty with glenoid bone grafting. *J Shoulder Elbow Surg* 2021;30:258–264.

83. Lowe JT, Lawler SM, Testa EJ, Jawa A. Laterization of the glenosphere in reverse shoulder arthroplasty decreases arm lengthening and demonstrates comparable risk of nerve injury compared with anatomic arthroplasty: a prospective cohort study. *J Shoulder Elbow Surg* 2018;27:1845–1851.

84. Lädermann A, Edwards TB, Walch G. Arm lengthening after reverse shoulder arthroplasty: a review. *Int Orthop* 2014;38:991–1000.

85. Walker M, Brooks J, Willis M, Frankie M. How reverse shoulder arthroplasty works. *Clin Orthop Relat Res* 2011;469:2440–2451.

86. Nagda SH, Rogers KJ, Sestokas AK, et al. Neer Award 2005: peripheral nerve function during shoulder arthroplasty using intraoperative nerve monitoring. *J Shoulder Elbow Surg* 2007;16:52–58.

87. Frandsen JJ, Tashjian RZ, Chalmers PN. Intrathoracic central glenoid screw: a case report. *J Shoulder Elbow Surg* 2020;29:e338–e340.

88. Levy J, Frankie M, Mighell M, Pupello D. The use of the reverse shoulder prosthesis for the treatment of failed hemiarthroplasty for proximal humeral fracture. *J Bone Joint Surg [Am]* 2007;89-A:292–300.

89. Lee M, Chebli C, Mounce D, Bertelsen A, Richardson M, Matsen F III. Intramedullary reaming for press-fit fixation of a humeral component removes cortical bone asymmetrically. *J Shoulder Elbow Surg* 2008;17:150–155.

90. Steinmann SP, Cheung EV. Treatment of peri- and prosthesis humerus fractures associated with shoulder arthroplasty. *J Am Acad Orthop Surg* 2008;16:199–207.

91. Sherfey MC, Edwards TB. Cement extrusion causing radial nerve palsy after shoulder arthroplasty: a case report. *J Shoulder Elbow Surg* 2009;18:e21–e24.

92. Lädermann A, Ceroni D, Magistris M, Hoffman P. Lésions du nerf sciatique en chirurgie de la hanche. *Rev Chir Orthop Repar Appar Mot* 2005;91:637–641.

93. Lädermann A, Walch G, Denard PJ, et al. Reverse shoulder arthroplasty in patients with pre-operative impairment of the deltoid muscle. *J Bone Joint Surg [Br]* 2013;95-B:1106–1113.