Review Article

Approach to Humeral Shaft Nonunion: Evaluation and Surgical Techniques

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ABSTRACT

Humeral shaft fractures account for 1% to 3% of all fractures. Traditional nonsurgical treatment with a functional brace is still the standard treatment of these fractures; however, modern studies have reported that nonunion rates may be as high as 33%. Recent information suggests that the development of nonunion after nonsurgical treatment may be identified as early as 6 to 8 weeks postinjury. Even with surgical treatment, nonunion rates as high as 10% have been reported. Regardless of the original treatment method, nonunion results in poor quality of life for the patient and therefore should be addressed. A thorough preoperative evaluation is important to identify any metabolic or infectious factors that may contribute to the nonunion. In most cases, surgical intervention should consist of compression plating with or without bone graft. Although most patients will achieve union with standard surgical intervention, some patients may require specialized techniques such as cortical struts or vascularized fibular grafts. Successful treatment of humeral shaft nonunion improves function, reduces disability, and improves the quality of life for patients. In this article, we outline our approach to the treatment of humeral shaft nonunion in a variety of clinical settings.

umeral shaft fractures are estimated to account for 1% to 3% of all fractures and lead to approximately 60,000 emergency visits in the United States annually.^{1,2} Historically, most humeral shaft fractures were managed nonsurgically. Functional bracing treatment was originally described by Sarmiento et al³ who asserted that this method of treatment offered high union rates with low complication rates. However, many modern studies have found that nonunion rates with nonsurgical treatment are as high as 20% to 33%.⁴⁻⁷ When functional bracing treatment is pursued, studies have found a 30% crossover to surgical treatment because of nonunion, delayed union, or inability to tolerate or accept the brace.^{8,9}

Nonunion is not exclusive to nonsurgical treatment because studies have shown that even with surgical intervention, nonunion rates range from 4% to 10%.⁵⁻⁷ Regardless of the original treatment method, nonunion is associated with pain, delayed return to function, and poor patient quality of life;

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therefore, appropriate identification of delayed or nonunion of the humeral shaft and prompt intervention is an important skill for orthopaedic surgeons.

Different surgical techniques to address humeral nonunion have been described including open reduction and plate fixation with or without bone graft, intramedullary fixation, cortical strut augmentation, and external fixator application. Although no universally agreed upon method to address humeral nonunion exists, open reduction and plate fixation with cancellous autograft is generally recognized as the benchmark.¹⁰ Regarding graft material, others have advocated for the use of alternative bone substitutes such as demineralized bone matrix (DBM), which has been shown to result in high union rates while avoiding donor site morbidity.¹¹ The purpose of this article was to perform a comprehensive review of the relevant literature in the past 10 years, in addition to definitive reference studies, and describe our approach to the evaluation and treatment of humeral shaft nonunion.

Indications/Contraindications

Primary Surgical Intervention

Although most humeral shaft fractures can be managed nonsurgically, clear and established surgical indications for humeral shaft fractures including concomitant forearm or upper extremity fractures, polytrauma, open fractures, and bilateral fractures exist. There is increasing evidence that primary surgical fixation for humeral shaft fracture may be indicated in additional settings as well. A study by Ring et al¹¹ found that proximal third humeral shaft fractures with oblique or spiral patterns have a higher rate of nonunion. In addition, Ali et al¹² found an overall union rate of 88% and 85% for conservatively managed fractures of the middle and distal third, respectively; however, the proximal third union rate was only 76%. Transverse or short oblique fractures with minimal fracture surface area for healing have been shown to have a much longer time to union, especially if there is distraction at the fracture site.¹³ Humeral fractures in the setting of an arthritic or stiff shoulder or elbow joint have higher rates of delayed and nonunion. Finally, prospective studies have revealed a notable rate of patient dissatisfaction with bracing treatment and have supported primary fixation for active individuals who desire a rapid return to function.⁹ Although most fractures can and should be initially managed nonsurgically, these findings suggest that proximal third humeral shaft fractures, transverse or short oblique fractures, humeral shaft fractures in the setting of adjacent joint arthritis/stiffness, and patient goals may all

represent scenarios that may meet relative indications for primary surgical intervention because of the higher rate of delayed or nonunion and eventual crossover to surgical treatment.

Predicting Nonunion in Fractures Initially Managed Nonsurgically

Nonunion is traditionally defined as absent clinical or radiographic healing nine months postinjury, with a lack of evidence of progressive healing on radiographs three month apart. In the case of humeral shaft nonunion, clinical and radiographic criteria have been developed to predict those fractures that are likely to go onto nonunion, thereby allowing earlier intervention and minimizing patient morbidity.

Fracture site mobility with pain at six weeks postinjury was described by Driesman et al¹⁰ as predicting future fracture nonunion with 82% sensitivity and 99% specificity. A radiographic scoring method called the Radiographic Union Score for HUmeral Fractures assigns a score between 1 and 3 to assess the quality of callus formation on each of the four cortices for a total score of 4 to 12. Oliver et al^{14} originally proposed the score and reported that a score < 8 was associated with future fracture nonunion with 75% sensitivity and 80% specificity. Although both clinical examination and radiographs are useful as individual metrics, Dekker et al¹⁵ advocated for the use of both simultaneously and found 15 times greater likelihood of nonunion in those who had gross mobility on examination and a Radiographic Union Score for HUmeral Fractures of seven or less at 6 weeks postinjury.

Based on this evidence, we evaluate patients at 6 weeks postinjury and use both clinical and radiographic data to identify delayed or impending nonunion. If concerning clinical and/or radiographic signs exist, we will offer surgery after a thorough discussion with the patient regarding the prognosis, risks, and benefits.

Investigation of Established Nonunion

Causes of nonunion fall into several categories including patient factors, infection, mechanical factors, and biologic/metabolic factors. Many patient and metabolic factors such as smoking, diabetes, and nutrition cannot be addressed preoperatively when treating an acute humeral shaft fracture surgically. However, these factors should be identified and optimized before surgical intervention for nonunion or delayed union.

Before surgery, a thorough workup for potential etiologies of the nonunion is recommended. In a landmark 2007 study, Brinker et al¹⁶ demonstrated correctable metabolic

Figure 1



Nonunion after nonsurgical treatment. A 52-year-old female sustained a ground level fall and was diagnosed with a humeral shaft fracture at an outside hospital. She was managed nonoperatively in a Sarmiento brace. She presented to our clinic 6 years after her injury complaining of pain and deformity in her left upper extremity. At the time of presentation, her examination was notable for a 30° rotational deformity. Radiographs demonstrated a hypertrophic nonunion of the humeral shaft fracture site with significant angulation (**A**). The patient had a past medical history notable for obesity with a BMI of 38 and type 2 diabetes mellitus that was well-controlled. She was a non-smoker. Given the hypertrophic nature of the nonunion and lack of any prior surgical intervention, we did not feel that an infection workup was necessary before surgery. The patient elected to proceed with surgical intervention for her nonunion (**B**). We used an anterolateral approach due to the midshaft location of the nonunion. We used a single compression plate for fixation due to the fracture location and good bone quality. Given that this was a hypertrophic nonunion, we elected to use morcellized bone graft from the nonunion site as our bone graft. At the 8-week follow-up visit, the patient reported no pain and good function of her arm. Radiographs demonstrated healing of her nonunion site (**C**). BMI =body mass index

or endocrine abnormalities in 84% of patients who failed to heal simple fractures.

In patients whose fractures were initially managed nonsurgically, a thorough metabolic workup should be completed to identify any reversible causes that may have contributed to the nonunion. Typical investigation would include serum levels of vitamin D, calcium, phosphorus, and parathyroid hormone, as well as a thyroid panel, blood urea nitrogen (BUN), and creatinine. Studies have shown that intervention for remediable factors (such as smoking cessation, improving nutrition, and correcting vitamin deficiency) can optimize the potential for success with surgical intervention for nonunion.^{16,17}

In patients whose fractures were initially managed surgically, the underlying infection is a major concern, and additional investigations should include a complete blood count with differential, ESR, and C-reative protein (CRP). If there is concern for infection based on these laboratory test results, this information should be considered during surgery and should influence the surgical technique (discussed later). Maresca et al reviewed 19 humeral shaft nonunions that were originally treated with open reduction and internal fixation (ORIF). The authors identified three common features among those that failed to achieve union: fracture comminution, open fracture, and inadequate fixation (ie, fracture not fixed using standard 4.5 mm dynamic compression plate).¹⁸ Based on their findings, surgeons should have a higher suspicion of impending

nonunion in patients with these fracture/fixation characteristics and should carefully evaluate these patients both clinically and radiographically.

Surgical Technique

Setup

We generally approach the humeral shaft using either the anterolateral approach or the posterior approach. We prefer the anterolateral approach for proximal third and midshaft humerus fractures. For this approach, we prefer to have the patient be in a semiseated position with the arm freely draped. The radial nerve is identified distally between the brachialis and brachioradialis and protected throughout the case. For distal third humeral shaft fractures, it may not be possible to place three bicortical screws distal to the fracture site using a standard 4.5 plate. In this case, we will instead use dual-column plating and will therefore use a paratricipital posterior approach. For this approach, the patient will be placed in the lateral decubitus position and their arm will be placed over an arm bolster. If the dissection needs to be carried proximally, we carefully identify and protect the radial nerve. This can be achieved by tracing the posterior brachial cutaneous nerve to the radial nerve or by developing the interval between the long head and lateral head of the triceps and locating the radial nerve in the





Nonunion after operative treatment. A 30-year-old male initially presented following an motor vehicle collision in which he sustained a left humeral shaft fracture (**A**). The patient had a BMI of 48 however he had no other medical comorbidities. He was initially treated at another institution who elected for nonsurgical management in a coaptation splint followed by a Sarmiento brace. About four months after his injury, he had pain and gross motion at the fracture site so he underwent ORIF with dynamic compression plating (**B**). Distal fixation of only three screws would typically be acceptable in most patients however is sub-optimal in a patient of this size. The patient presented to us 3 years later complaining of acute onset of pain after lifting a glass of water with his left arm. His radiographs showed hardware failure and evidence of an atrophic nonunion (**C**). At this time, a laboratory workup was performed to evaluate for contributing factors to his nonunion. He was noted to have vitamin D deficiency and he began vitamin D supplementation before revision surgery. The patient underwent revision ORIF of his nonunion. For this surgery, we elected to proceed with dual plate fixation due to the more distal location of the fracture. We selected plates with locking capability due to the atrophic nature of the nonunion and to allow for stability of the construct even in areas with poorer bone quality. For graft selection, we chose iliac crest autograft. At follow-up visits, the patient reported no pain and good range of motion in both his shoulder and elbow. Radiographs demonstrated healing of his nonunion site (**D**). BMI = body mass index, ORIF = open reduction and internal fixation

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spiral groove. Of note, radial nerve palsy can occur after nonunion surgery in 6.9% to 18.5% of patients.^{19,20} Multiple studies have found that no association exists between surgical approach and incidence of radial nerve palsy.^{19,20} Therefore, we advocate for the use of the surgical approach that is most familiar for the treating surgeon and the approach that will allow for adequate exposure and fixation of the nonunion site.

In general, we will use 4.5 compression plates when treating a standard humeral shaft nonunion. It is important to place at least three bicortical screws through the plate, both proximal and distal to the nonunion site.

Figure 3



Cortical strut allograft. A 70-year-old male presented following an assault in which he sustained a right proximal third humeral shaft fracture. He underwent ORIF due to persistent angulation in a splint. He subsequently had a fall from height about 2 months postoperatively, and radiographs demonstrated hardware failure with varus angulation (**A**). A metabolic work-up for any correctable deficiencies was negative. He underwent revision ORIF and the decision was made to use a cortical strut allograft along the medial side of the humerus to enhance screw purchase (**B**). ORIF = open reduction and internal fixation

In more distal fractures of the humeral shaft, the length may be insufficient for appropriate fixation in the distal fragment. In this scenario, dual column plating with 3.5 anatomic plates is recommended.

Nonunion After Nonsurgical Care

We classify nonunion that develops after nonsurgical care into one of two categories: atrophic nonunion or hypertrophic nonunion. Atrophic nonunions lack the biologic capacity for healing; therefore, preoperative workup to identify any metabolic or endocrine factors that may contribute to nonunion should be addressed. At the time of surgery, the sclerotic bone ends are débrided back to healthy bleeding bone and the intramedullary canals are re-established with a drill. A compression plate is then applied. Atrophic nonunions will benefit from biologic enhancement at the nonunion site, including autologous bone graft, bone morphogenetic protein (basic metabolic panel), or DBM.

Hypertrophic nonunions differ in that they possess the biologic capacity for healing but lack the necessary sta-

bility to achieve union (Figure 1, A). In these cases, we débride the hypertrophic bone, mobilize and align the bone fragments, and apply a compression plate (Figure 1, B and C). The hypertrophic bone can morcellized and used as autograft. We typically do not use iliac crest autograft, BMP, or DBM in these cases because bony union can generally be achieved without these adjuvants; therefore, the added cost and morbidity cannot be justified.

Nonunion After Previous Surgical Intervention

Nonunion after previous surgery can be categorized as either aseptic or septic/possibly septic. If based on laboratory test results and/or previous cultures, we are confident that the patient does not have an active infection contributing to the nonunion, and we will proceed with hardware removal, débridement of the nonunion site, and revision ORIF (Figure 2, A and D). Because cultures may often be positive even if no readily apparent infection exists, it is typically prudent to perform a thorough débridement in this setting. In the case of an



Figure 4



Vascularized fibula graft. A 58-year-old female sustained a gunshot wound to the right upper extremity resulting in a midshaft humerus fracture. She had undergone ORIF acutely following that injury. She presented to our clinic 30 years following her injury with persistent arm pain and swelling after multiple failed revisions. Radiographs demonstrated a humeral shaft nonunion with a large bone defect (**A**). She underwent revision ORIF, with a vascularized fibula graft due to the size of the bone defect (**B**). ORIF = open reduction and internal fixation

aseptic nonunion, we will often use iliac crest autograft, BMP, or DBM to enhance the biological healing factors at the nonunion site.

In the case of septic or possibly septic nonunion, all hardware is removed and at least three tissue samples are obtained for culture. The nonunion site and entire surgical field are thoroughly débrided and copiously irrigated. In cases with gross purulence and contamination of the hardware and nonunion site, staged reconstruction may be necessary. We advocate for the placement of an antibiotic cement spacer to confer stability at the nonunion site, admission to the hospital for IV antibiotics, and return to OR for repeat débridement, antibiotic spacer exchange, and cultures. Once negative cultures are obtained, the spacer can be removed and definitive fixation can be placed. Definitive fixation can be placed at the time of initial irrigation and débridement if the surgeon is comfortable with the quality of the débridement, the patient has few comorbidities, a susceptible organism is known, and good soft-tissue coverage can be obtained. Our preference is to avoid autograft and allograft in the setting of infection because we feel it may act as a nidus for infection. If bone graft is necessary, we prefer to use antibiotic-impregnated bone substitutes in the place of traditional bone grafts. Calcium sulfate beads are useful in this scenario because they are osteoconductive and can be mixed with vancomycin, gentamicin, or tobramycin for elution of a high local concentration of antibiotics. When closing, vancomycin powder is typically placed in the surgical site. The patient should be promptly placed on broadspectrum antibiotics postoperatively. Culture results are used to guide antibiotic selection, and the patient is placed on a 6-week course of antibiotics. We will use oral antibiotics if the culture sensitivities identify a suitable oral antibiotic option, otherwise we will use intravenous antibiotics.

Special Considerations

Poor Bone Quality

In the case of severe osteopenia or osteoporosis, surgical fixation for humerus nonunion can be technically challenging. The osteopenic bone may not provide adequate screw purchase, leading to continued instability at the fracture/nonunion site, mechanical failure, and persistent nonunion.²¹ In these cases, we advocate for the use of a

cortical allograft strut (Figure 3, A and B). In contrast to cancellous allograft or DBM, the allograft strut possesses inherent structural integrity. This allows for improved resistance to compression, bending, and torsional forces. We use the technique described by Van Houwelingen and McKee²² which involves the use of a cortical strut placed along the medial aspect of the humerus, opposite from the plate which is placed on the lateral cortex. This construct thereby "sandwiches" the native humeral shaft and allows for improved screw fixation in the far cortex. After the plate is placed, the fracture site is packed with iliac crest autograft or BMP to stimulate healing. In their original case series using this technique, Van Houwelingen observed that 83% of patients achieved union at an average of 3.4 months postoperatively.²²

Periprosthetic Fracture

Periprosthetic humeral shaft fractures are associated with a higher rate of nonunion than the standard humeral shaft fracture.²³ The adjacent joint, which is typically stiff, results in increased motion being transmitted through the fracture site when the patient attempts to move their shoulder or elbow. In addition, the disruption of endosteal blood supply from broaching or from the position of the prosthesis itself may contribute to delayed fracture healing. Although type C fractures (fractures distal to the stem) can be managed nonsurgically if satisfactory alignment can be achieved and maintained in a fracture brace, the high nonunion rate seen in these fractures often warrants surgical intervention. When planning for the surgical treatment of these fractures, the surgeon must first determine whether the humeral component is stable. If the humeral component is loose, the prosthesis is revised to a long-stem humeral component. The tip of the prosthesis should extend two to three cortical diameters beyond the fracture site. If the prosthesis is stable, plate fixation is used with a combination of both cerclage wires and screws. If cerclage wires are used, it is critical to ensure the radial nerve is not injured or entrapped during cerclage placement. As discussed in the previous section, if the patient has poor bone quality, an allograft strut may be used in this setting as well.

Vascularized Fibula Graft

In recalcitrant humeral shaft nonunions with large bony defects where conventional techniques have failed to achieve union, we recommend the use of a vascularized fibula graft (Figure 4, A and B). This graft provides increased vascularity at the fracture site, which results in more rapid bone healing, and it provides greater biomechanical strength than nonvascularized bone grafts.²⁴ In addition, the placement of a vascularized graft in a large bone defect may reduce the risk of infection, whereas nonvascularized grafts may act as a nidus for infection in this setting. In general, we turn to the vascularized free fibula graft for bone defects greater than 6 to 8 cm in which previous surgical attempts have failed to achieve union. A published case series by Adani et al on this technique shows a 70% union rate in patients with bone defects greater than 6 cm who have undergone two or more previous surgeries without success. The remaining 30% of patients achieved union with an additional surgery involving bone grafting or a second fibular graft.²⁴

Nonunion After Intramedullary Nailing

In the femur or tibia, nonunion after treatment with an intramedullary nail can usually be successfully managed with exchange nailing (nail removal, overreaming, and insertion of a larger diameter intramedullary nail). In the upper extremity, this is not the case. Robinson et al^{25} found that only two of five (40%) patients achieved union with exchange nailing of the humerus. Similarly, McKee et al treated 19 patients with nonunion after intramedullary nailing; 9 patients underwent nail removal and ORIF, whereas 10 patients underwent exchange nailing. Nine of nine (100%) patients who underwent ORIF achieved union, whereas only 4 of 10 (40%) patients who underwent exchange nailing achieved union.²⁶ Although traditional techniques advocate for nail removal before ORIF, others describe retention of the nail and the use of plating for augmentation. This avoids further dissection, iatrogenic rotator cuff damage, and additional bone loss that can occur with bone removal. Gessman et al used augmentation plating for humeral shaft nonunion in 37 patients and achieved union in 97% of patients at a mean of 6 months.²⁷ In our practice, the intramedullary nail is usually kept in place unless there is concern for infection or if removal is necessary to allow for adequate bicortical screw purchase.

Postoperative Care/Considerations

The quality and stability of fixation dictate the postoperative recommendations. We generally recommend immobilization and nonweightbearing for our patients for 1 to 2 weeks postoperatively while incisions heal. Once sutures are removed at the first postoperative visit, the patient may begin shoulder and elbow range of

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motion and up to 5 pounds of weight bearing for activities of daily living. At the 6-week mark or once there is radiographic evidence of healing, they may advance their weight bearing.

Pearls and Pitfalls

Pearls

- 1. Most humeral shaft fractures can and should be treated nonsurgically.
- 2. Primary surgical intervention may be warranted in certain fractures to prevent delayed or nonunion.
- 3. Correct nutrition, smoking, and vitamin deficiency preoperatively to enhance your success rate before intervening.
- 4. Conventional techniques may not be adequate for bone defects greater than 5 to 6 cm. In this scenario, vascularized bone grafts should be considered.

Pitfalls

- 1. Many failed surgically-treated nonunions will have positive cultures despite negative preoperative investigations. The most common organisms are *Cutibacterium acnes* and *Staphylococcus epidermidis*.
- 2. The radial nerve should be isolated and protected throughout any case at the mid humeral level or below.
- 3. Improve fixation during the second or third operation by using longer plates.
- 4. Intramedullary exchange nailing is not effective at achieving union. A plate can be placed around the nail or the nail should be removed followed by ORIF.

Outcomes

Humeral nonunion can have a notable negative effect on a patient's quality of life, ability to perform activities of daily living, and independence; therefore, intervention is almost universally warranted. There is, however, no consensus as to the best surgical technique for the treatment of a humeral shaft nonunion. Different methods described in the literature include ORIF, intramedullary nail fixation, external fixation, and allograft struts. Peters et al²⁸ performed a systematic review of 36 studies evaluating the union rate associated with these various methods of fixation in nearly 1,200 humeral nonunion patients. They found that plate fixation with autologous bone graft achieved a mean union rate of 98% (range 75% to 100%) and plate fixation without bone graft achieved a mean union rate of 95% (range 75% to 100%). Intramedullary nailing was associated with 88% (range 56% to 100%) union rate when used with autologous bone graft and 66% (range 29% to 95%) union rate without bone graft. Bone strut fixation was found to have a 92% (range 83% to 100%) union rate, whereas external fixation was found to have a 98% (range 89% to 100%) union rate. Bone strut and external fixators were however associated with 20% and 22% complication rate, respectively. Although most of these methods were comparable at achieving union, the authors concluded that plate fixation with autologous bone graft is the preferred fixation method for humeral shaft nonunion because of high union rates with low complication rates.28

Bone graft and/or bone substitute is an important consideration during nonunion surgery. Although autologous bone graft is the benchmark for treatment of nonunion, it is notably associated with donor site morbidity and the risk of complications from the graft harvest site. The iliac crest is the most commonly used donor site for autograft, and literature suggests up to a 20% complication rate is associated with graft harvest, including infection, hematoma, fracture, chronic pain, and sensory disturbances.²⁹ Given this relatively high incidence of donor site morbidity, we prefer to avoid autologous bone graft in most cases. Hierholzer et al³⁰ reported on a cohort of patients with atrophic delayed union or nonunion of the humeral shaft. Fourty-five patients underwent ORIF with iliac crest autograft, whereas 33 patients underwent ORIF with DBM. Union was achieved in 100% of patients in the autologous bone graft group and 97% of patients in the DBM group; time to union was 4.5 and 4.2 months, respectively. However, 44% of patients in the autologous bone graft group experienced a complication related to the donor site. Based on these findings, the authors concluded that DBM provided comparable union rates and time with union in the setting of humeral shaft nonunion and advocated for the use of DBM over autologous bone graft.³⁰

Living with a humeral shaft nonunion is associated with substantial disability and loss of independence. Although many studies have shown success in achieving radiographic union through surgical intervention, fewer studies have investigated the change in functional outcomes after surgery. Ring et al³¹ assessed the Constant and Murley Score (CMS), Enforced Social Dependency Scale (ESDS), and Disabilities of the Arm, Shoulder, and Hand (DASH) Questionnaire for elderly patients with humeral shaft nonunion, both preoperatively and postoperatively. In the CMS where a high score demonstrates higher quality of function, CMS score increased from 9 to 72 points after surgical treatment of nonunion. In the ESDS and DASH where a high score indicates greater disability, they found that the ESDS decreased from 39 to 9 and the DASH decreased from 77 to 24 after surgical intervention for nonunion.³¹ Marti et al³² looked at shoulder and elbow function as well as patient-reported satisfaction in 51 patients who underwent surgical intervention for nonunion. One year after surgery, they found that 49 of 51 patients had essentially normal range of motion of the ipsilateral shoulder and elbow. In addition, 96% of their patients rated their result as excellent or good one year after nonunion repair.³²

Summary

Humeral shaft nonunions are associated with poor quality of life for patients because of persistent pain and diminished function. Although most humeral shaft fractures can still be managed nonsurgically, it is important to closely monitor patients both clinically and radiographically to identify impending nonunion and offer early intervention. To optimize success in treating patients with a humeral shaft nonunion, it is important to first perform a thorough investigation into any reversible factors that may be contributing to the nonunion. We categorize nonunions into atrophic or hypertrophic and aseptic or septic/possibly septic and tailor our surgical approach accordingly. Our standard technique involves ORIF with a 4.5 compression plate or dual 3.5 anatomic plates for distal fractures. Although most patients will achieve union after a single intervention, some patients may experience a recalcitrant nonunion, requiring a specialized technique to improve the chances of success. In patients with poor bone quality or those with large bone defects, we recommend the use of a cortical strut allograft and vascularized fibula graft, respectively. When successful, treatment of humeral shaft nonunion improves function, reduces disability, and improves the quality of life for patients.

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