Metadata of the chapter that will be visualized online

Chapter Title	Primary Arthroplasty for Proximal Humeral Fractures and Fracture Sequelae Following Implant Failure	
Copyright Year	2022	
Copyright Holder	Springer Nature Singapore Pte Ltd.	
Author	Family Name	**Ankem**
	Particle	
	Given Name	**Hari K.**
	Suffix	
	Division/Department	Department of Orthopaedic Surgery
	Organization/University	University of Louisville Louisville,
	City	KY
	State	USA
	Country	
Corresponding Author	Family Name	**Kamineni**
	Particle	
	Given Name	**Srinath**
	Suffix	
	Organization/University	Department of Orthopaedic Surgery
	City	(Elbow Shoulder Research Center)
	State	University of Kentucky Lexington
	Country	KY, USA AU1

Abstract

Proximal humeral fractures and fracture-dislocations, which are not amenable to predictable anatomical fixation, pose several treatment challenges, especially in elderly individuals. Malunion of the fracture fragments can be an outcome, while humeral head avascular necrosis and fracture nonunion can complicate an attempted internal fixation leading to articular surface degradation and secondary osteoarthritis. These patients often present with painful, stiff shoulders secondary to a distorted proximal humerus, scarred deltoid, rotator cuff tears, and/or atrophied rotator cuff muscles. The anatomical sequelae noted from failed initial treatment makes shoulder arthroplasty more challenging, often with less predictable results and a higher risk of complications.

Primary hemiarthroplasty of the shoulder is indicated for treating elderly, osteoporotic proximal humeral fractures which are often complicated by comminution, which are of three and more parts, and sometimes associated with head splitting and fracture-dislocations. The important factors influencing the outcomes include restoration of native humeral height and version with healing of the tuberosities in an acceptable position. Tuberosity malunion and nonunion equate to poor function. Hemiarthroplasty for neglected proximal humeral fractures and for revising failed internal fixation is known to fare worse compared to those performed in primary osteoarthritis and acute fractures. In current practice, fractures with distorted proximal humeral architecture, poor bone

Author's Proof

stock, and associated cuff pathology, the reverse shoulder arthroplasty is a reliable treatment option, backed by increasingly positive short and mid-term follow-up data.

Keywords (separated by "-")	Primary - Hemi - Total - Reverse shoulder - Arthroplasty - Proximal - Humeral - Fractures - Sequelae and implant failure

Author's Proof

Primary Arthroplasty for Proximal Humeral Fractures and Fracture Sequelae Following Implant Failure

Hari K. Ankem and Srinath Kamineni

Uncorrected Proof

Contents

Introduction 2
Open Reduction and Internal Fixation 4
Arthroplasty 6
Proximal Humeral Fracture Sequelae Classification: 7
Conclusion 13
References 14

Abstract

Proximal humeral fractures and fracture-dislocations, which are not amenable to predictable anatomical fixation, pose several treatment challenges, especially in elderly individuals. Malunion of the fracture fragments can be an outcome, while humeral head avascular necrosis and fracture nonunion can complicate an attempted internal fixation leading to articular surface degradation and secondary osteoarthritis. These patients often present with painful, stiff shoulders secondary to a distorted proximal humerus, scarred deltoid, rotator cuff tears, and/or atrophied rotator cuff muscles. The anatomical sequelae noted from failed initial treatment makes shoulder arthroplasty more challenging, often with less predictable results and a higher risk of complications.

Primary hemiarthroplasty of the shoulder is indicated for treating elderly, osteoporotic proximal humeral fractures which are often complicated by comminution, which are of three and more parts, and sometimes associated with head splitting and fracture-dislocations. The important factors influencing the outcomes include restoration of native humeral height and version with healing of the tuberosities in an acceptable position. Tuberosity malunion and nonunion

H. K. Ankem
Department of Orthopaedic Surgery, University of Kentucky, Lexington, KY, USA

S. Kamineni (✉)
American Hip Institute, Des Plaines, IL, USA

© Springer Nature Singapore Pte Ltd. 2022

A. Banerjee et al. (eds.), *Handbook of Orthopaedic Trauma Implantology*,
https://doi.org/10.1007/978-981-15-6278-5_29-1

Author's Proof

equate to poor function. Hemiarthroplasty for neglected proximal humeral fractures and for revising failed internal fixation is known to fare worse compared to those performed in primary osteoarthritis and acute fractures. In current practice, fractures with distorted proximal humeral architecture, poor bone stock, and associated cuff pathology, the reverse shoulder arthroplasty is a reliable treatment option, backed by increasingly positive short and mid-term follow-up data.

Keywords

Primary · Hemi · Total · Reverse shoulder · Arthroplasty · Proximal · Humeral · Fractures · Sequelae and implant failure

Abbreviations

GT	Greater tuberosity
HA	Hemiarthroplasty
NCA	Non-constrained arthroplasty
ROM	Range of motion
RSA	Reverse shoulder arthroplasty

Introduction

Fractures involving the proximal humerus are commonly classified by Neer's method [1] which is based on the number of fracture fragments displaced by more than 1 centimeter or angulated 45°. The humeral head, humeral shaft, and each of the tuberosities are considered as the four fragments (Fig. 1). Alternatively, the AO/OTA group classifies these fractures based on location and surgical neck condition which reflects risk of compromise to the humeral head blood supply [2]. AU2

The history, clinical examination, and imaging findings are critical in order to establish an effective treatment decision and surgical plan. Patient demographics such as age, time from injury, functional level, pre-morbid conditions, and the ability to participate in rehabilitation are vital components in the treatment algorithm. Routine preoperative plain radiographs portray the articular surface incongruity from humeral head splitting if present. In addition, radiographs are helpful in identifying the number and displacement of the actual fracture fragments, as well as surgical neck involvement and displacement indicating possible compromise of the humeral head blood supply. CT scans with three-dimensional reconstructions of the proximal humerus are useful (Fig. 2), although not essential if the surgeon is familiar with interpreting plain radiographs. CT scans with 3D reconstructions can be of particular value to the treating surgeon when planning fixation method in complex fracture as well as in choosing implant design when selecting arthroplasty as the treatment modality.

Comminution and displacement involving the surgical neck region compromise the blood supply to the humeral head. This factor plays a critical role in surgical decision making between internal fixation and arthroplasty. Fracture features that

Uncorrected Proof

Author's Proof

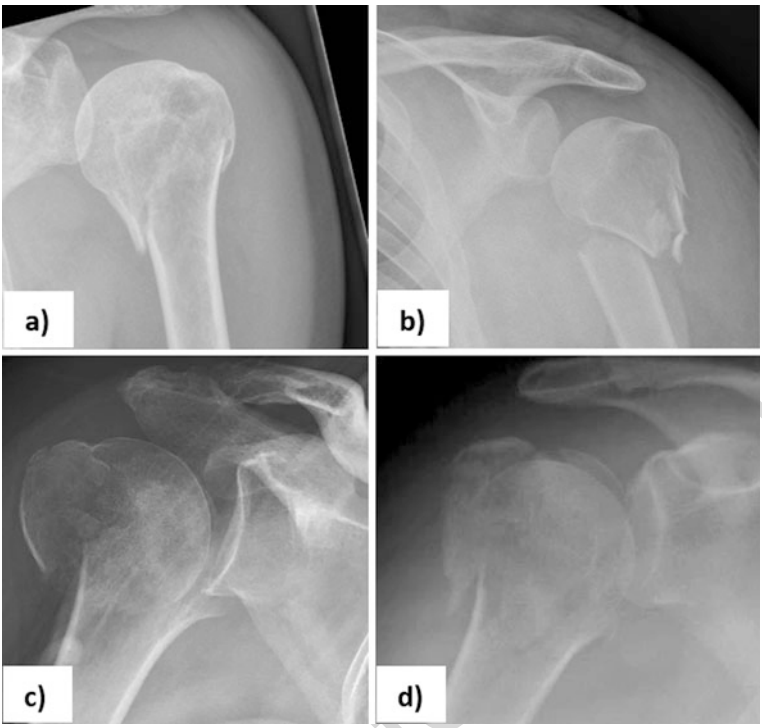


Fig. 1 Neer's classification of Fractures of the proximal humerus based on number of displaced fragments as (**a**) one-, (**b**) two-, (**c**) three-, and (**d**) four-part fractures

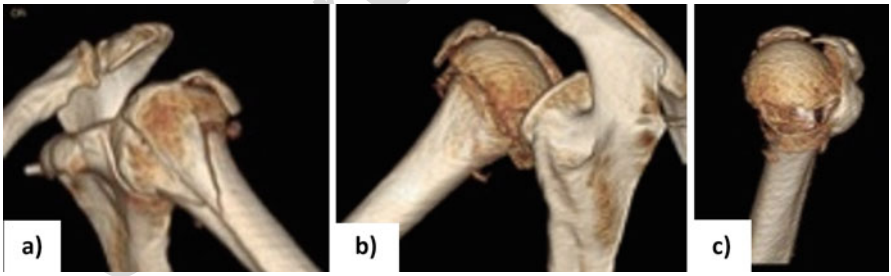


Fig. 2 (**a**–**c**) Preoperative 3D CT image depicting a proximal humeral four-part fracture

increase the risk of humeral head avascular necrosis (AVN) include: a short medial head metaphyseal spike of less than 8 mm, absent posteromedial bony contact, and humeral head split [3]. These findings should prompt the clinician to strongly consider primary arthroplasty as the definitive treatment.

Proximal humeral fractures that are minimally displaced tend to unite well with conservative treatment, with 80% of treated subjects achieving good to excellent outcomes [4–6]. However, the ideal method of treating the severely displaced and

Author's Proof

complicated proximal humeral fracture is debatable [4–6]. The treatment of displaced or unstable proximal humeral fractures varies depending on patient factors, as well as surgeon preferences and experience. Options include open reduction and internal fixation with proximal humeral plate and screws, intramedullary nail, percutaneous or minimally invasive fixation with pins or screws, and arthroplasty [7–11].

Based on the current clinical evidence, it is difficult to universally favor either joint replacement, internal fixation, or conservative treatment [12, 13]. All three categories of management have a place in the treatment algorithm, and literature is starting to better delineate which treatment modality is suited to which fracture/sequelae personality.

Open Reduction and Internal Fixation

Displaced three- and four-part fractures in elderly patients present a unique challenge for surgeons. Patient age, bone quality, type of fracture, and time since injury are the important factors that determine the decision to intervention [14].

Internal fixation of proximal humeral fractures is compounded by loss of blood supply to the head fragment, osteopenic/porotic bone, comminution, chronologically and physiologically elderly patients, and damage to the rotator cuff. All of these factors increase the rate of failure of osteosynthesis [9, 11]. Poor clinical results and high failure rates are reported among elderly patients with three- and four-part proximal humeral fractures, with internal fixation [11]. Locking plates and intramedullary devices may offer initial stability of reconstructed fractures allowing early rehabilitation, but results are unpredictable in elderly fragility fractures; however, improved plate and screw technology including locking constructs has been helpful in treatment of these patients.

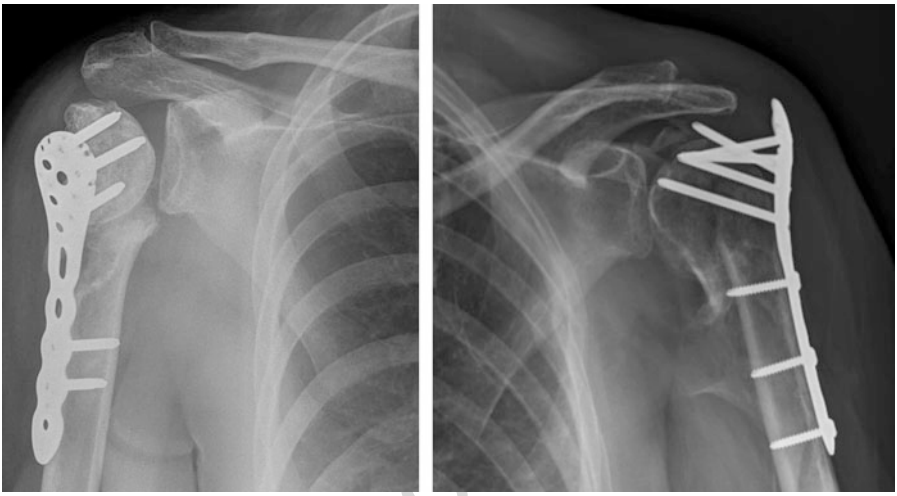
Open reduction and internal fixation of the displaced three-part and four-part proximal humeral fractures may be considered as a treatment option in elderly patient with adequate bone stock. This approach has one hypothetical advantage and particularly in those who are younger (<60 years of age). In the event of AVN occurring in the humeral head, a future revision to arthroplasty is more probable with anatomically healed tuberosity fragments. However, in conditions of poor bone quality, likely compromised humeral head blood supply, and articular surface injury; primary arthroplasty is preferable due to the high rate of failure with initial operative fixation.

Internal fixation of the proximal humeral fractures was shown to have 98% success rate of union in a recent systematic review [10] that was conducted in which subjects achieved a Constant score of 74 with forward flexion up to 139 degrees and external rotation to 48 degrees. However, other studies quoted a high percentage of complications (13.7%) reporting on proximal humeral fractures that were fixed with internal fixation. [15] The reported complications included AVN of the humeral head, loss of internal fixation, screws penetrating the articular surface, and impingement from hardware [9, 11]. Hemiarthroplasty for neglected proximal

Uncorrected Proof

Author's Proof

humeral fractures and their sequelae following failed internal fixation as a salvage procedure is known to fare much worse compared to that performed primarily in osteoarthritis and acute fracture indications [16, 17]. Hence the decision making between ORIF and arthroplasty is important, and furthermore complications associated with chosen treatment modality must be considered. The failed internal fixation complications were depicted in Figs. 3 and 4.



AU3 AU4 **Fig. 3** (**a**, **b**) Failed fixation of the proximal humeral fracture (two-part) with varus collapse and screws perforating humeral head requiring removal

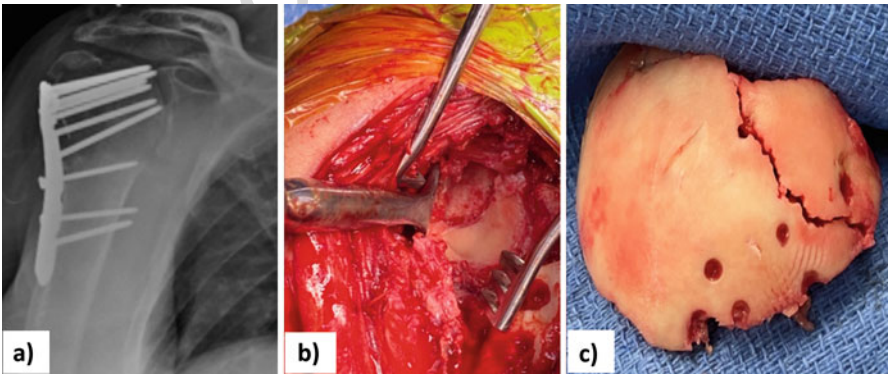


Fig. 4 The consequences of failed ORIF (**a**) include glenoid bone loss due to erosion by the perforated screws (**b**). Locking screws can penetrate the humeral head as the head collapses (**c**)

Author's Proof

Arthroplasty

Hemiarthroplasty of the shoulder is indicated in treating elderly osteoporotic proximal humeral fractures, not amenable to conservative management, and are often complicated by comminution. The latter precluding the possibility of internal fixation [19]. The consequences of tuberosity malunion and nonunion equate to poor functional outcomes. Similarly, continued glenoid erosion by a metallic prosthetic head also may lead to poor patient functional outcomes.

Poor outcomes are reported following hemiarthroplasty for the acute proximal humeral fractures in older individuals with osteoporosis due to migration, nonunion, malunion, or resorption of tuberosities [20]. Anatomical total shoulder replacement with approximation of tuberosities to the surgical neck and prosthesis, while restoring humeral length and lateral offset, helped address these difficult [21, 22] fractures with poor bone quality.

In general, it is agreed that the primary anatomical total shoulder replacement fares better when compared to the hemiarthroplasty in elderly fractures. It is also well-accepted that primary arthroplasty outperformed secondarily converted joint replacement procedures in terms of long-term complications and functional outcome. However, in patients with severe osteoporosis the use of this type of implant is still limited, with less predictable outcomes.

Cazeneuve et al. [23] reported medium-term follow-up results at 6.6 years in 36 elderly patients with osteoporotic proximal humeral fractures treated primarily with reverse shoulder prosthesis. In their series with a Constant score of 53 points, 23 patients (63%) had radiologic evidence of glenoid component loosening and a significant percent developed scapular notching. The authors highlight that continued advancements in RSA design and bearing surfaces, improved surgical technique, and long-term follow-up studies are needed to determine the role of reverse total shoulder arthroplasty in the treatment of these fractures. They also suggested complete removal of tuberosities while avoiding excessive anteversion at the initial surgical preparation quoting reasons for high percentage of dislocation in their series from impingement adding to the instability.

Secondary treatment of these fractures that failed primary treatment is complex and can be fraught with complications. Malunited fracture fragments with or without AVN of the humeral head and nonunion are common along with joint surface irregularity that poses additional challenges. Furthermore, features such as underlying damage to the rotator cuff, with adhesions from prior surgical intervention, deltoid muscle scarring, and disuse atrophy make a secondary arthroplasty procedure difficult with poor results and high rates of complications [24–26]. It is known that results of arthroplasty for neglected proximal humeral fractures and their sequelae following failed internal fixation are inferior to those performed primarily in osteoarthritis and acute fractures [16, 17].

The concept of reverse shoulder arthroplasty came into existence to compensate for poor rotator cuff function that was further compromised by nonunion, malunion, and resorption of tuberosities. In fractures with distorted proximal humeral

Uncorrected Proof

Author's Proof

architecture and poor bone stock, and associated rotator cuff pathology; evidence favors reverse shoulder arthroplasty (RSA) over non-constrained arthroplasty (NCA).

Proximal Humeral Fracture Sequelae Classification:

Proximal humeral fracture sequelae have been classified into two categories (Intra-capsular and Extra-capsular) with four subtypes described by Boileau et al. [18] (Fig. 5). This classification describes the behavior of these fractures and is helpful in surgical planning and predicting outcomes.

In Category I, the tuberosity relationship with respect to the proximal humerus is well maintained hence a greater tuberosity osteotomy is not required while considering implanting an anatomical shoulder prosthesis, leading to predictably good outcomes. This category is subdivided into Type 1, humeral head collapse or AVN with minimal tuberosity malunion, and Type 2, locked shoulder dislocation or fracture-dislocation of the proximal humerus. Additionally, within the category I of proximal humeral fracture healing sequelae, the Type 1 sequelae were further divided by Moineau et al. [27] into four subgroups as 1A – humeral head

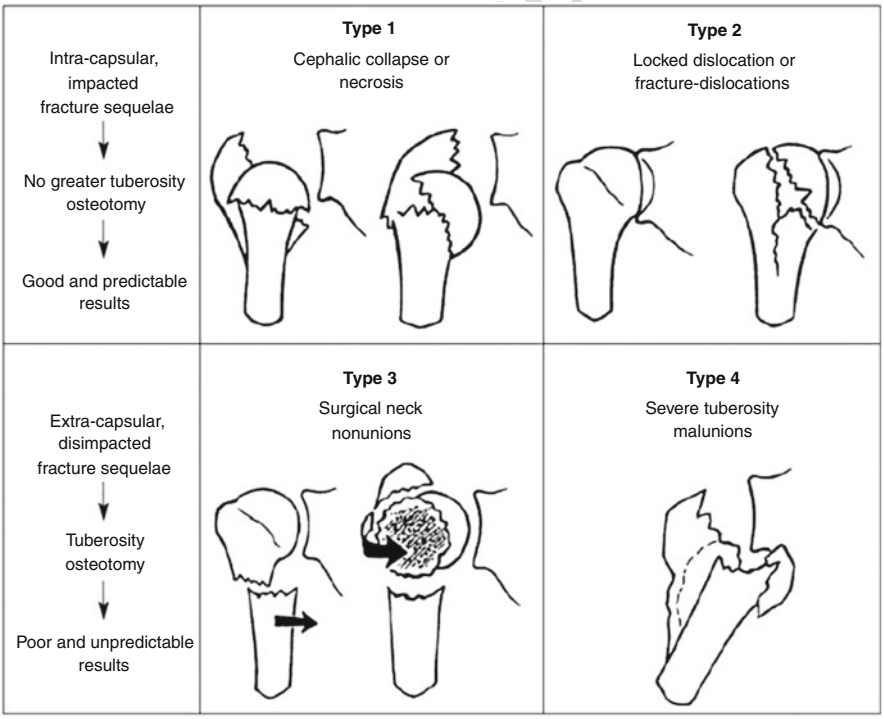


Fig. 5 Boileau et al. [18] classification of healed proximal humeral fracture sequelae

Author's Proof

posttraumatic AVN without tuberosity malunion; 1B – posttraumatic OA without AVN or tuberosity malunion; 1C – proximal humeral malunion in valgus; and 1D – proximal humeral malunion in varus.

In Category II, extracapsular displaced proximal humeral fracture sequelae, the relationship between tuberosities, humeral head, and shaft are grossly distorted during healing. This category is also further subdivided into those with surgical neck nonunion (Type 3), and those with severe tuberosity malunion (Type 4). In Category II sequelae, tuberosity osteotomy is necessary in order to perform an anatomic prosthesis, hence the results are poorer and less predictable.

According to Mansat et al. [17, 28], the results of total shoulder arthroplasties (anatomical/"non-constrained") for neglected proximal humeral fractures and their sequelae following failed internal fixation is known to fare worse compared to that performed in primary osteoarthritis or hemiarthroplasty performed for acute fractures. Based on their review, these authors concluded that the satisfaction may be expected in 15%–72% of the cases, with 85% having pain relief and having attained ROM of 110 degrees of active forward elevation and 20 degrees of active external rotation.

These authors [17, 28] reported complication rates varying between 20% and 48% in this category of proximal humeral fractures compared to other etiologies. Likewise, the revision rates varied from 3% to 35%. They concluded that the final outcomes were affected by preoperative factors, most notably initial treatment method, type of fracture sequelae, and the need for greater tuberosity osteotomy. Better results were noted among those with sequelae after initial conservative treatment compared to those treated initially with surgical management. Similarly, if the type of sequelae included posttraumatic arthritis without any distortion of the tuberosities or AVN, better results were noticed when compared to posttraumatic arthritis with nonunion, humeral head defect, and/or malunion. The results were poor and less predictable if performing an anatomical or non-constrained shoulder arthroplasty requiring a greater tuberosity osteotomy (Fig. 6).

Moineau et al. [27] reported outcomes to be unfavorable when an anatomical prosthesis was implanted for type 1 fracture sequelae in instances of varus deformity, greater tuberosity osteotomy, or rotator cuff fatty atrophy. In these circumstances, the authors recommended a reverse total shoulder prosthesis (RSA).

Boileau et al. [18] reported poor Constant scores in one-third of cases, in a series of 71 non-constrained arthroplasties performed in different proximal humeral fracture sequelae. Good to excellent Constant scores were obtained in type 1 and 2 proximal humeral fracture sequelae in which osteotomy of the greater tuberosity (GT) was not required. Cases with type 3 and 4 sequelae, which needed a GT osteotomy, were found to have fair or poor results and failed in achieving active forward flexion above horizontal. These authors concluded that whenever possible, GT osteotomy should be avoided while performing non-constrained shoulder arthroplasty for the treatment of proximal humeral fracture sequelae.

These authors further reinforced their previous study findings by updating their study results in which they reported on 203 patients with proximal humeral fracture sequelae. Among them, those that were treated with non-constrained arthroplasty

Uncorrected Proof

Author's Proof

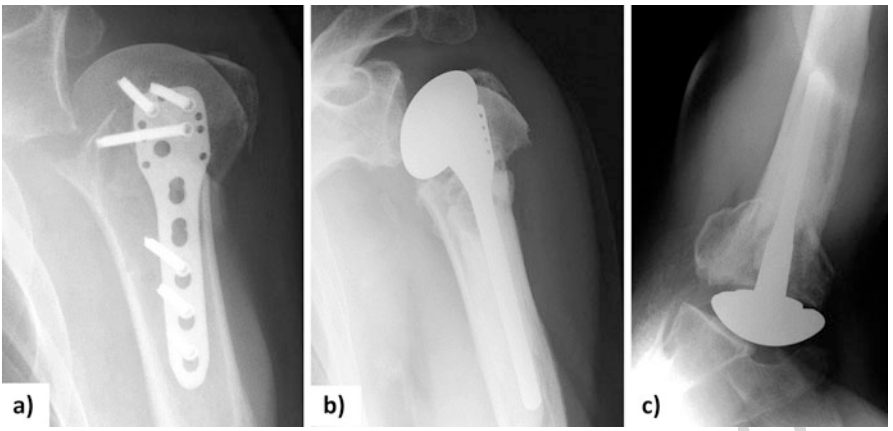


Fig. 6 (**a**) Open reduction internal fixation with plate (incompletely reduced fracture) with proximal humeral fracture sequelae Category 1, type 1. Followed by revision of the former with anatomic – non-constrained shoulder prosthesis (NCA) (**b** & **c**) without an osteotomy of the greater tuberosity

(NCA) in type 1 and type 2 sequelae obtained good post-op Constant scores (62 and 61 points, respectively) [18, 29]. In this follow-up study, the authors noted total shoulder arthroplasty to fare better than hemiarthroplasty, with NCA (along with GT osteotomy) treated patients obtaining 36 and 42 points as post-op Constant scores in Type 3 and Type 4 fracture sequelae, respectively. They no longer recommended using anatomical or non-constrained prosthesis, instead they proposed using either bone grafting [15] or fracture prosthesis with a low-profile for patients with Type 3 sequelae and reverse total shoulder arthroplasty (R-TSA) for those patients with Type 4 sequelae. They recommended surgeons accept distorted proximal humeral anatomy when possible by adapting the prosthesis and their surgical technique to the altered anatomy in order to avoid GT osteotomy.

The results of NCA were slightly better than RSA in Type 1 fracture sequelae in patients with intact rotator cuff, restoring both active elevation and external rotation [30]. RSA was better than NCA in those patients with Type 1 fracture sequelae with head collapse or AVN and a rotator cuff that is either atrophied or injured and not functioning. Hence, either NCA or RSA may be chosen for Type 2 sequelae. In locked posterior fracture dislocations, they preferred using NCA, while RSA was more favorable in proximal humeral fracture sequelae with chronic anterior dislocation of the shoulder. With regard to the management of surgical neck fracture nonunion (Type 3 proximal humeral fracture sequelae), these authors suggested internal fixation along with peg bone graft for fixing the nonunion as both NCA and RSA had inferior outcomes [15]. However, when surgical neck nonunion is also associated with tuberosity nonunion, severe humeral head cavitation, or osteoarthritis; humeral head replacement and tuberosity fixation with bone grafting is recommended. Lastly, in Type 4 sequelae with severe malunion of the proximal

Uncorrected Proof

Author's Proof

humerus with displaced and malunited tuberosities, RSA along with greater tuberosity osteotomy is preferred.

The treatment of proximal humeral fracture sequelae requiring greater tuberosity osteotomy was associated with poor outcomes as stated above. In Boileau and Neyton's experience [30], reverse total shoulder arthroplasty offered better outcomes compared to non-constrained shoulder arthroplasty when greater tuberosity malunion and or nonunion was addressed as part of the treatment plan. Additionally, these authors noticed improved patient reported outcomes and satisfaction by converting a failed hemiarthroplasty to a reverse shoulder prosthesis, especially with a convertible or platform stem that could be retained at the time of revision [31–33]. However, this procedure was associated with risk of higher complication rates.

Kilic et al. [34] retrospectively reviewed 55 patients with proximal humeral fracture sequelae, 36 NCA, and 19 RSA. Within the group treated with NCA, 32 patients had either type 1 or 2 sequela, with improvement of Constant scores from 19 points to 68 points. The majority of the patients in the RSA treated group had either type 3 or 4 sequelae (17 out of 19), and their Constant scores improved from 9 points to 47.5 points. The authors hence recommended NCA for type 1 and 2 sequelae and RSA for type 3 and 4 sequelae.

Later, following the recommendations as per the Boileau et al. [18] classification, Alentorn-Geli et al. [35] reported their results comparing treatments between 12 subjects with hemiarthroplasty (HA) and 20 subjects who had reverse shoulder arthroplasty. Six out of 12 subjects in the HA treated group had type 1 sequela while 10 out of 20 among RSA treated group had type 4 sequela. The HA treated group had more complications, with two subjects revised to RSA, either for painful limitation of function or infection and one subject to TSA following glenoid erosion.

In a mixed group comprising a large series of 191 shoulder arthroplasties, Wall et al. [36] reported on 33 RSAs performed for proximal humeral fracture sequelae [18]. This specific subset of RSAs scored inferiorly when compare to RSA that was performed for either rotator cuff arthropathy, massive rotator cuff tears, or osteoarthritis (OA). Similar observations were reported in another series [37] with rotator cuff arthropathy treated with RSA having better Constant scores when compared to patients with fracture sequelae that had RSA (83 vs 73 points). Nonunion sequelae (type 3) fared worse compared to malunited proximal humeral fractures (type 4 sequelae) with Constant scores of 56.5 vs 86.8 points [37]. The type 4 sequelae subset achieved better functional ROM. Likewise, Fevang et al. [38] reported RSA outperformed NCA and HA in their study looking into management options for proximal humeral fracture sequelae.

In contrast to the above studies, Willis et al. [39] felt that instead of osteotomy of the malunited tuberosities, implant design modification itself would allow better postoperative function. While reporting their results on 16 patients with proximal humeral fracture sequelae (six patients with type 1 and nine patients with type 4) [18] treated with RSA, these authors found no difference among the sequelae types that were statistically significant. In the treated subjects, ASES scores increased from

Uncorrected Proof

Author's Proof

28 to 63 points, forward flexion from 53 to 105 degrees, and external rotation from 5 to 30 degrees.

Martinez et al. [40] published their initial results of 18 cases of RSA (six being composite prosthetic allografts) for proximal humeral fracture treatment nonunion, with a modular platform system. The outcomes improved in Constant scores from 26 to 55 points, forward flexion from 35 to 90 degrees, external rotation from 5 to 30 degrees, and subjective shoulder value from 10% to 50%. In a follow-up study [41], 44 cases of RSA were performed for different sequelae of proximal humeral fractures (type 1 in 16, type 2 in 8, type 3 in 14, and type 4 in 6). Results were similar with improvements in Constant scores from 28 to 58 points, forward flexion from 40 to 100 degrees, external rotation from 15 to 35 degrees and subjective shoulder value from 13% to 56% [40]. Prosthetic instability was the most common complication noticed with the highly modular implant design.

In a recent study, Zafra et al. [42] reviewed their results of 35 patients with RSA for proximal humeral nonunion. The average follow-up was 4.25 years with statistically significant improvements in postoperative pain, functional ROM, and Constant scores. While significant pain reduction, functional improvement, and a high degree of satisfaction were achieved, instability in this particular subset of proximal humeral fracture sequelae remains a concern.

Instability following RSA for proximal humeral fracture sequelae and failed hemiarthroplasty is a serious complication. In an attempt to mitigate against instability, Guarrella et al. [43] recommended comparing the full humeral length radiographs between right and left sides for preoperative planning and templating the humeral implant height appropriately. Equally important is the residual glenoid bony anatomy which can be verified with CT imaging. CT is particularly helpful in planning the required lateral offset for the anticipated glenoid implant. Other studies suggested that maintaining deltoid length tension relationship and lateralizing the center of rotation as the key factors for prosthetic stability in RSA [44, 45]. Comparing the opposite side, when the humeral length is inadequate, a thicker polyethylene insert with a metallic spacer allows for correction up to 15 mm. These authors felt that if greater degrees of correction were to be needed, it would mandate revision to a prosthesis with a longer humeral stem, Figs. 7 and 8 [44, 45]. These authors also noted that when the intraoperative humeral length is deemed appropriate, closed reduction with examination under anesthesia confirms the joint to be stable, sling immobilization with or without an abduction pillow for 3–6 weeks is effective for maintaining stability while tissues heal.

When dealing with fractures, complex fracture sequelae, and failed fixation revision to arthroplasty, the surgeon is responsible for not only a grasp of fundamental principles but also technically adequate execution of the procedure. As a tertiary referral center for complications from other shoulder surgeons, we witness fundamental principles being breached more commonly than is reported. While all the fundamental principles are too numerous to mention, two example cases are presented to highlight the issue. In Fig. 9, there was excessive lengthening of the arm, which caused complete axillary nerve and deltoid dysfunction. In Fig. 10, failure to follow the time-tested AO principles of bypassing a cortical defect by two

Uncorrected Proof

Author's Proof

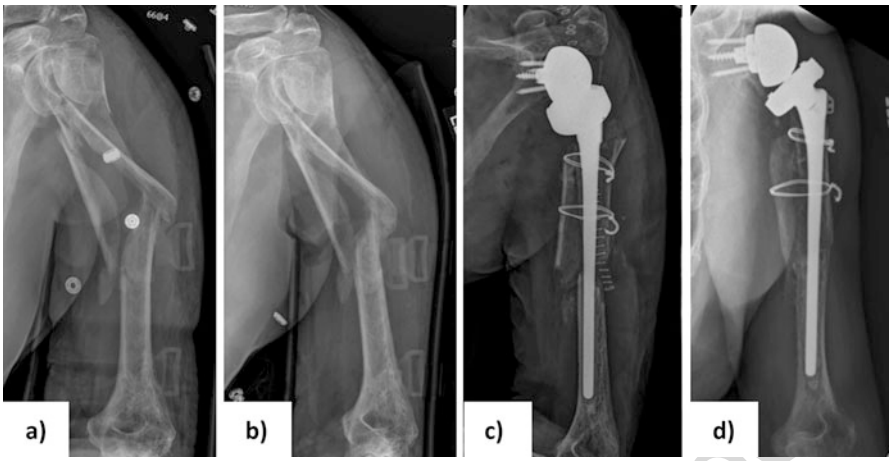


Fig. 7 Distorted proximal humeral anatomy with Type 4 fracture sequelae in category II as per Boileau's classification: (**a**) Acute injury, (**b**) treated nonoperatively in outside hospital, (**c**) treated with fracture mobilization and reverse shoulder arthroplasty, (**d**) 12-month follow-up demonstrating implant in-situ with preserved and healed proximal humerus

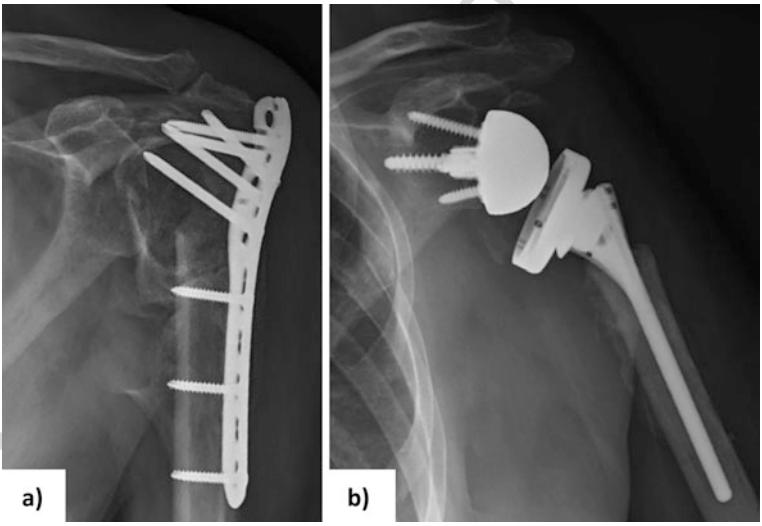
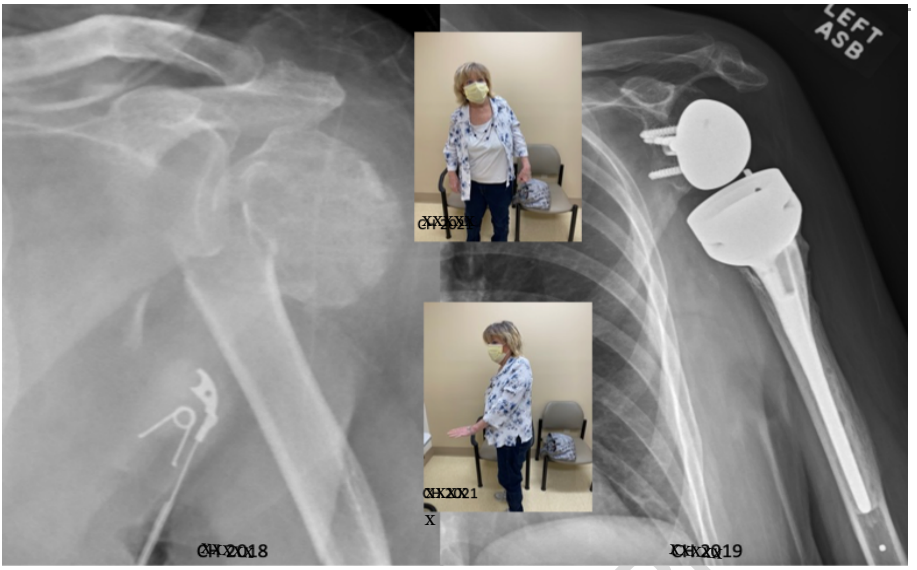


Fig. 8 (**a**) Proximal humeral fracture referred for fixation failure due to cut-out from bone, (**b**) treated with plate removal and standard reverse shoulder arthroplasty, preserving proximal humeral bone stock

cortical diameters, not checking post-operative X-rays on two consecutive operations, and not understanding the utility of long cemented versus uncemented stemmed humeral stems in revision surgery led to catastrophic failure. Our experience of dealing with such referred patients allows us to conclude that most

Author's Proof



AU6 **Fig. 9** Proximal humerus fracture treated with an over lengthened RSA, resulting in complete axillary nerve and deltoid dysfunction. This lady presented to us having fallen and broken her contralateral right shoulder. (Permission granted by patient to use clinical photos)

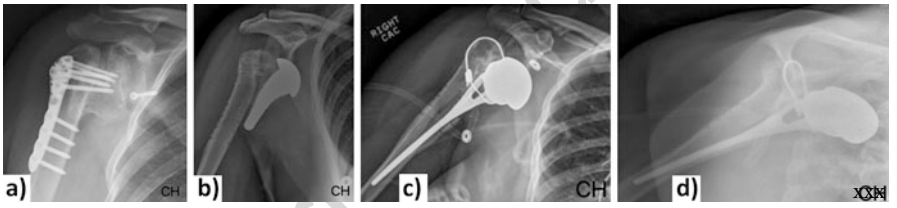


Fig. 10 (**a**) A failed proximal humerus ORIF that required revision surgery in a 41-year-old female patient (**b**) was treated with a short stemmed, uncemented anatomic arthroplasty. The surgeon failed to bypass the most distal cortical defect, following screw removal and failed to check postoperative radiographs which demonstrated the newly implanted humeral component wholly outside the humeral canal. (**c**) The same surgeon performed a revision surgery, and while she used a longer stem in this second surgery, failed to reduce the joint, which remained dislocated, and also resulted in an extended humeral fracture distal to the deltoid tuberosity

345 complications can be avoided with better training, and personal insight, that allows a
346 surgeon to understand her/his limitations, leading to a referral to a more
347 sub-specialized surgeon.

348 Conclusion

349 Proximal humeral fractures and their sequelae that are complicated due to several of
350 the patient related factors seen in elderly patients are not only difficult to treat but
351 pose unique challenges in their management. Poor outcomes were reported in older

Author's Proof

individuals following hemiarthroplasty for acute shoulder fractures from osteoporosis resulting in implant failure with migration, nonunion, malunion, and/or resorption of tuberosity fragments. Anatomical total shoulder replacement, with approximation of tuberosities to the surgical neck and prosthesis fins, restored humeral length and lateral offset. However, poor bone quality and dysfunctional rotator cuff compromise the outcome.

Factors identified to be most consequential to the final outcome are: (1) deranged proximal humeral anatomy; (2) relationship of the tuberosities to the humeral shaft – malunion or nonunion, (3) need for greater tuberosity osteotomy, and (4) quality of proximal humeral bone stock and rotator cuff integrity.

Proximal humeral anatomy with minimal distortion, tuberosities healed to the shaft in an acceptable position, and a functioning rotator cuff, treated with non-constrained arthroplasty (NCA) result with good functional outcomes. If distorted proximal humeral anatomy permits, modifying the surgical technique along with the implant configuration is an acceptable option, without the need to resort to tuberosity osteotomy. If the rotator cuff integrity is questionable, a reverse shoulder prosthesis (RSA) is recommended for elderly individuals. If there is gross distortion of proximal humeral anatomy and or malunion of the tuberosities, mandating a greater tuberosity osteotomy, NCA can only achieve poorer functional results. For fracture sequelae with surgical neck nonunion, intramedullary peg bone graft with osteosynthesis is recommended. RSA is recommended for late sequelae with tuberosity malunion, nonunion surgical neck fractures in elderly patients with questionable rotator cuff quality. Finally, bilateral humeral length comparison to maintain effective deltoid length tension relationship and lateralization of the glenoid component helps address the instability concerns while dealing with fracture sequelae surgery and in revision to reverse prosthesis scenarios. AU5

References

1. Neer CS II. Displaced proximal humerus fractures. Part I. Classification and evaluation. J Bone Joint Surg Am. 1970;52:1077–89.
2. Muller ME, Allgower M, Schneider R, Willeneger H. Manual of internal fixation: techniques recommended by the AO-Group. 2nd ed. Berlin/New York: Springer; 1979.
3. Hertel R, Hempfing A, Stiehler M, Leunig M. Predictors of humeral head ischemia after intracapsular fracture of the proximal humerus. J Shoulder Elb Surg. 2004;13:427–33.
4. Gaebler C, McQueen MM, Court-Brown CM. Minimally displaced proximal humeral fractures: epidemiology and outcome in 507 cases. Acta Orthop Scand. 2003;74:580–5.
5. Olerud P, Ahrengart L, Ponzer S, Saving J, Tidermark H. Internal fixation versus nonoperative treatment of displaced 3-part proximal humeral fractures in elderly patients: a randomised controlled trial. J Shoulder Elb Surg. 2011;20:747–55.
6. Zyto K. Non-operative treatment of comminuted fractures of the proximal humerus in elderly patients. Injury. 1998;29:349–52.
7. Resch H, Povacz P, Frohlich R, Wambacher M. Percutaneous fixation of three- and four-part fractures of the proximal humerus. J Bone Joint Surg (Br). 1997;79:295–300.
8. Magovern B, Ramsey ML. Percutaneous fixation of proximal humerus fractures. Orthop Clin North Am. 2008;39(4):405–16.

Uncorrected Proof

Author's Proof

9. Agudelo J, Schurmann M, Stahel P, et al. Analysis of efficacy and failure in proximal humerus fractures treated with locking plates. J Orthop Trauma. 2007;21:676–81.
10. Thanasas C, Kontakis G, Angoules A, Limb D, Giannoudis P. Treatment of proximal humerus fractures: a systematic review. J Shoulder Elb Surg. 2009;18:887–44.
11. Owsley K, Gorczyca JT. Fracture displacement and screw cutout after open reduction and locked plate fixation of proximal humeral fractures. J Bone Joint Surg Am. 2008;90:233–40.
12. Lanting B, MacDermid J, Drosdowech D, Faber KJ. Proximal humeral fractures: a systematic review of treatment modalities. J Shoulder Elb Surg. 2008;17:42–54.
13. Solberg BD, Moon CN, Franco DP, Paiement GD. Surgical treatment of three and four-part proximal humeral fractures. J Bone Joint Surg Am. 2009;91:1689–97.
14. Krishnan SH, Bennion PW, Reineck JR, Burkhead WZ. Hemiarthroplasty for proximal humeral fracture: restoration of the Gothic arch. Orthop Clin North Am. 2008;39:441–50.
15. Lin JS, Klepps S, Miller S, Cleeman E, Flatow EL. Effectiveness of replacement arthroplasty with calcar grafting and avoidance of greater tuberosity osteotomy for the treatment of humeral surgical neck non-unions. J Should Elbow Surg. 2006;15:12–8. https://doi.org/10.1016/j.jse.2005.04.010.
16. Besch L, Daniels-Wredenhagen M, Mueller M, Varoga D, Hilgert RE, Seekamp A. Hemiarthroplasty of the shoulder after four-part fracture of the humeral head: a long term analysis of 34 cases. J Trauma. 2009;66(1):211–4.
17. Mansat P, Guity MR, Bellumore Y, Mansat M. Shoulder arthroplasty for late sequelae of proximal humeral fractures. J Shoulder Elb Surg. 2004;13:305-12.22450·.
18. Boileau P, Trojani C, Walch G, Krishnan SG, Romeo A, Sinnerton R. Shoulder arthroplasty for the treatment of the sequelae of fractures of the proximal humerus. J Should Elbow Surg. 2001;10:299–308. https://doi.org/10.1067/mse.2001.115985.
19. Dines DM, Warren RF, Altchek DW, Moeckel B. Posttraumatic changes of the proximal humerus: malunion, nonunion and osteonecrosis. Treatment with modular hemiarthroplasty or total shoulder arthroplasty. J Should Elbow Surg. 1993;2:11–21.
20. Boileau P, Krishnan SG, Tinsi L, et al. Tuberosity malposition and migration: reasons for poor outcomes after hemiarthroplasty for displaced fractures of the proximal humerus. J Shoulder Elb Surg. 2002;2002(11):401–12.
21. Neer CS II, Watson KC, Stanton FJ. Recent experience in total shoulder replacement. J Bone Joint Surg Am. 1982;64:319–37.
22. Tanner MW, Cofield RH. Prosthetic arthroplasty for fractures and fracture-dislocations of the proximal humerus. Clin Orthop Relat Res. 1983;179:116–28.
23. Cazeneuve JF, Cristofari DL. The reverse shoulder prosthesis in the treatment of fractures of the proximal humerus in the elderly. Bone Jt J (Br). 2010;92-B(4) https://doi.org/10.1302/0301-620X.92B4.
24. Antuna S, Sperling JW, Sanchez-Sotelo J, Cofield RH. Shoulder arthroplasty for proximal humeral malunions: long- term results. J Should Elbow Surg. 2002;11:122–9. https://doi.org/10.1067/mse.2002.120913.
25. Duquin TR, Jacobson JA, Sanchez-Sotelo J, Sperling JW, Cofield RH. Unconstrained shoulder arthroplasty for treatment of proximal humeral nonunions. J Bone Joint Surg Am. 2012;94:1610–7. https://doi.org/10.2106/JBJS.J.01975.
26. Jacobson JA, Duquin TR, Sanchez-Sotelo J, Schleck CD, Sperling JW, Cofield RH. Anatomic shoulder arthroplasty for treatment of proximal humerus malunions. J Should Elbow Surg. 2014;23:1232–9. https://doi.org/10.1016/j.jse.2013.11.015.
27. Moineau G, McClelland WB, Trojano C, Rumian A, Walch G, Boileau P. Prognostic factors and limitations of anatomic shoulder arthroplasty for the treatment of posttraumatic cephalic collapse or necrosis (Type-1 proximal humeral fracture sequelae). J Bone Joint Surg Am. 2012;94:2186–94. https://doi.org/10.2106/JBJS.J.00412.
28. Mansat P, Bonnevialle N. Treatment of fracture sequelae of the proximal humerus: anatomical vs reverse shoulder prosthesis. Int Orthop (SICOT). 2015;2015(1):1–7. https://doi.org/10.1007/s00264-014-2651-0.

Uncorrected Proof

Author's Proof

29. Boileau P, Chuinard C, Le Huec J-C, Walch G, Trojani C. Proximal humeral fracture sequelae. Impact of a new radiographic classification on arthroplasty. Clin Orthop Relat Res. 2006;442: 121–30. https://doi.org/10.1097/01.blo.0000195679.87258.6e.
30. Boileau P, Neyton L. Reverse shoulder arthroplasty in proximal humerus fracture sequelae. Constrained or non-constrained prosthesis? In: Shoulder concepts 2008 – proximal humeral fractures and fracture sequelae. under the direction of P Boileau, G Walch, D Molé, L Favard, C Lévigne, F Sirveaux and JF Kempf. Sauramps Médical; 2008. p. 265–269.
31. Castagna A, Delcogliano M, de Caro F, Ziveri G, Borroni M, Gumina S, Postacchini F, De Biase CF. Conversion of shoulder arthroplasty to reverse implants: clinical and radiological results using a modular system. Int Orthop. 2013;37:1297–305. https://doi.org/10.1007/s00264-013-1907-4.
32. Ortmaier R, Resch H, Matis N, Blocher M, Auffarth A, Mayer M, Hitzl W, Tauber M. Reverse shoulder arthroplasty in revision of failed shoulder arthroplasty – outcome and follow-up. Int Orthop. 2013;37:67–75. https://doi.org/10.1007/s00264-012-1742-z.
33. Scarlat MM. Complications with reverse total shoulder arthroplasty and recent evolutions. Int Orthop. 2013;37:843–51. https://doi.org/10.1007/s00264-013-1832-6.
34. Kilic M, Berth A, Blatter G, Fuhrmann U, Gebhardt K, Rott O, Zenz P, Irlenbusch U. Anatomic and reverse shoulder prostheses in fracture sequelae of the humeral head. Acta Orthop Traumatol Turc. 2010;44:417–25. https://doi.org/10.3944/AOTT.2010.2272.
35. Alentorn-Geli E, Guirro P, Santana F, Torrens C. Treatment of fracture sequelae of the proximal humerus: comparison of hémiarthroplasty and reverse total shoulder arthroplasty. Arch Orthop Trauma Surg. 2014;134:1545–50. https://doi.org/10.1007/s00402-014-2074-9.
36. Wall B, Nové-Josserand L, O'Connor DP, Edwards TB, Walch G. Reverse total shoulder arthroplasty: a review of results according to etiology. J Bone Joint Surg Am. 2007;89:1476–85.
37. Wellmann M, Struck M, Pastor MF, Gettmann A, Windhagen H, Smith T. Short and mid-term results of reverse shoulder arthroplasty according to the preoperative etiology. Arch Orthop Trauma Surg. 2013;133:463–71. https://doi.org/10.1007/s00402-013-1688-7.
38. Fevang BT, Lygre SHL, Bertelsen G, Skredderstuen A, Havelin LI, Furnes O. Pain and function in eight hundred and fifty-nine patients comparing hemiprostheses, resurfacing prostheses, reversed total and conventional total prostheses. Int Orthop. 2013;37:59–66. https://doi.org/10.1007/s00264-012-1722-3.
39. Willis M, Min W, Brooks JP, Mulieri P, Walker M, Pupello D, Frankle M. Proximal humeral malunion treated with reverse shoulder arthroplasty. J Should Elbow Surg. 2012;21:507–13. https://doi.org/10.1016/j.jse.2011.01.042.
40. Martinez AA, Bejarano C, Carbonel I, Iglesias D, Gil-Albarova J, Herrera A. The treatment of proximal humerus nonunions in older patients with reverse shoulder arthroplasty. Injury. 2012;43:S3–6. https://doi.org/10.1016/j.injury.2011.12.015.
41. Martinez AA, Calvo A, Bejarano C, Carbonel I, Herrera A. The use of the Lima reverse shoulder arthroplasty for the treatment of fracture sequelae of the proximal humerus. J Orthop Sci. 2012;17:141–7. https://doi.org/10.1007/s00776-011-0185-5.
42. Zafra M, Uceda P, FloresM CP. Reverse total shoulder replacement for nonunion of a fracture of the proximal humerus. Bone Joint J. 2014;96:1239–43. https://doi.org/10.1302/0301-620X.96B9.
43. Guarrella V, Chelli M, Domos P, Ascione F, Boileau P, Walch G. Risk factors for instability after reverse shoulder arthroplasty. Should Elb. 2019;0(0):1–7. https://doi.org/10.1177/1758573219864266.
44. Ladermann A, Williams MD, Melis B, et al. Objective evaluation of lengthening in reverse shoulder arthroplasty. J Shoulder Elb Surg. 2009;18:588–95.
45. Boileau P, Melis B, Duperron D, et al. Revision surgery of reverse shoulder arthroplasty. J Shoulder Elb Surg. 2013;22:1359–70.

Uncorrected Proof

Author's Proof

Index Terms:

Arthroplasty 6–7
Avascular necrosis (AVN) 3–4, 6–9
Boileau's classification 12
Greater tuberosity 8
Hemiarthroplasty 4, 6, 8–11, 14
Internal fixation 4
Neer's classification 3
Non-constrained arthroplasty (NCA) 9
Open reduction and internal fixation 4–7
Osteoarthritis 10
Proximal humeral fractures
  arthroplasty 6–7
  Neer's classification 3
  open reduction and internal fixation 4–7
  sequelae classification 7–13
Reverse shoulder arthroplasty (RSA) 6–7, 9–14
Reverse total shoulder arthroplasty (R-TSA) 9
Total shoulder replacement 6, 14

Uncorrected Proof

Author's Proof

Author Queries

Chapter No.: 29-1 472307_0_En

Query Refs.	Details Required	Author's response
AU1	Please be aware that your name, affiliation and email address and if applicable those of your co-author (s) will be published as presented in this proof. If you want to make any changes, please correct the details now. Note that corrections after publication will no longer be possible. Please note that we standardly publish professional e-mail addresses, but not private ones even if it is provided in the manuscript. If you have a different preference regarding publication of your email address, please indicate this clearly on the proof. If no changes are required, please respond with "Ok".	
AU2	Figures have been renumbered in order to maintain sequential order. Please check if okay.	
AU3	Please check if edit to the figure caption 3 is okay.	
AU4	Please check if you have this image in your original file.	
AU5	"Acknowledgments" have been deleted as it is not a part of chapter structure.	
AU6	Please confirm, can we mask the patient eye in the figure 9 as per Springer Standard.	

Uncorrected Proof

Note:
If you are using material from other works please make sure that you have obtained the necessary permission from the copyright holders and that references to the original publications are included.