16 Humeral Head Nonunion

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16.1 Introduction

Proximal humerus fractures are common injuries, accounting for about 5% of all fractures of the appendicular skeleton. The majority of these fractures (approximately 85%) occur as the result of a low-energy injury and are non-displaced or minimally displaced fractures. Such fractures heal without surgical intervention, but those that progress to nonunion have a negative effect on overall glenohumeral function and the ability to perform activities of daily living [1–6].

The incidence of nonunion of the proximal humerus fracture is quite rare ranging from 1 to 10%.

A large single-center clinical study performed by Court-Brown and McQueen [7] reported a nonunion rate of 1.1% in their prospective study of patients treated nonsurgically for proximal humerus fractures.

Hanson et al. [8] prospectively followed 124 patients with proximal humerus fractures that were managed nonsurgically. At 1-year follow-up, only 3% required surgery for fracture nonunion.

Iyengar et al. [9] performed a meta-analysis of 12 studies with a total of 650 patients who underwent non-operative treatment of their proximal humerus fracture and found a 2% incidence of nonunion (range 0–7%).

The etiology of a proximal humerus nonunion is multifactorial. There is an interaction between fracture-related issues, the medical conditions, and habits of the patients.

Fracture characteristics including translation and metaphyseal comminution can increase the risk of nonunion.

Several studies have identified two-part surgical neck fracture as the most common fracture pattern associated with fracture nonunion [10–12] probably due to the disruption of the medial soft tissues and blood supply that are important for fracture healing.

Court-Brown and McQueen [7] found an 8% rate of nonunion in patients with metaphyseal comminution and a 10% rate in patients with surgical neck translation between 33 and 100%. It is unclear if greater amount of comminution and translation increase the risk of nonunion because of decreased bone contact area or disruption of blood supply.

The authors of the largest prospective review of proximal humerus nonunion were not able to define predictive criteria for the development of nonunion due to the very low incidence of this pathology that should require studies with unrealistically large number of patients.

Interposed soft tissues between fracture fragments may also represent a crucial factor in nonunion development. Nayak et al. [13] in their

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S. Gumina et al. (eds.), *Reverse Shoulder Arthroplasty*, https://doi.org/10.1007/978-3-319-97743-0_16

retrospective analysis found that interposed structures (especially the long head of biceps) blocked healing in 8 of 17 cases of nonunion (47%). Duralde et al. [14] reviewed 20 patients surgically treated for proximal humerus nonunion and found soft tissue interposition in 8 of 12 cases (67%) initially treated non-operatively.

Inadequate initial immobilization of humerus fracture after surgical operation or in patients treated conservatively may also compromise the bone healing process.

Nutritional deficiencies and metabolic bone disease (e.g., diabetes, osteopenia, obesity) are recognized as contributors to delayed unions or nonunions and should be identified with appropriate laboratory markers [10]. Persons who smoke are at 5.5 times higher risk than nonsmokers for developing nonunion [8].

16.2 Patient Evaluation

Patients with proximal humerus nonunion typically report pain, stiffness, and disability associated with shoulder dysfunction. The pain is usually absent or moderate at rest and increases during shoulder activities. Physical examination usually reveals diminished shoulder range of motion due to soft tissue contracture, with or without disuse atrophy of the deltoid and periscapular muscles. Axillary nerve function must be assessed, and electromyography is mandatory if neurologic injury is suspected. Integrity of rotator cuff should also be evaluated with a MRI scan.

Court-Brown and McQueen [7] measured the shoulder range of motion of patients following proximal humerus fractures that achieved union comparing to patients who developed nonunions at 6, 13, 26, and 52 weeks. They found that, instead of linear increasing of shoulder motion, patients with proximal humerus nonunion had less mobility with lost motion in all directions except external rotation after 26 weeks.

Radiographic evaluation of proximal humerus nonunion includes true AP view taken in the scapular plane with the shoulder in neutral, internal rotation, and external rotation. Outlet and axillary radiographs should also be made in the radiographic series.

The type of nonunion (e.g., hypertrophic versus atrophic) should be defined. Radiographically, hypertrophic nonunions are characterized by hypertrophic and sclerotic bone ends with fracture callus that failed to bridge the fracture site having the appearance of an "elephant's foot," whereas atrophic nonunions appear osteopenic with the absence of callus. In general, hypertrophic nonunions develop when insufficient mechanical stability and/or axial alignment exists and the vascularity and biologic environment for fracture healing are preserved. With atrophic nonunion, vascularity and the biologic environment are often compromised, which causes an inadequate fracture healing response. Lytic or mixed lytic and blastic lesions can be signs of underlying pathologic or metastatic processes. Signs of a sequestrum or involucrum are pathognomonic for infection.

Radiographs also should be evaluated for evidence of osteonecrosis of the humeral head and extent of bone loss. Comparison views of the contralateral shoulder may be helpful. In case of unclear diagnosis of nonunion, a CT scan should be performed with two- and three-dimensional reconstructions allowing better evaluation of tuberosity malunions, head cavitation, intra-articular extensions, and glenohumeral arthritic changes.

Nuclear imaging exams may offer additional information by evaluating callus vascularity and metabolic activity and presence of acute or chronic infection at nonunion sites.

Laboratory analysis in patients affected by proximal humerus nonunion can help to determine the cause of failure and the factors that should be corrected to allow bone healing. If infection is suspected, preoperative laboratory exams should include an erythrocyte sedimentation rate and C-reactive protein level, which are nonspecific markers of systemic inflammatory response. A white blood cell count may show leukocytosis with increased percentages of polymorphonuclear cells. However the gold standard for diagnosing infection is cultures taken from the nonunion fracture site.

Other endocrine markers should be assessed in patients affected by nonunion. Brinker et al. [15] founded that thyroid function, vitamin D, and calcium levels were altered in 37 patients with unexplained nonunion despite adequate reduction and stabilization or in case of history of multiple low-energy fractures with at least one progressing to nonunion or in non-displaced fracture of the pubic rami or sacral ala not healed, demonstrating that metabolic and endocrine abnormalities may be associated with nonunion.

When proximal humerus fracture nonunion is established, a descriptive classification should be used in order to compare the results from different studies and try to underline prognostic elements.

Checchia et al. [16] proposed a descriptive classification system based on their retrospective review of 21 cases.

They divided nonunions in four groups. High two-part nonunions include nonunions secondary to two-part fractures of the surgical neck of the humerus with very small proximal fragment and three-part fractures where the greater and lesser tuberosity is consolidated. Low two-part nonunions are also related to two-part fractures of the surgical neck, but nonunion occurs between the lesser tuberosity and the insertion of the pectoralis major tendon, and the proximal fragment is larger than in the previous group. Complex nonunions describe three-part, four-part, or head-splitting fractures where the surgical neck nonunion is associated with tuberosity nonunion that is displaced more than 5 mm. Finally lost fragment nonunion includes a scenario with a large degree of bone loss after open fractures and/or post-traumatic osteomyelitis.

Checchia classification has not widely been utilized in other studies, and therefore no treatment algorithms were performed basing on this system.

16.3 Timing of Surgery

Nonunion is typically diagnosed 6–9 months following injury [10]. The median time to union or bridging callus of nonsurgically managed proximal humerus fractures is 13–14 weeks, and an appropriate workup should be performed at that time in the absence of healing [7, 8]. The diagnosis of nonunion in the proximal humerus can be made when there is lack of callus formation on two consecutive radiographs taken 6 to 8–10 weeks after injury. Moreover, poor shoulder function and increasing pain should alert the physician about a nonunion risk.

Surgical management is recommended at approximately 3–6 months following injury if an impending nonunion is suspected, because wasting time increases soft tissue contractures at glenohumeral joint with predictable poor results after revision surgery.

Beredjiklian et al. [17] reviewed the results of 39 patients and noted significant difference in outcomes among patients who underwent late surgical management (after 1 year) of proximal humerus malunion. This was ascribed to more capsular contractures, muscle atrophy, and irreparable rotator cuff tear.

Intervening at this time (within 6 months) may help to prevent disabling glenohumeral dysfunction that is always associated with chronic proximal humerus nonunions in order to optimize the outcome.

16.4 Nonsurgical Management

Patients affected by symptomatic proximal humerus nonunion are commonly elderly with medical comorbidities. Moreover, surgical management of this pathology is technically challenging, and the postoperative course requires compliance and family assistance networks. Therefore surgical option is reserved for highly motivated patients with low medical comorbidities that place them at an acceptable risk for surgical management. Patients with minimal pain and mild shoulder function disability may be appropriate candidates for nonsurgical management [18]. Some authors consider a nonfunctional deltoid muscle a contraindication for operative treatment [16].

A few studies [13, 19] reported that up to 50% of patients affected by proximal humerus nonunion are minimally symptomatic with acceptable shoulder function.

A comprehensive conversation should be undertaken with patients in order to assess their pain and shoulder impairment and to elucidate them about the risks of surgical treatment and the duration of post-op rehabilitation program.

16.5 Surgical Management

16.5.1 ORIF

Many techniques have been described for surgical management of proximal humerus nonunion. Regardless of the implant used, the critical step is the preparation of the nonunion site with meticulously resection of scar, fibrous tissue, and avascular bone.

The aim of the therapy consists of an optimized combination of biological and biomechanical factors [10, 20–22].

Osteosynthesis using locking plate fixation techniques is preferred in the presence of good bone quality without significant medial calcar comminution or osteopenia that may compromise adequate fixation [23–28]. Clinical and radiographic assessment of function and integrity of tuberosity is mandatory in deciding whether or not osteosynthesis is the appropriate treatment. In case of surgical neck nonunion, rigid fixation can be achieved with a variety of plates, including 3.5- and 4.5-mm plates made for the proximal humerus, blade plates, and 4.5-mm T-plates. Fixed-angle locking or blade plates provide a biomechanically stable construct in the setting of osteoporotic bone [29, 30].

Isolated greater and lesser tuberosity nonunions are less common than surgical neck nonunions. The bone quality of the tuberosity fragment and rotator cuff function are critical components in determining the most appropriate surgical option. In patients with large tuberosity fragments and a viable and functional rotator cuff, osteosynthesis may be achieved with buttress plating with autogenous bone graft. Tension band techniques, transosseous suture fixation, or current suture anchor configurations used in modern rotator cuff repair techniques that provide compression across the fracture site with autogenous bone grafting augmentation can be used for comminuted tuberosity fragments, only if rotator cuff is intact without fatty degeneration. A deltoid-splitting or deltopectoral approach can be used for greater tuberosity osteosynthesis. A deltopectoral approach is suggested for lesser tuberosity nonunions. Arthroscopic techniques have also been described for managing greater tuberosity nonunions [31].

Autogenous or allograft bone augmentation is recommended to facilitate osteosynthesis. Large amounts of cancellous bone allograft can be obtained from the iliac crest, but the patient must be advised of the possibility of donor site pain. The alternative choice is using allograft if donor site morbidity is unacceptable [10].

Free vascularized fibular allograft may be considered for patients who need significant biologic augmentation along with mechanical support.

Healy et al. [32] retrospectively reviewed their experience and reported union in 12 of 13 patients following ORIF with bone graft in patients affected by proximal humerus nonunions. Ring et al. [33] reviewed 25 patients with proximal humerus fracture nonunion treated with blade plate and autogenous iliac crest cancellous bone graft. Fracture union was achieved in 23 patients (92%), and functional results were classified as good to excellent in 20 (80%). Two patients had complications due to iliac crest harvest. Allende and Allende [30] reported union in all seven patients treated with a locking 90° blade plate (average follow-up, 22 months). The average time to union was 5.9 months. At latest follow-up average DASH score was 25 points, and Constant score was 72.7 points.

The use of intramedullary peg graft with fixed-angle locked plating was first described by Walch et al. [34] that treated 20 patients with pseudarthrosis of the proximal humerus with 6–10 cm corticocancellous autogenous bone graft (11 iliac crest, 6 anterior tibial crest, and 3 middle-third of the fibula). The stability of the fracture site was obtained by T-plate osteosynthesis. Although a 96% union rate was achieved, donor site morbidity was high with 50% of patients developing a pathological fracture after harvesting from the anterior tibial crest. Other authors have strictly used iliac crest bone graft; however incidence of persistent pain postoperatively remains substantial.

Badman et al. [18] described the technique of using fibular strut allograft as an intramedullary implant that allows to maintain the humeral head in the correct position and to improve the stability of the implant (fixed-angle plate), without the morbidity of graft donor site. Badman and Mighell [35] reported 94% rate of union at an average of 5.4 months. Complications involved two posterior cord brachial plexus palsies that improved within 3 months and two cases of adhesive capsulitis treated with arthroscopic capsular release.

Fibular strut allograft has several advantages. It provides additional biologic and structural support to the poor-quality bone found at the proximal humerus, it is mechanically stronger than cancellous bone allograft or allograft, and it avoids the donor site morbidity. This technique is useful in both the acute proximal humerus fracture scenario and chronic nonunion scenario when medial calcar support is compromised secondary to significant medial calcar comminution or osteopenia (Figs. 16.1, 16.2a, b, and 16.3a, b).

Fig. 16.1 Proximal humerus nonunion of surgical neck in 54-year-old patient (With permission of M. Fontana)

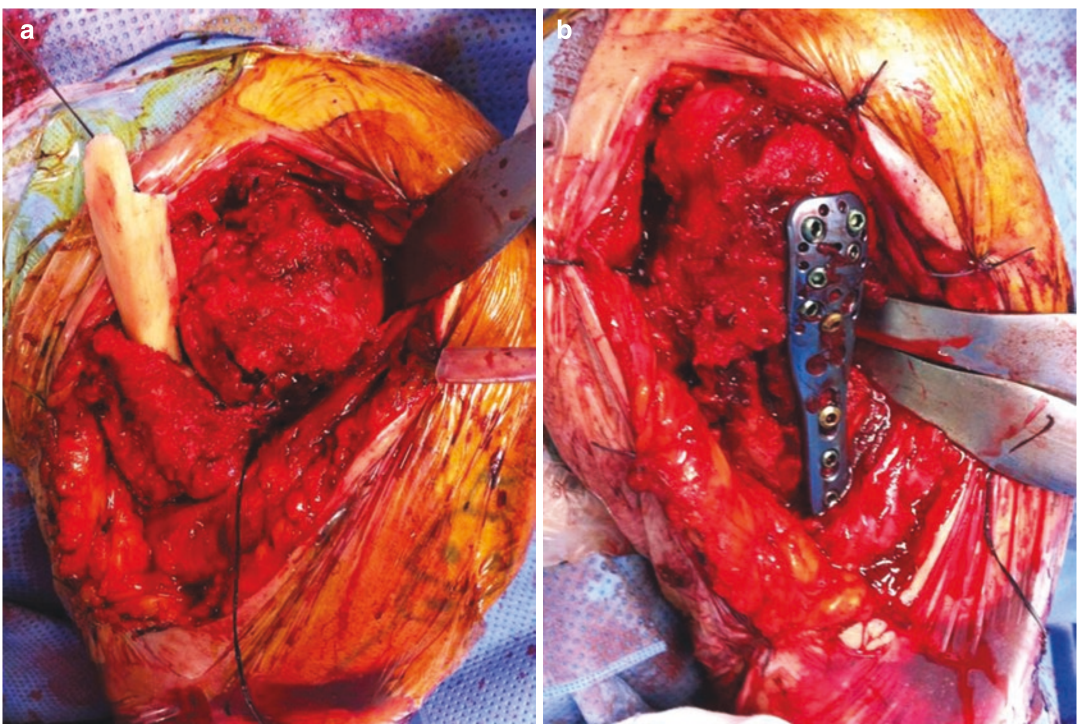

Fig. 16.2 (**a**) Intraoperative view of fibular allograft locked into humerus diaphysis with humeral head translated (With permission of M. Fontana). (**b**) Intraoperative view of reduced fracture with fixed-angled locked plate in place (With permission of M. Fontana)

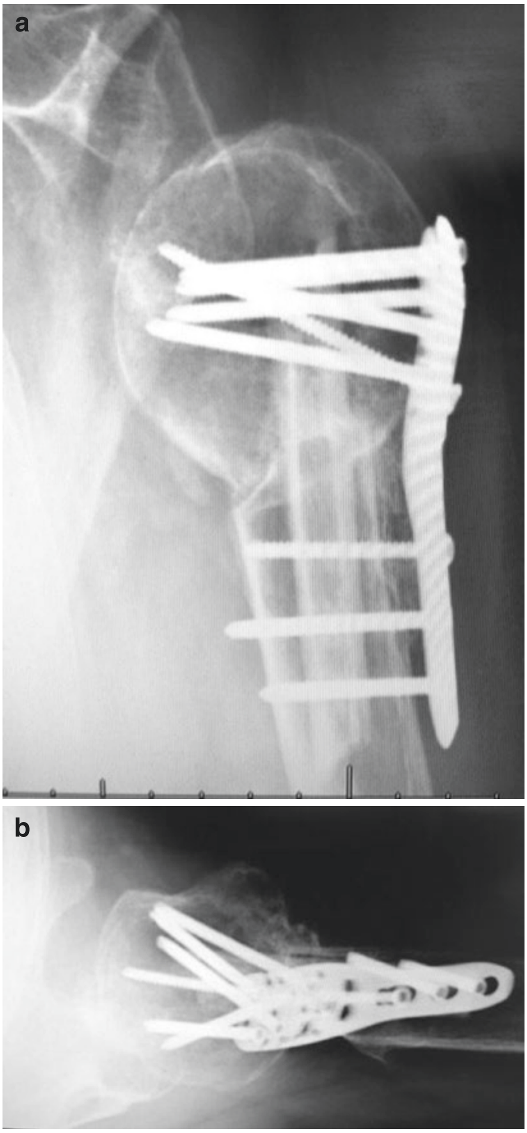

Fig. 16.3 (**a**, **b**) AP and axial view of healed proximal humerus nonunion treated with fibular allograft and fixed-angled locked plate (With permission of M. Fontana)

Another option of treatment is represented by the third generation of interlocked intramedullary nails. Historically, results were disappointing following intramedullary nailing to manage proximal humerus nonunion. Early mobilization of intramedullary devices with subsequent subacromial impingement necessitated a second surgery following union for nail removal. Most patients, however, progressed to union and regained good shoulder function [10].

Recently, Yamane et al. [11] published encouraging results with the use of interlocking intramedullary nails to manage proximal humerus fracture nonunion in 13 patients. The average follow-up was 37.8 months. All patients achieved union. All patients were satisfied with the results and had improved shoulder range of motion postoperatively. It is important to know that 11 of 13 patients treated in this study had no previous surgical operation and the other two were treated with percutaneous pinning or intramedullary nailing.

In addition to bone graft and hardware fixation, in case of proximal humerus nonunion, the human bone morphogenetic proteins (i.e., rhBMP-2) could be used combined with bone graft due to their important role in physiological fracture healing and bone regeneration [36].

The current literature supports the use of BMP only for tibial nonunion [37] and in general for long bone nonunion, but no studies were performed on its use in proximal humerus nonunion. A Cochrane review of BMP use for fracture nonunion in adults concluded that there is a paucity of data available and its role remains unclear. Therefore, the use of biologic augments such as rhBMP-2 has to be considered "off label" for the treatment of proximal humerus nonunion and is not approved by FDA.

16.6 Surgical Management

16.6.1 Shoulder Replacement

Proximal humerus nonunion with severe head cavitation, poor bone stock inadequate to achieve solid internal fixation, and glenohumeral osteoarthritis should be treated with an arthroplasty.

The decision to perform unconstrained arthroplasty (i.e., hemiarthroplasty, total shoulder arthroplasty) to manage proximal humerus nonunion depends in part on the quality of bone stock, the viability of the humeral head, and, most important, tuberosity integrity and position as well as rotator cuff functional status. Total shoulder replacement is considered in the setting of concomitant glenohumeral osteoarthritis with a functional and intact rotator cuff.

In case of tuberosity diaphysis discontinuity and/or severe distortion of the anatomy, a greater tuberosity osteotomy is needed, with predictable poor functional results of an unconstrained shoulder replacement.

When rotator cuff has been involved with muscle atrophy and/or tuberosity is absent, a reverse shoulder arthroplasty can be considered in older patients.

Boileau et al. [38] investigated factors important to successful patient selection for unconstrained arthroplasty (i.e., hemiarthroplasty, total shoulder arthroplasty) in the setting of proximal humerus malunion or nonunion. They retrospectively reviewed 203 consecutive patients with sequelae of proximal humerus fractures that had been managed with unconstrained glenohumeral arthroplasty. Of the unconstrained arthroplasties performed, 59% were hemiarthroplasty. Total shoulder arthroplasty was indicated for patients with preexisting pain secondary to glenohumeral osteoarthrosis or glenoid erosions noted at the time of surgery. The authors suggested that tuberosity integrity and anatomic position are critical for a good functional outcome following unconstrained arthroplasty. Furthermore, they recommended reverse total shoulder arthroplasty in cases of tuberosity osteotomy. Although arthroplasty has been shown to reliably relieve pain in patients with proximal humerus nonunion, return to preinjury function is less predictable [11, 14]. Nayak et al. [13] retrospectively reviewed seven patients who underwent hemiarthroplasty for proximal humerus nonunion. All patients were able to perform activities of daily living and had less pain as well as increased function and range of motion. However, no patients returned to their preinjury level of activity. Antuña et al. [12] published the results of 25 shoulders managed with unconstrained arthroplasty (mean follow-up, 6 years). Twenty-one patients underwent hemiarthroplasty and four total shoulder replacement. Twenty of 25 patients considered themselves better than preoperatively with variable Neer functional score (13 unsatisfactory results). Anatomic or near anatomic union of the tuberosity was a significant factor in achieving greater active forward elevation ($P = 0.02$). The authors pointed out the importance of using heavy no absorbable sutures, bone graft to fill gaps between the tuberosities and the diaphysis, and restricting post-op rehabilitation program to minimize the risk of complications.

Dunquin and all [39] reviewed the Mayo Clinic experience treating 67 proximal humerus nonunion with unconstrained shoulder replacement. Their results were similar to those published by Antuna: patient satisfaction in terms of pain was high, but motion was less predictable, with average elevation of 104° and external rotation of 50°. Active elevation was significantly decreased in patients with tuberosity nonunions, but this did not influence the pain level. Bone grafting did not prevent tuberosity nonunions. Other complications included 11 severe subluxations or dislocations, 2 deep infections, and 1 late periprosthetic fracture.

The strong relationship between postoperative range of motion and tuberosity healing has led some authors to suggest reverse total shoulder replacement as a viable alternative to unconstrained arthroplasty.

Reverse total shoulder arthroplasty is a viable option in the setting of proximal humerus nonunion with humeral head collapse, nonfunctional rotator cuff, and muscle atrophy and/or radiographic evidence of severe tuberosity malunion or resorption (Fig. 16.4a, b). Reverse implant relies on the deltoid muscle to achieve elevation and abduction, so it is crucial to perform electromyography in case of concerns about deltoid function. Otherwise reverse shoulder replacement requires tuberosity healing for optimum function especially to regain rotational movement and decrease post-op complications.

In a study of 18 patients treated with reverse total shoulder arthroplasty for proximal humerus nonunion, Martinez et al. [27] reported significant improvements in average active forward elevation (35–90°; $P < 0.0001$), external rotation (15–30°; $P < 0.0001$), and internal rotation (25–55°;

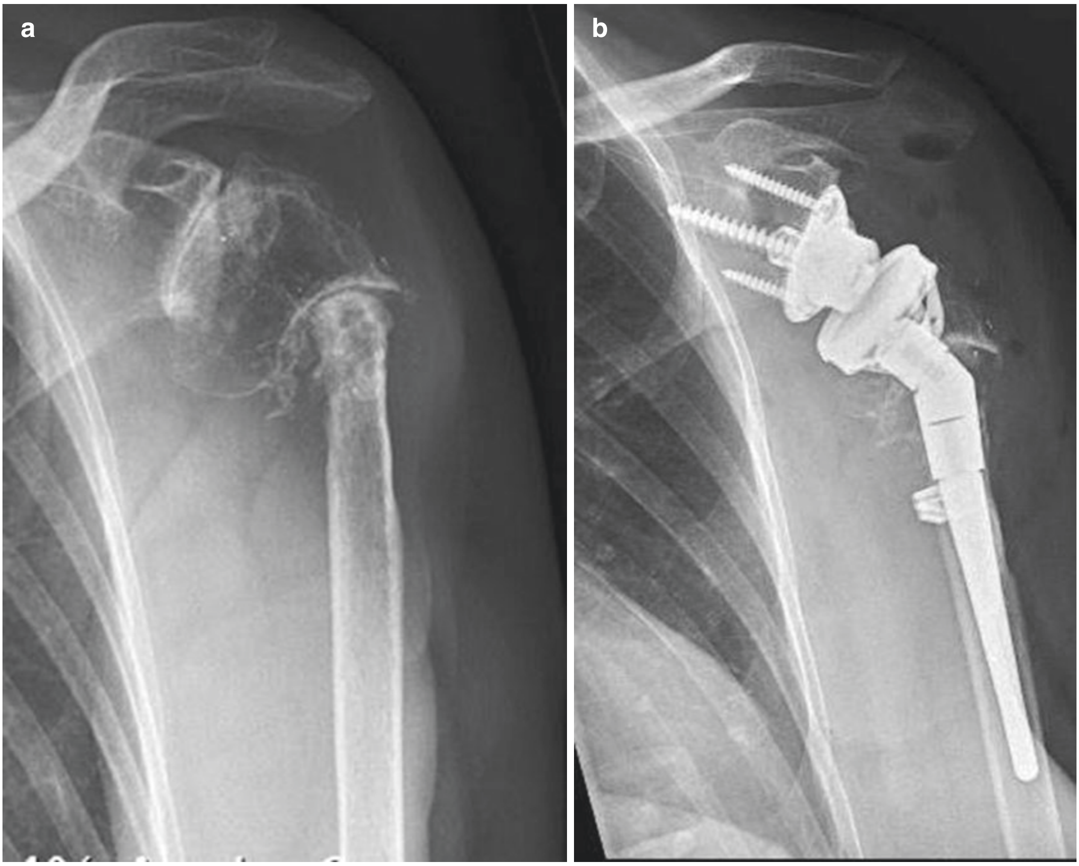

Fig. 16.4 (**a**) Long-lasting proximal humerus nonunion of surgical neck with resorption of tuberosity, relevant osteopenia, and glenohumeral osteoarthritis in 79-year-old patient (**b**) treated with reverse shoulder arthroplasty (With permission of H.R. Block)

$P < 0.0001$) at an average follow-up of 28 months. Fourteen patients were either satisfied or very satisfied with the result of the operation. Complications included one transient axillary nerve palsy, two deep infections, and two dislocations. Zafra et al. [40] published a prospective, multicentre study of 35 patients (mean follow-up of 51 months) who underwent a reverse total shoulder replacement for the treatment of proximal humerus nonunion. They reported a significant decrease of pain and significant improvement of range of motion and Costant score but a total of nine complications in seven patients: six dislocations, one glenoid loosening in a patient who had previously suffered dislocation, one transitory paresis of the axillary nerve and one infection.

16.7 Conclusions

Proximal humerus fractures are common, and the majority of them healed without any surgical procedure. A small percentage develop into nonunion, but the small study size available in the literature causes difficulty in determining the true rate. Nonunion of proximal humerus represents a big challenge due to biological problems from the initial injury and previous surgeries, poor bone stock, humeral head cavitation, soft tissue contracture, and infection.

Patients developing nonunions present restricted range of motion, pain, and greater problems to perform activities of daily living. Once nonunion has been identified, every effort should be made to treat the problem before 6 months after the initial injury in order to prevent the formation of soft tissue contractures.

Treatment options include nonsurgical management for minimally symptomatic patients with medical comorbidities. Surgical options range from osteosynthesis with standard, fixed-angle, or locked plate and interlocked intramedullary implants to arthroplasty using hemi-, total, or reverse shoulder replacement.

Surgery may provide for the use of augments such as cancellous allograft and allograft or structural grafts to increase rate of bone healing. When union is achieved with internal fixation, the results in terms of range of motion and Constant scores are significantly higher compared to arthroplasty options. Positive prognostic factors include simpler fracture patterns, better bone stock, and intact vascularity. Younger age and less medical comorbidity may also play a role in improving functional outcome. Moreover technological advances in locking plate and interlocking design had enlarged the indication for osteosynthesis in proximal humerus nonunion.

In case of head cavitation, poor bone quality, and glenohumeral osteoarthritis, shoulder arthroplasty offers favorable results in terms of pain control but less predictable functional outcome, which seems to be correlated with tuberosity healing.

Reverse shoulder replacement offers the theoretical advantage of decreased dependence on tuberosity union, but only one small study reviewed the results of this implant in treating proximal humerus nonunion. Therefore more studies are needed to better understand the role of inverse implant in treating this challenging pathology.

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