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REVERSE SHOULDER ARTHROPLASTY (C CHAMBERS AND E CRAIG, SECTION EDITORS)

Periprosthetic Fractures in Reverse Total Shoulder Arthroplasty: Current Concepts and Advances in Management

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Abstract

Purpose of Review Expanded indications for reverse total shoulder arthroplasty (RSA) have raised awareness of associated complications, including periprosthetic fractures. The purpose of this article was to provide a comprehensive update on how, when, and why RSA-related periprosthetic fractures occur, as well as to describe the current treatment strategies.

Recent Findings Periprosthetic acromial and scapular spine fractures occur in up to 4.3% of cases and periprosthetic humeral fractures occur in approximately 3.5% of RSA procedures. Fractures of the coracoid process and clavicle have also been reported. Current literature has identified several risk factors for intraoperative or postoperative fracture, including underlying osteoporosis, revision arthroplasty, use of a superiorly placed screw during metaglene fixation, and disruption of the scapular ring by transection of the coracoacromial ligament.

Summary Periprosthetic fracture associated with RSA is a clinically significant event that warrants prolonged postoperative vigilance, timely diagnosis, and shared patient decision-making regarding treatment. Further research is needed to identify optimal treatment strategies and characterize long-term clinical outcomes following RSA-related periprosthetic fracture.

Keywords Reverse shoulder arthroplasty · Humeral fracture · Scapular fracture · Acromion · Clavicle · Coracoid process

Introduction

Since Paul Grammont introduced the modern reverse total shoulder arthroplasty (RSA) design more than 30 years ago, RSA has developed into a mainstay treatment for a variety of shoulder pathologies, including rotator cuff tear arthropathy, massive irreparable rotator cuff tears, complex proximal humerus fractures, and failed shoulder arthroplasty [1–3]. RSA is utilized with increasing frequency [4–7]. Since 2014, the number of RSA procedures performed each year in the USA has exceeded that of anatomic total shoulder arthroplasty, estimated at 80,000 procedures annually [6]. Concurrent with the success of RSA has been an increased recognition of its associated complications, including scapular notching, infection, glenosphere dissociation, neuropraxias, and periprosthetic fracture [8••, 9, 10]. We may expect total numbers of related complications to increase commensurate with the anticipated surge in RSA utilization. Clinicians are challenged to understand RSA-related complications in order to heighten recognition, counsel patients, improve implant designs and surgical techniques, and ultimately, maximize patients' clinical outcomes following RSA.

Periprosthetic fractures are the second most common complication associated with RSA, accounting for approximately 20% of all complications and trailing only implant instability [11]. In comparison to fractures associated with anatomic total shoulder arthroplasty, periprosthetic fractures in the setting of RSA occur more than three times as frequently [11]. In light of this, the aim of the present article is to synthesize the most up-to-date understanding of how, when, and why RSA-related periprosthetic fractures occur, as well as describe current treatment strategies. In contrast to prior review articles that have focused on one anatomic class of fractures or grouped all

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anatomic sites into a single category, this article is organized based upon four anatomic entities: acromion/scapular spine, humerus, clavicle, and coracoid process. In doing so, we hope to highlight needed areas for continued research efforts that can minimize the incidence and mitigate the impact of all fractures associated with RSA.

Acromion and Scapular Spine Fractures

Biomechanics

The acromion and scapular spine are anatomic sites uniquely predisposed to fracture in the setting of RSA. By design, the traditional Grammont-style RSA alters the center of rotation of the glenohumeral joint to a more distalized and medialized position, thereby, relying on the overlying deltoid to promote shoulder motion [12]. Conventional RSA implants lengthen the arm by approximately 2.5 cm, increasing the abductor moment arm to propel the deltoid to enact shoulder abduction [13]. These biomechanical changes are intended to accommodate for diminished or absent rotator cuff function, however in doing so, they increase the forces transmitted across the acromion and scapula, including the scapular spine and coracoacromial ligament—termed the "scapular ring"—which serves as a deltoid attachment site [14••]. Although their clinical significance has only recently garnered appreciation, acromial and scapular spine fractures may result in deleterious perturbations of deltoid function that impede overall shoulder motion and, in turn, the long-term outcomes associated with RSA [15].

The early success and expanded utilization of RSA has prompted innovations to improve upon the original Grammont-style design. Subsequent design iterations, such as a short, lateralized humeral stem, and inferior glenosphere offset, were devised to counteract some of the commonly encountered complications associated with RSA, including implant instability and scapular notching [12, 16]. Newer design alterations, particularly humeral stems with increased offset, may effectively reduce the risk of scapular notching, yet they may also increase stresses seen at the acromion. Increased deltoid tensioning has been proposed as a cause for increased stress on the inferior aspect of the acromion [17]. While fractures of the acromion and scapular spine may have initially been considered secondary in importance to concerns of implant instability, newer implant designs may have increased the biomechanical underpinnings for their occurrence.

Diagnosis

An acromial or scapular spine fracture following RSA refers to a new fracture line in these anatomic entities, as identified on radiographs or computed tomography (CT) that correlates with a patient's clinical symptoms, including new-onset pain or loss of function (Fig. 1) [13]. Timely diagnosis affords clinicians with the opportunity to communicate with patients and initiate treatment to improve long-term outcomes. Perhaps due to the amorphous clinical presentation and relative infrequency of these fractures, the earliest outcomes studies of RSA lack specifics on how this complication was diagnosed [13]. The spectrum of post-RSA acromial pathology can be divided into acromial stress reactions, characterized by clinical symptoms in the absence of imaging findings, and acromial stress fractures, in which radiologic findings are present [13, 18••].

Fractures may occur as sequelae of minor trauma to the upper extremity; however, they often have an insidious onset [8••]. In a case series of 26 periprosthetic scapular fractures, half of patients denied antecedent trauma [19••]. Patients with acromion or scapular spine fractures in this setting will often have point tenderness at the fracture/stress site, and it is therefore critical to localize the site of the patient's pain during physical examination [13]. A majority of acromial and scapular spine fractures occur within the first 2 years following surgery [19••, 20]. In a recent systematic review, Patterson et al. [21•] reported the mean time to diagnosis of an acromion/scapular spine fracture was 9 months (range, 1.3–24 months). However, clinical suspicion should remain high as post-RSA scapular fractures have been reported to occur as much as 8 years following surgery [22].

Radiographs are a required initial series, but are insufficiently sensitive to be used exclusively. A superimposed clavicle on an anteroposterior view can often obfuscate fine detail of the acromion and scapular spine. Levy et al. [23•] demonstrated that, among a cohort of 18 patients with post-RSA acromial or scapular spine fractures, radiographs were negative in 7 patients (39%) and therefore required computed tomography (CT) for diagnosis. In another series, Neyton et al. [19••] reported that among 26 patients diagnosed with a scapular spine fracture, 5 lacked radiographic findings and required CT for diagnosis. The interobserver reliability for the diagnosis of post-RSA acromion and scapular spine fractures based on radiographs alone is poor [23•]. CT offers the further advantage of identifying nondisplaced acromial and scapular spine fractures, facilitating prompt treatment that may prevent subsequent fracture displacement [13]. For these reasons, it is recommended that patients with postoperative pain over the acromion or scapula without radiographic signs of fracture undergo CT imaging [24, 25]. Single photon emission computed tomography (SPECT) has been cited as a useful adjunct for identifying acromial stress reactions in the post-RSA patient with clinical symptoms who lack radiographic evidence of fracture [13]. No evidence characterizing SPECT for this clinical setting is yet available.

Incidence

Historically, reported rates of fracture to the acromion or scapular spine following RSA have ranged from 1.0 to 15.8% [15,

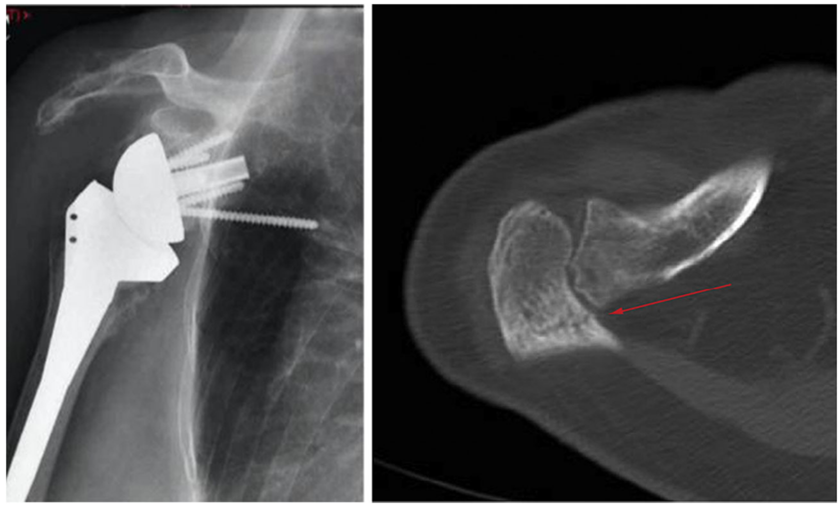

Fig. 1 A post-RSA radiograph does not demonstrate evidence of fracture (**a**). However, an acromion base fracture is demonstrated on CT (**b**). (Reproduced from Neyton L, Erickson J, Ascione F, Bugelli G, Lunini E, Walch G. [19••])

20, 21•]. A critical review of the existing literature reveals several inconsistencies in methodology that likely contribute to this relatively wide estimate. First, diagnostic criteria are not standardized [15, 16]. As an example, Zmistowski et al. [18••] reported an incidence of 4.2% of patients with an acromial stress fracture following RSA. When including all acromial stress reactions (i.e., patients with clinical symptoms without radiographic evidence of fracture), the authors calculated an incidence of 10.5%. Moreover, inclusion of cases with preoperative acromial pathology will overestimate the incidence of true post-RSA acromion and scapular spine fractures [16]. Conversely, studies relying on radiographs will not identify fractures seen exclusively on CT and will therefore underestimate the true incidence. Few studies defined their diagnostic criteria, and no other studies reported incidence rates that delineated among the spectrum of post-RSA acromial pathology. Finally, available follow-up data varied across studies. Among four studies published since 2018, the incidence has ranged from 1.3 to 4.3% [16, 18, 19••, 26]. It is expected that reported incidence rates will continue to increase as more RSA is performed, as further attention is paid to identifying fractures, and as the mean follow-up period of existing patient cohorts increases [13, 20].

Risk Factors

Identification and assessment of the risk factors associated with post-RSA acromion and scapular spine fractures offer a powerful means for understanding how these fractures occur and, potentially, offer strategies for prevention. The literature is replete with identifiable risk factors (Table 1); however, their relative significance as contributors to acromion and spine fracture is less certain.

Osteoporosis represents the most commonly reported risk factor [27]. In a case-control study of 265 patients who underwent RSA, 31% of patients with an acromion or scapular spine fracture had osteoporosis in comparison with 18% of control patients, leading to an odds ratio of 1.97 [28]. In a separate analysis of 101 acromial stress injuries following RSA, acromial pathology was identified in 22.5% of patients with osteoporosis compared with in 9.5% of patients without osteoporosis [18••]. While this study also cited female sex as a predictor, the analysis did not control for osteoporosis, and, therefore, this data may only suggest that females are more likely to have osteoporosis. Beyond osteoporosis, there is minimal evidence that identifies patient-related risk factors. To date, no association has been found between post-RSA acromion or scapular spine fracture and autoimmune disease, smoking, alcohol abuse, or corticosteroids [13]. Preoperative acromial pathology, such as acromial fragmentation or os acromiale, has also not been shown to impair clinical outcomes following RSA [29, 30]. Surgical indication may provide prognostic information, as lower rates of acromion and spine fracture were identified among patients with posttraumatic arthritis and proximal humerus fractures [15]. Note that patients undergoing RSA for a proximal humerus fracture are at increased risk for periprosthetic humeral fracture [31].

Technical factors related to implant design and surgical technique comprise the greatest area of investigation into risk factors for periprosthetic acromion and scapular spine fracture. Comparison of surgical approaches, including deltopectoral, anterosuperior, and superolateral, failed to identify any association with increased fracture incidence [20]. Lateralized glenosphere design has been associated with increased rate of acromial and scapular spine fractures [15, 32]. This finding is consistent with recent biomechanical data that glenosphere lateralization increases stress placed on the acromion during functional shoulder activities by approximately 17% [33].

Decreased deltoid lengthening has been identified as an independent predictor of acromial fracture [18]. The shortened deltoid is theorized to be at a reduced mechanical advantage

Table 1 Documented risk factors of reverse shoulder arthroplasty-associated periprosthetic fractures

Characteristic	Acromion/ scapular spine	Humerus
Osteoporosis	✓	✓
Revision arthroplasty	✓	✓
Lateralized glenosphere	✓	
Decreased deltoid lengthening	✓	
Intact rotator cuff	✓	
Metaglene fixation with superior screw	✓	
Onlay humeral stem	✓	
Proximal humerus fracture treatment		✓
Short humeral stem		✓

and therefore exerts greater force at the acromion during functional shoulder motion.

The presence of an intact rotator cuff, particularly the subscapularis, has been proposed to increase the risk of acromion and scapular spine fractures following RSA. A biomechanical study showed that an intact rotator cuff acts as a deltoid antagonist, thereby increasing the work load of the deltoid and, as a result, increasing acromial stresses [34]. Further, repair of the subscapularis in conjunction with glenosphere lateralization during RSA increases acromial stress forces during biomechanical testing, which has also correlated with diminished clinical outcomes scores in comparison with patients who do not undergo subscapularis repair [35••, 36•]. However, a clinical analysis failed to correlate rotator cuff integrity with acromial fracture [16].

Screw positioning during glenoid fixation has been scrutinized as a potential modifiable risk factor. A higher incidence of scapular fracture has been associated with a RSA construct that contains a screw placed above the central glenoid axis [8••]. In another series, Ascione et al. [16] reported that more than half of post-RSA acromial fractures occurred at the distal tip of the superior screw, consistent with a theory that a superior screw engaging the scapular spine acts as a stress riser. A biomechanical study has corroborated this clinical association by demonstrating that metaglene fixation incorporating a screw superior to its central axis exhibits a lower load-to-failure (i.e., less biomechanical strength) than RSA constructs with only an inferior screw placed below the central glenoid axis [8••]. After changing their surgical technique to an "inferior-only" metaglene fixation technique, Kennon et al. [8••] reported that the acromial fracture rate following RSA dropped from 4.4 to 0%. While these findings are promising, it should be noted that the implant used in this study allows for 3 inferior locking screws, whereas many other implants allow for only a single inferior locking screw. The fixation strength of a metaglene construct with a single inferior-only screw has not been reported, but may be insufficient to prevent implant instability.

Following this rationale that a superiorly place screw may act as a stress riser, some authors have advocated for use of a short posterior screw (≤ 20 mm) for metaglene fixation to avoid placing into the scapular spine [13]. One downside to this approach is that the scapular spine has recently been identified, along with the lateral border of the scapula, to have the greatest trabecular bone density and therefore is recognized as an ideal site for glenoid screw fixation [37].

As one of the more recent innovations in RSA implant design, an onlay humeral stem prosthesis has been theorized to increase risk for scapular spine fracture [16]. A case series of 1953 RSA procedures using a Grammont-style inlay humeral stem reported an incidence of scapular fractures of 1.3%, lower than the 4.3% incidence reported in another study using a newer onlay model [19••]. A subsequent study identified a higher incidence of scapular fractures when a short, curved, onlay stem was used as compared with an historical control of Grammont-style inlay stem [38]. Further research is needed to delineate how implant-related factors, including glenosphere size, metaglene positioning, and polyethylene liner size, affect the risk of periprosthetic acromial and scapular fractures [8••].

In a recent study from our institution, we showed that transection of the coracoacromial ligament significantly altered the stress patterns on the acromion and scapular spine [14••]. The "scapular ring" consists of the acromion, scapular spine, coracoid, and coracoacromial ligament (CAL) (Fig. 2). The CAL acts to dissipate hoop stresses imparted on the ring. CAL transection paradoxically decreases the strain on the acromion by allowing for a cantilever effect, which results in an increased focus of strain at the scapular spine (Levy type III) by up to 19%. The authors suggest that preservation of the CAL during surgical exposure for RSA may be a modifiable risk factor to reduce the rate of scapular spine fractures.

Classification

Two published classification schemas have been devised to characterize acromial and scapular spine fractures in the setting of RSA [23•, 39]. Despite the authors' intentions to organize the collective thinking on this subclass of periprosthetic fracture, subsequent studies have applied these classification systems inconsistently, which has further complicated the literature. Nonetheless, an awareness of these schemas provides further conceptualization of the spectrum of pathology and enables greater apprehension of the existing literature. Crosby et al. [39] classified scapular fractures following RSA into three types based on their location relative to the acromioclavicular joint as identified on radiographic and/or CT imaging. Type 1 is an avulsion fracture of the anterior acromion. Type 2 is an acromion fracture that extends posterior to the acromioclavicular joint. Type 3 is a fracture of the scapular spine. Separately, Levy et al. [23•] created a

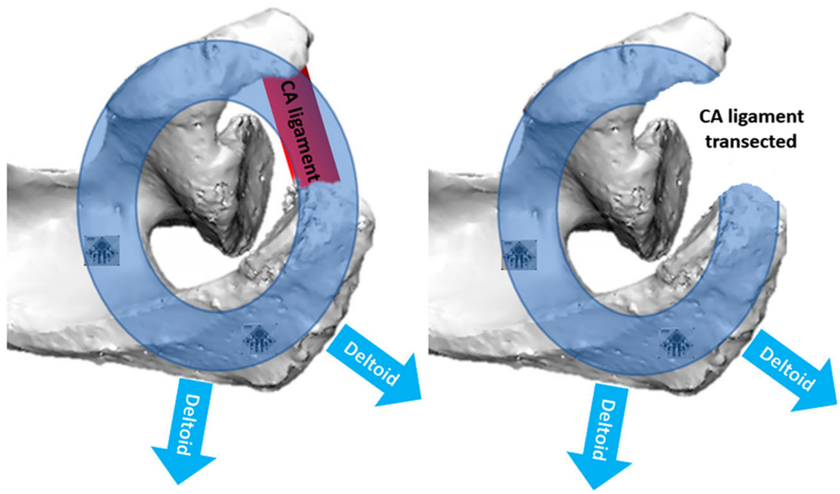

Fig. 2 Illustration of the scapular ring concept. The coracoacromial ligament (CAL) distributes strain patterns through the scapula. Transection of the CAL during reverse shoulder arthroplasty may result in increased strain seen at the scapular spine. (Reproduced from Taylor et al. [14••])

classification based on the fracture's location relative to the origin of the deltoid (Fig. 3). The anterior and middle portions of the deltoid are involved in Levy type 1 fractures, the middle and part of the posterior deltoid are involved in Levy type 2 fractures, and Levy type 3 fractures involve the middle and entire posterior deltoid origin [23•]. An important distinction is that normal scapulothoracic motion is preserved in Levy type 1 fractures, whereas RSA biomechanics may be affected when a greater portion of the deltoid insertion is disrupted [16]. An analysis of 53 patients with post-RSA acromion or scapular fractures estimated the Levy classification to have moderate interrater reliability (kappa = 0.42) [28].

Treatment

Acromial and scapular spine stress reactions (i.e., pain without fracture line on radiographs) are managed conservatively. Patients should be placed back into a sling with an abduction pillow and with elbow support to take tension off of the deltoid for 6–8 weeks. The patient should be seen back in the office after this time period and evaluated for point tenderness and with repeat shoulder radiographs.

Despite a dearth of high-level evidence in the current literature to guide treatment, the vast majority of post-RSA acromion and scapular spine fractures are treated nonsurgically (Fig. 4) [20]. A systematic review of 15 articles encompassing 114 acromial fractures showed that 88% were treated nonoperatively while 12% were treated surgically [20]. Yet, as the frequency and magnitude of this complication becomes better understood, there exists a biomechanical rationale for surgical restoration of these anatomic structures in select cases. Acromial and scapular spine fractures can lead to decreased tension of deltoid fibers that impairs shoulder function [26]. Scapula fractures can result in reduced range of motion and worse clinical outcomes [40].

In their classification of acromion and scapular spine fractures, Crosby et al. [39] proposed a general treatment algorithm in which type 1 fractures are treated nonoperatively. Nonoperative treatment consists of immobilization in an abduction splint for 6 weeks, followed by gradual increase in motion and daily activity [16, 19••]. Type 2 fractures are treated with AC joint resection, and unstable type 3 fractures are treated with open reduction and internal fixation. No subsequent study has reported on the validity of this approach.

Surgical treatment is technically challenging for multiple reasons [40]. First, open reduction must counter the distractive force of the deltoid [19••, 26]. Second, a fixation construct must achieve stabilization in a thin layer of bone that is frequently osteoporotic [26]. Surgical options include open reduction and internal fixation (ORIF) with plating, ORIF with tension band wiring, and revision RSA with ORIF [20].

Outcomes

It is well established that patients with postoperative acromial or scapular spine fractures have worse clinical outcomes than those without such fractures [13, 16, 19••, 21•, 22, 40]. While this finding may seem obvious, it underscores the importance of timely diagnosis and treatment. If periprosthetic scapular fractures did not alter the postoperative course following RSA, their clinical significance may be questionable. However, compared with patients without such fractures, those with acromial spine fractures have reduced forward flexion and abduction, as well as a reduced mean constant score and mean American Shoulder and Elbow Surgeons (ASES) score [21•].

The evidence pertaining to clinical outcomes following treatment of periprosthetic acromion and/or scapular fractures is largely based on case series of limited sample sizes. A 2019 systematic review of 114 cases demonstrated increased union rate among operatively treated patients (88%) compared with those treated conservatively (44%) [20]. In this composite patient cohort, mean constant score at the time of fracture diagnosis was 10.5 and increased to 57 at the time of final

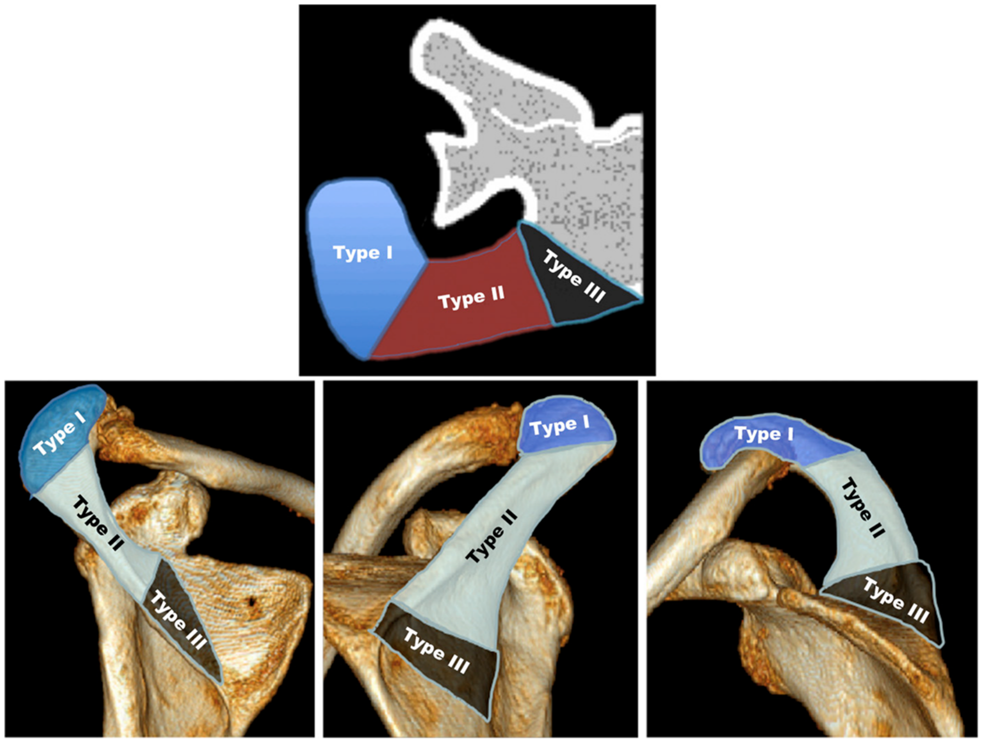

Fig. 3 Illustration of the Levy classification of postoperative acromial fractures following reverse shoulder arthroplasty. Type 1 fractures involve the anterior and middle portions of the deltoid, type 2 fractures involve the middle and part of the posterior deltoid, and type 3 fractures involve the middle and entire posterior deltoid origin. (Reproduced from Levy et al. [23•])

follow-up among patients treated nonoperatively. Those treated operatively began with a mean constant score of 10.3 and increased to 73 among surgical patients [20]. Neyton et al. [19••] reported that nonoperative treatment resulted in a nonunion rate of 62.5% at 6 weeks. Among surgically treated patients, 40% of acromial fractures and 33% of scapular spine fractures healed by radiographic analysis. In comparison, acromial stress reactions (i.e., clinical symptoms without radiographic fracture) appear to have reliable symptom resolution, with one study reporting that approximately 95% of patients having symptoms resolved by 6 months [18••].

Reporting of mid-term and long-term treatment outcomes of periprosthetic acromion and scapula fractures is anticipated to increase commensurate with increased procedure volume and awareness of this complication from RSA [21•]. In order to maximize the information garnered from these research efforts, we recommend prospective, multicenter studies that characterize patient demographics, specify surgical technique and RSA implants, carefully define surgical fixation strategies, and report on validated patient-reported clinical outcomes.

Humerus Fractures

Periprosthetic humerus fractures can be categorized broadly as either intraoperative or postoperative events. An intraoperative fracture is a surgical complication with direct clinical

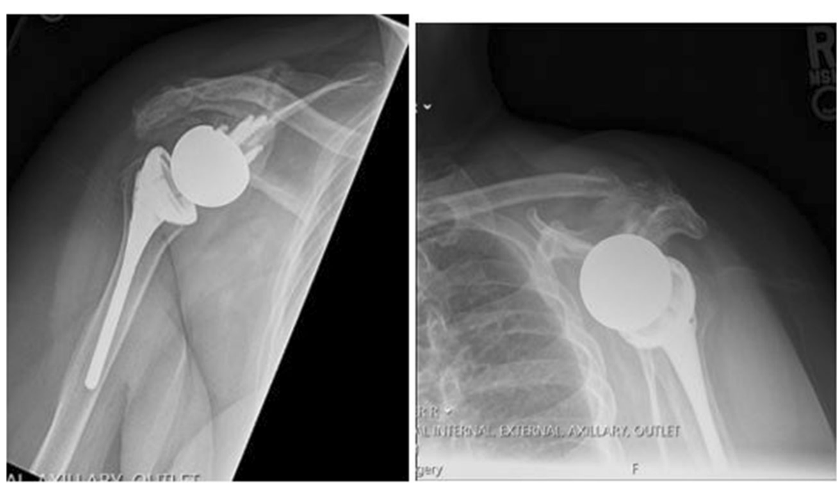

Fig. 4 Right shoulder anteroposterior radiograph of a 74-year old female 3 months status-post right reverse shoulder arthroplasty. Findings demonstrate a Levy III fracture. Patient was treated with 6 weeks of additional sling immobilization. Most recent follow-up demonstrated persistent chronic scapular spine fracture with persistent mild pain

consequence; they are associated with increased length of surgery, may require additional procedures, and may alter a patient's postoperative course [41••]. Conversely, some authors have postulated that not all postoperative fractures should be regarded as a surgical complication, since the patient population undergoing RSA is at increased risk for falls and native proximal humerus fractures [42]. Regardless, both intraoperative and postoperative humerus fractures following RSA require careful investigation and informed discussion with patients. The diagnostic work-up, described previously for evaluating acromial and scapular spine fractures, applies equally in the setting of postoperative periprosthetic humerus fractures.

Incidence

Periprosthetic humeral fractures in the setting of RSA have an estimated incidence of 3.3–3.5% [1, 10, 11]. A systematic review of 782 RSA procedures identified an incidence rate for proximal humerus fractures of 3.45% [10]. This total incidence was comprised of 2% intraoperative fractures and 1.4% postoperative fractures. These estimates are limited by their reliance on pooled data across multiple single-center, retrospective case series with heterogeneous patient demographics, implant designs, and follow-up duration. Further, fractures of the greater tuberosity likely account for a significant number of periprosthetic fractures; however, are often not included or reported in studies. Among 203 RSA procedures followed for a mean of 79 months, Garcia-Fernandez et al. [1] reported 3 intraoperative humeral fractures and 4 postoperative fractures, the latter occurring at an average of 1-year following surgery. A separate analysis of 31 patients who underwent RSA using a short metaphyseal humeral stem with a mean follow-up of 36 months reported an postoperative humeral fracture incidence rate of 12.9% [42].

Risk Factors

Several characteristics relating to either the patient, surgical indication, or surgical technique have been identified as factors that increase the risk of periprosthetic humeral fracture. Special attention should be paid to minimize the risk of intraoperative fracture, particularly in patients with osteopenia, rheumatoid arthritis, and in the revision setting [43]. Conversion from failed prior shoulder arthroplasty to RSA traditionally requires humeral implant removal, predisposing to intraoperative fractures [44•]. In an analysis of 230 such revision cases over 8 years, Wagner et al. [41••] reported an intraoperative periprosthetic rate of 16% (36/230). Of these, 81% occurred during component removal and 19% during preparation of the humeral canal. The authors identified female sex, a history of instability, and prior hemiarthroplasty as risk factors for intraoperative periprosthetic humerus fracture [41••, 45]. Technical challenges of arthroplasty in a revision setting included loss of tissue planes, bone loss, and, at times, infection [45]. An implant-specific removal device may reduce the risk of intraoperative fracture during this step [41••]. Alternatively, a platform humeral prosthesis may obviate the need for humeral implant removal when performing this procedure if the stem can be retained [46]. Van Thiel et al. [47] also described a vertical osteotomy stabilized with cerclage cables as a means to minimize fracture risk during humeral implant removal. In addition to RSA in the setting of failed prior arthroplasty, RSA performed for proximal humerus fracture has also been associated with a higher rate of subsequent periprosthetic fracture [31].

Humeral implant design characteristics may influence the risk of periprosthetic fracture. Specifically, a short stem design and improved metaphyseal ingrowth fixation design has become popular as it preserves native bone stock and reduces the amount of intramedullary reaming required [48, 49•]. However, some have speculated that the short stem implant may pose a risk for a fracture at the metadiaphysis due to the potential for developing a stress riser [3]. Other authors argue that the shorter stem shifts the stress riser from the diaphysis to the metaphysis, where there is greater healing potential and greater chance of successful nonoperative treatment [42].

Classification

The most commonly employed classification system for periprosthetic humeral fractures was devised in 1995 by Cofield and Wright [50]. This system described fractures in relation to the tip of the humeral stem; type A comprised fractures proximal to the tip, type B comprised fractures at the tip and extending distally, and type C comprised fractures distal to the tip of the humeral stem [51]. Whereas this system has been most amenable for describing postoperative humeral fractures, Campbell et al. [52•] proposed a classification system that incorporated fractures not restricted to the humeral diaphysis (Fig. 5). In this four-part system, type 1 involves the lesser or greater tuberosity, type 2 involves the surgical neck, type 3, the metadiaphyseal junction, and type 4, the middle and distal humeral diaphysis [52•]. To date, the intra- and inter-rater reliability of these classification schemas have not been reported.

Treatment and Outcomes

The existing evidence basis to guide treatment decision-making relies on few published retrospective case series and expert opinion. Many of the treatment principles are borrowed from experience treating native proximal humerus fractures. In general, treatment decisions must consider the fracture's location, displacement, and local bone quality. Wagner et al. [41••] proposed a treatment algorithm for intraoperative humerus fracture in the setting of RSA. In this schema, fractures

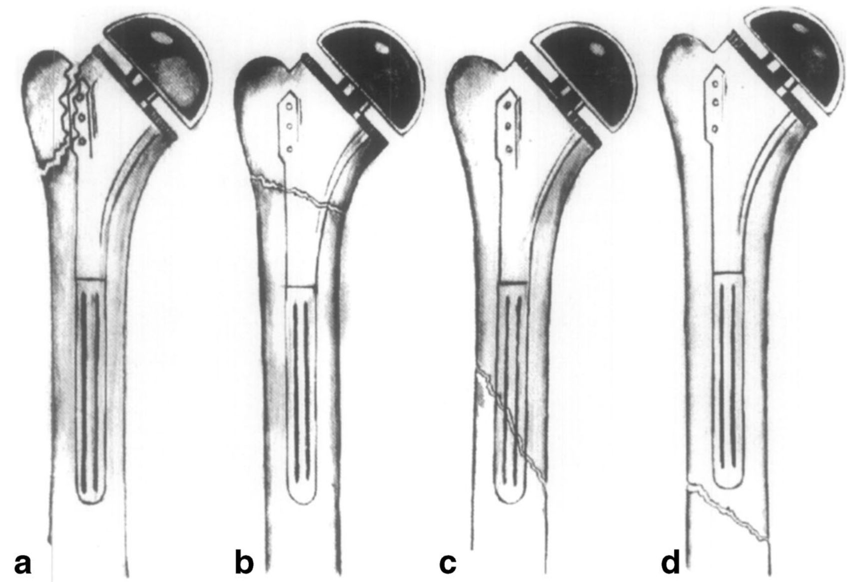

Fig. 5 Campbell Classification of periprosthetic humeral fractures. **a** Type 1 involves the lesser or greater tuberosity, **b** type 2 involves the surgical neck, **c** type 3 the metadiaphyseal junction, and **d** type 4 the middle and distal humeral diaphysis. (Image reproduced from Campbell et al. [52])

of the greater tuberosity are stabilized with a suture fixation construct, nondisplaced metaphyseal fractures are secured with multiple cerclage wires, and displaced fractures of the metaphysis are fixed using cables and strut allograft [41••]. The authors do not alter patients' postoperative rehabilitation course.

It is important to note, particularly with regard to the intraoperative tuberosity fracture, that the majority are avulsion types secondary to tension on the rotator cuff in patients with osteoporotic bone. They typically occur during humeral preparation after glenosphere insertion, specifically when externally rotating the humerus. In patients with osteoporotic bone and an intact rotator cuff, the supraspinatus can be released prior to humeral preparation to reduce the tension on the tuberosity while retaining the positive external rotation power of the posterior rotator cuff. Furthermore, from a technical standpoint, one must remember that the reason for the fracture is poor bone quality. Therefore, a suture repair is most effective with sutures in the rotator cuff (stronger than their bone) that are then secured to the implant prior to placing the final humeral prosthesis.

In a separate case series of periprosthetic humerus fractures, Garcia-Fernandez et al. [1] applied the Wright-Cofield classification to guide treatment. A proximal humerus locking plate and cerclage wires were used to fix a postoperative type A fracture. Dynamic compression plating with cerclage wires was used for fixation of a displaced postoperative Type B fracture, with maintenance of the humeral stem. Given their location distal to the humeral implant, type C fractures can typically be treated with a trial of nonoperative treatment using a brace as in a native humeral shaft fracture [51]. Conversely, unstable proximal humerus fractures in the setting of a well-fixed implant are generally treated with a proximal humerus locking plate secured with multiple screws above and below the fracture site and cerclage cables [53].

The limited data available on outcomes following RSA-related humerus fractures are encouraging. Mean time to fracture union is estimated to range from 2 to 6 months [1]. Mineo et al. [54] reported on two postoperative periprosthetic humerus fractures treated with open reduction and internal fixation. Both patients had healed by 5 months following fracture fixation. In another series of intraoperative periprosthetic humerus fractures, two Campbell type 1 fractures treated with cerclage wiring and retention of a cementless stem demonstrated full radiographic healing by 10 weeks [1]. A Campbell type 4 fracture of the mid-diaphysis was treated with placement of a long humeral stem and multiple cerclage wires, which resulted in a healed fracture at 6 months. Further research is needed to compare treatment strategies and assess long-term clinical outcomes associated with periprosthetic humerus fractures in the setting of RSA.

Clavicle Fractures

Clavicular stress fractures following RSA are extremely rare. Consequently, the literature related to this complication is scarce, limited to three case reports [55–57]. Kim et al. [56] postulated that, in the setting of rotator cuff tear arthropathy, the humeral head's superior migration can also translate anteriorly in the setting of a torn subscapularis. In this scenario, the humeral head may cause subtle erosion of the clavicle preoperatively, which may lead to a lower threshold for fracture during or after RSA. No evidence is yet available that tests this hypothesis.

Among three reported cases of postoperative clavicle fractures, two patients were treated conservatively with continued immobilization until radiographic healing [56, 57]. Patients experienced relief in pain and persistent functional deficits at follow-up between 14 and 30 months postoperatively. Anakwenze et al. [55] identified a midshaft clavicle fracture 10 weeks following RSA. After an additional 10 weeks of failed conservative treatment, the patient underwent open reduction and internal fixation. The patient reported satisfaction in pain and functional levels at 1 year following RSA.

Coracoid Process Fractures

Fractures of the coracoid process are another exceedingly rare complication following RSA. Nonetheless, in the evaluation of the painful postoperative patient, scrutiny of the coracoid process must be included on physical exam and review of postoperative imaging. In the single case report by Anakwenze et al. [58], two coracoid process fractures were identified at 3 months and 15 months respectively. Both cases required CT for diagnosis and both patients achieved satisfactory outcomes with nonoperative management. Given its uncommon occurrence, it remains possible that this may be an underdiagnosed condition in the painful postoperative patient; however, further studies are needed to better document postoperative coracoid process fractures.

Conclusions

Reverse shoulder arthroplasty offers a viable surgical treatment to a host of complex shoulder conditions. Among complications associated with its use, periprosthetic fracture is a clinically significant event that warrants prolonged postoperative vigilance, timely diagnosis, and shared patient decision-making regarding treatment. Continued advancements in RSA implant design and surgical technique must take into consideration the biomechanical forces transmitted across the acromion to minimize the risk of periprosthetic acromial fracture. Humeral implant removal during conversion to RSA from prior failed shoulder arthroplasty is a high-risk moment for intraoperative humerus fracture. Surgical techniques aimed to minimize this risk must continue to be developed. Given the relatively low incidence of periprosthetic fractures in RSA, a prospective, multiinstitutional clinical registry offers the most efficient means for studying long-term clinical outcomes and optimal treatment strategies.

Compliance with Ethical Standards

Conflict of Interest Christopher Brusalis declares that he has no conflict of interest. Samuel Taylor declares that he has the following potential conflict of interest: paid consultant for DJO Global.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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