5 Treatment Strategy for Nonunions and Malunions

[DE1]

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Surgical management of nonunions and malunions requires a sound understanding of the principles and biomechanics of internal fixation, the biology of fracture union, and the limits of the specific implants employed. Due to the unique nature of each patient's problem, patients with a nonunion or malunion require an individualized treatment plan with specific goals. This chapter focuses on general principles and strategies, allowing the reader to individualize management. Using these principles the reader should be able to develop an individualized treatment plan. The initial evaluation of malunions and nonunions is generally similar, but the management is discussed separately because they require different treatment algorithms.

Evaluation

The evaluation of a patient with a malunion initially focuses on identifying if the perceived problem is a deformity of functional or future pathomechanical significance.[1,2] Nonunion evaluation, on the other hand, focuses on the potential etiologies for the nonunion and the degree of dysfunction caused by the nonunion. Both require a complete history, initial treatment, as well as any complications of that treatment. One should document the pain severity and frequency as well as any pain medication taken on a daily basis. A thorough review of systems is necessary, including a list of medications the patient uses, taking particular note of steroids, tobacco, nonsteroidal anti-inflammatory drugs (NSAIDs), anticoagulants, and antiseizure medications.

Complaints of pain in the extremity with nonunion or malunion should be thoroughly considered and potential etiologies assessed. There are several potential etiologies for pain after a fracture other than the non- or malunion of the bone. Local pain factors can often be determined on physical exam by focusing on reproducing the symptoms and additionally by selective injection of local anesthetic. As Mast has noted (pers. comm.), more remote causes of pain may lie in adjacent or ipsilateral joints **(Table 5–1).** Around the knee, for example, possibilities include arthrosis, joint instability, or mechanical symptoms due to an associated meniscal tear. As a result of the anatomy of the peripheral nerves and the possibility of referred pain, the hip should always be carefully evaluated for synovitis in patients complaining of knee pain.

Physical examination should start with an evaluation of gait. Gross alignment in the frontal and sagittal planes should be determined. Joint motion, including the rigidity of the end point, as well as excessive mobility, is important to document. Ipsilateral joint contractures should be carefully assessed and considered as part of the patient's problem list. Motion at the site of the nonunion should be noted and differentiated from local joint motion. Rotational alignment should be determined compared with the normal side. Leg length discrepancy should be evaluated with note of apparent and true limb lengths.

Radiographic evaluation should include anteroposterior and lateral views of the involved extremity. Oblique radiographs of the involved side are also important for planning purposes[3] because most malunions occur out of the standard orthogonal planes. Stress views are helpful in determining mobility of the nonunion. Special views, such as tibial plateau views, may be necessary as well. Standing hip-knee-ankle views[4] are necessary to determine alignment with malunions. Anteroposterior and lateral views of the contralateral uninvolved extremity are necessary for preoperative planning purposes. Two-dimensional computed tomographic (CT) scans are helpful when evaluating rotational deformities,[5] degree of fracture consolidation, and leg length discrepancies. High-quality three-dimensional (3-D) CT scans often provide a summary image that plain radiographs cannot. However seductive 3-D CT scans may appear, a thorough study of the plain radiographs is necessary for decision making when using plain and fluoroscopic images intraoperatively. Magnetic resonance imaging (MRI) is a helpful adjunct to diagnose other potential etiologies of pain and dysfunction **(Fig. 5–1)** such as ligamentous or meniscal injuries as well as avascular necrosis.

Table 5—1 Potential Etiologies for Pain Following Fracture

Local	Remote
Neuroma	Ipsilateral joint or back
Hardware	adjacent
	distant but referring
Heterotopic ossification	

Figure 5–1 Magnetic resonance imaging demonstrating an intra-articular step-off as well as a meniscal tear in a patient with persistent knee pain after fracture.

Surgical Treatment for Malunions

Indications

Unfortunately, there are no scientifically based parameters regarding the need for surgical intervention for malunions. Therefore, functional limitations are the most consistently cited indication for surgical intervention in patients with a malunion. The indications for surgical correction of malunions in the upper extremity focus on the patient's ability to position the hand in space. A primary indication for surgical treatment of an upper extremity malunion is inability to perform activities of daily living because of the malunion. A relative indication would be a patient-specific desire to perform an activity impaired by the malunion. The primary concerns regarding malalignment in weight-bearing joints are quite different. The long-term implications of joint overload are significant in lower extremity malunions, due to impact on both articular cartilage health and the capsular and ligamentous tissues.[6,7]

In addition to malalignment, the treatment decision in extremity malunions must be made considering the patient's age, activity level, functional demands, and medical status. Clearly the risk:benefit ratio must be evaluated. For example, malrotation in the lower extremity after intramedullary nailing is a frequent complication; however, symptoms do not correlate with the degree of deformity.[8] This is likely due to the spherical shape of the femoral head allowing for rotational compensation during gait. Although Muller et al[6] have recommended derotation for asymmetry of 10 to 15 degrees or more, there are no clear data to support that conclusion. Therefore, the surgical indications for malrotation should be made on an individual basis and, in clinical practice, often reflect the patient's ability to compensate for the malrotation during gait.

Patients will often present with concerns regarding cosmesis after malalignment of a fracture. The principle issues in these circumstances are whether there are functional limitations and reconciling this with the patient's perception of the deformity. Potential indications to consider deformity correction following a malunion include: (1) mechanical overload,[8] (2) dysfunction, (3) capsuloligamentous strain, (4) subjective complaints, and (5) cosmesis.

Preoperative Planning

Preoperative planning is a tool used to improve outcomes while caring for these patients with complex problems. Although drawings are a key element to preoperative planning, they are only the final stage in a thought process. This process should state the goal of the procedure; document all issues in a patient problem list; define the surgical tactic, including the planned technique of reduction; and then ultimately include the radiographic tracings. [DE2]

While seeming oversimplified, the first step of the preoperative plan is to state the problem and goals of surgery. This aids in determining the principles of treatment and also increases the likelihood that the procedure will address the concerns of the treating surgeon and the patient.

The patient's problem list should record the explicit problem (e.g., diaphyseal malunion), as well as implicit problems (e.g., impending joint degeneration). Confounding factors include the previous incision; the presence of hardware and its sequelae (e.g., screw holes or bony defects); systemic factors (e.g., diabetes mellitus); and then, in a separate column, how each issue will be addressed. The key principles employed in lower extremity correction are outlined in **Table 5–2.**

The surgical tactic is a stepwise algorithm outlining the procedure and should address each issue identified in the

Table 5—2 Principles for Lower Extremity Correction (Hierholzer)

1. Restore normal axial alignment. Mechanical axis bisects ankle/knee/center of femoral head.[12–14]
2. Restore ankle and knee joints parallel to floor.[16]
3. For hip, need concentric coverage and containment of femoral head. Tip greater trochanter at center of femoral head for lever arm and efficient gait.[2,17]
4. Equalize leg lengths within 2 cm to avoid problems with gait or spine

A,B

Figure 5–2 (A) An example of an intra-articular malunion and **(B)** its correction with an osteotomy.

problem list. The surgical tactic should be divided into stages, each with a limited goal. Success in these difficult cases is more certainly achieved if one can break the procedure down into a series of steps, each with limited goals, leading to the desired end result.

The surgeon should strongly consider performing the proposed surgical correction with cut-outs of paper tracings of the fragments prior to the surgery to assure the desired result will be achieved. In very complex malunions it is sometimes helpful to obtain a plastic bone model of the deformity to aid in planning for the correction. It is important to recognize that measured lengths on nondigitalized radiographs have an approximate magnification of 20%. The magnification on digitalized radiographs is variable but can often be found at the bottom of the film. Further reading on preoperative planning is available from other sources.[9]

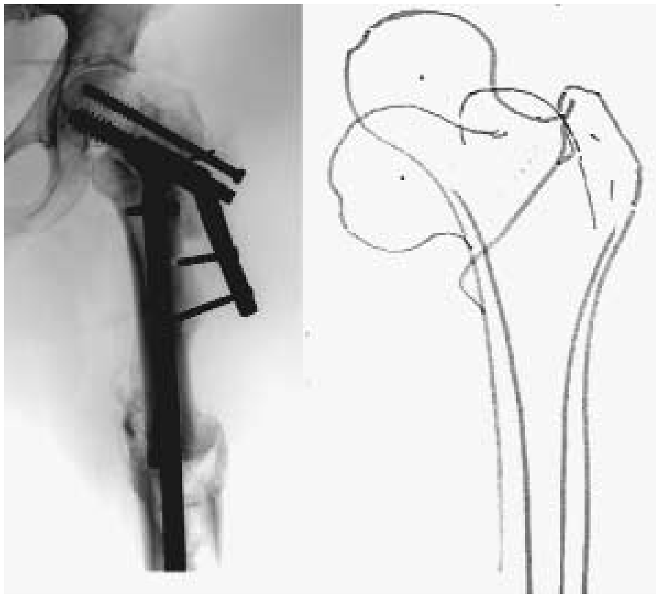
Patients with poor soft tissue coverage require additional consideration. First, incisions should be planned so that hardware, tendon, or bone will not be exposed should wound problems occur. For example, in the distal tibia with a preexisting anteromedial wound, a posteromedial approach[10] for reconstruction will minimize damage to the blood supply of the soft tissues.[11] Second, a paucity of soft tissue usually means a limited blood supply will be available for union. Consideration should be given to improving vascular supply via vascularized bone graft or soft tissue transfer. Finally, in patients with poor soft tissue coverage, the surgeon should give consideration to gradual correction via distraction osteogenesis (Ilizarov) techniques.

Anatomy

Epiphyseal or intra-articular malunions will require intervention if there is a residual articular cartilage step-off or joint line obliquity of the knee or ankle based on standing radiographs.[12] The goals of treatment as outlined by Schatzker[12] are an accurate reduction of the joint surface
[DE3] with stable internal fixation, and the use of continuous passive motion (CPM) postoperatively. Early motion is advantageous because it promotes articular cartilage healing while also minimizing postoperative joint stiffness. Schatzker's goals may be accomplished by performing an intra-articular osteotomy with reduction or by osteotomy of the metaphysis to normalize the alignment or, in the case of degenerative arthritis, overcorrecting the alignment to unload the joint **(Fig. 5–2A,B).**

Metaphyseal malunions require intervention when there is residual joint line obliquity or malalignment on the standing hip-knee-ankle radiographs. Deformity correction is most easily evaluated by superimposing tracings of the abnormal side on the normal side **(Fig. 5–3A,B).** This technique will make evident the change necessary to normalize the limb. In the lower extremity, each plan must be superimposed on hip-knee-ankle tracings so as to avoid a translation, which can affect mechanical alignment. This problem is most commonly seen around the hip where valgus osteotomy without lateralization of the shaft will predictably lead to valgus malalignment **(Fig. 5–4A,B).** Although the type of osteotomy required will be determined by the tracing, the choices are limited to oblique, opening, and closing wedges. Osteotomy choice should create the desired change as well as create intrinsic stability.[14] **Fig. 5–5A–D** shows two preoperative plans for the same patient. **Fig. 5–5A,B** shows adequate deformity correction with a 120 degree angled blade plate, but inadequate stability with a medial open area. **Fig. 5–5C,D** shows the preferred preoperative plan employing an adult 90 degree osteotomy plate with minimal residual opening medially thus improving stability in the final construct.

Hierholzer states that opening wedge osteotomy in the [DE4]
lower extremity is to be avoided because it is intrinsically unstable. We believe this to be true in the absence of structural bone graft. In contrast, closing wedge and oblique osteotomies are easily made stable. Whenever possible the surgeon should create an osteotomy, which leaves a residual obliquity thus allowing an increased surface area for healing and for application of a lag screw. The technique of osteotomy should be performed as demonstrated in **Fig. 5–5C,D.** However, fragment mobilization should be

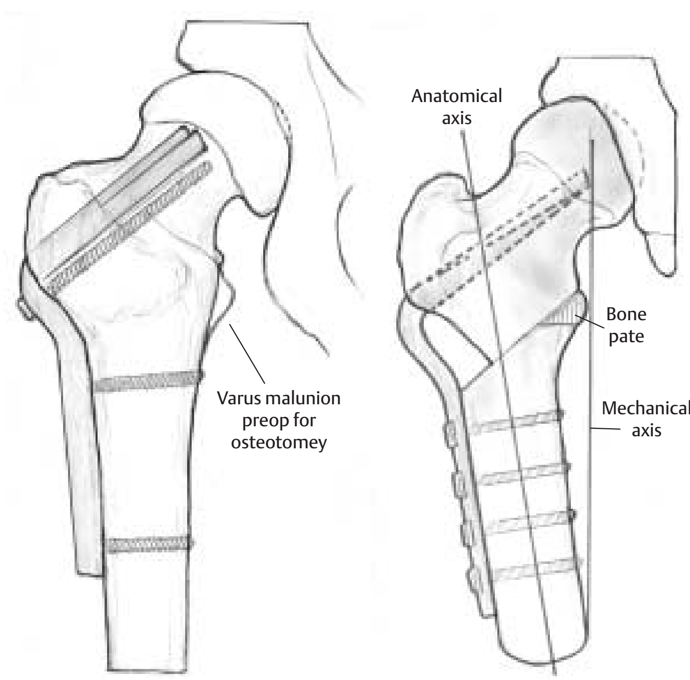


A,B

Figure 5–3 **(A)** An ipsilateral pertrochanteric and shaft fracture with failed internal fixation. **(B)** Superimposition of the involved side on the reversed tracing of the uninvolved side.

done using tools with broad surfaces to minimize crushing of the bone. Manipulation of the diaphysis is also helpful in realigning the fragments (e.g., valgus intertrochanteric osteotomy).[15]

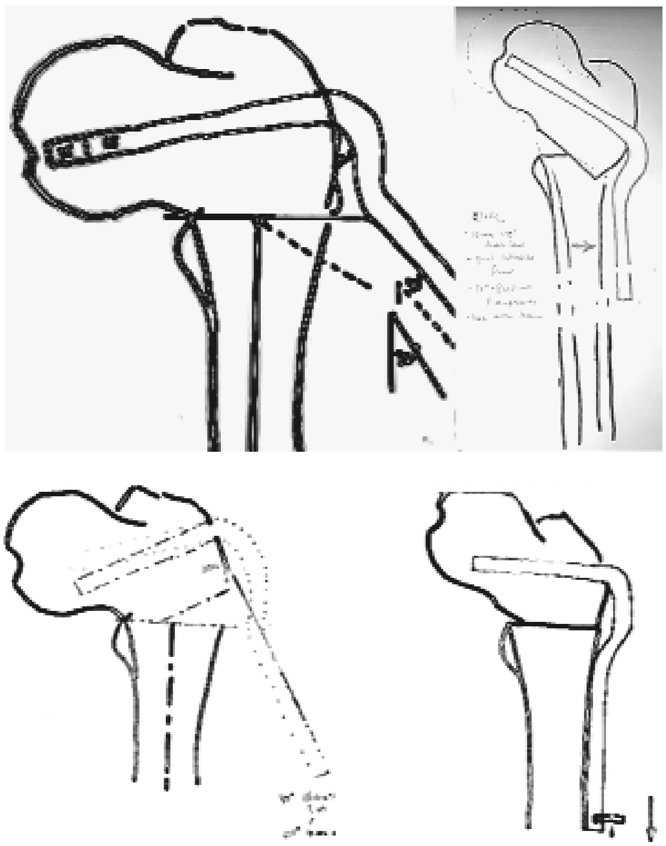
Fixation of a metaphyseal osteotomy must account for the limited capacity of cancellous bone to hold a cortical screw when compared with cortical bone.[16] In cancellous bone therefore it is wise to use fixed-angle devices such as blade plates or locking plates because these provide larger surface areas to avoid cut-out **(Fig. 5–6).** Locking screws and plates fail by forcing the bone to cut around the screw to have failure rather than the screws



A,B

Figure 5–4 **(A,B)** A valgus osteotomy of the proximal femur with lateralization of the shaft, reestablishing a normal anatomical and mechanical axis.

[DE33]



A,B

C,D

Figure 5–5 Demonstrates two different plans for the same deformity. **(A,B)** Correction of the deformity without ideal stability, yielding a suboptimal plan. **(C,D)** A plan that yields both adequate deformity correction and stability. [DE34]

sequentially pulling out as occurs with conventional plates. Once a blade plate or locked plate is seated in the metaphysis, compression will maximize construct stiffness and resist failure. The surgeon should take care to assure that the blade or locked plate has an adequate bony bridge (e.g., 1.5 cm for valgus osteotomy) to resist failure based on pull-out of the implant from the metaphysis **(Fig. 5–7)** during compression.[7,17]

Diaphyseal malunions require thorough evaluation because they often have multiplanar involvement. In his [DE5] evaluation of long-bone malunions, Milch[3,18] has determined that long bones can be considered straight or curved based on whether the mechanical axis is collinear with the anatomical axis. Examples of straight bones include the tibia, ulna, and humerus. This is of importance because a malunion or a curved bone such as the femur is more difficult to fully correct in all planes and may require a mathematically generated oblique osteotomy.[17]

Diaphyseal deformities often involve shortening in addition to the recognized coronal or sagittal plane abnormality. Therefore, length must be evaluated prior to creating a preoperative plan. If shortening is present, it is important to recognize that a closing wedge osteotomy will further shorten the limb, and therefore an oblique osteotomy may be a better choice to allow correction of both the shortening and the malalignment. If an oblique osteotomy is used, it will be necessary to prebend the plate[19] and add a lag screw.

General Principles of Internal Fixation for Malunions

The conventional wisdom in fracture fixation is that one should stabilize the epiphysis with screws, the metaphysis with plates, and the diaphysis with a rod. Although this holds true for acute fractures, compression is the fundamental tool for successful treatment of mal- and nonunions. Fixation after osteotomy or after nonunion treatment should focus on generating compression across the bony defect. Exceptions include femoral and some tibial nonunions where a reamed intramedullary nailing will trigger increased periosteal blood flow,[20] and the increased rod size will create a construct stiff enough

Figure 5–6 A radiograph demonstrating blade plate fixation in the metaphysis of the distal femur and tibia.

Figure 5–7 Radiograph showing inadequate bony bridge under the shoulder of the blade plate leading to loss of fixation in the proximal fragment.

to generate union. However, most nonunions and malunions require fixation in compression using either a lag screw through the plate,[21] or an external fixator in the case of the proximal or distal tibial.[22] Internal fixation for malunion or nonunion has the advantage of being definitive, biomechanically predictable, and cosmetic, and it requires limited patient or surgeon aftercare. The disadvantage of open reduction and internal fixation (ORIF) is that imprecise correction, if not recognized intraoperatively, will require revision surgery.[21]

Successful internal fixation requires a mechanically sound construct able to resist cyclic muscular contraction generated during early functional activity.[15] For internal fixation, this requires a plate with sufficient length to resist torsional forces. Ring et al[23] found that, with humeral nonunions in osteoporotic bone, successful constructs used plates with lengths 80% of the length of the bone. The modern trend in choosing a longer plate length for reconstruction mimics the current trend in fracture treatment.[24] The use of the Articulating Tensioning Device (Synthes, Paoli, Pennsylvania) is helpful in generating compression in osteoporotic bone or in the femur where
[DE6] greater than 100 kp is required.[25] Successful internal fixation requires bony surfaces with satisfactory cortical contact to achieve bony stability to protect the implant. If a defect is present, bone grafting is required at the osteotomy or nonunion site.

Types of Deformity

Rotational Deformities

Rotational malalignment is common after intramedullary nailing. Unfortunately, there are no scientifically supported criteria available in the literature to establish the degree of malrotation in the lower extremity that represents pathological significance. Once the decision has been made to correct malrotation, a transverse osteotomy is the ideal surgical intervention. In the case of shortened and malrotated femurs following intramedullary nailing, Samuel[26] reported using an oblique derotational osteotomy to correct modest deformities. It is important to limit correction using this technique because large corrections create poor bony apposition at the osteotomy site. Direct surgical exposure is mandatory when performing a transverse osteotomy. Careful placement of Homan retractors is done to minimize stripping of soft tissue attachments. Threaded Kirschner wires are inserted at an angle mimicking the degree of malrotation, which had been determined preoperatively either by clinical exam or by CT scanning **(Figs. 5–8A,B; 5–9)**. The osteotomy is performed with a saw with care to avoid thermal necrosis of the bone. Derotation is then performed using temporary external fixation or clamp fixation to stabilize the bone. Evaluation of the correction is then performed by comparing the

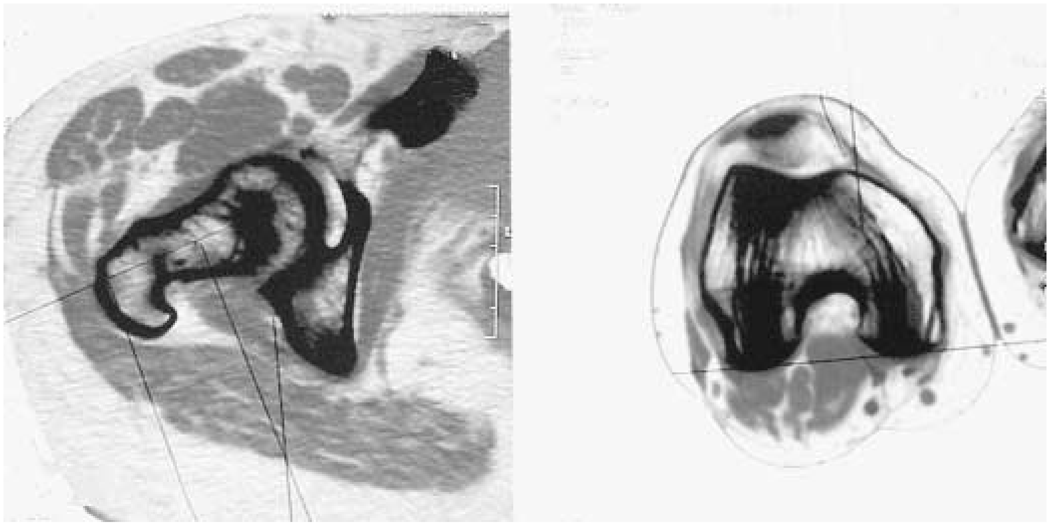


Figure 5–8 (A,B) Computed tomographic scan cuts demonstrating the severe retroversion of the proximal femur, which clinically appears as external rotation.

[DE35]

positions of the implanted K-wires or by comparison with the contralateral limb.

Angular Deformities

Significant lower extremity single plane deformities are usually in the frontal plane. Often the goal is simple restoration of mechanical alignment. Although this is usually done by using an opening or closing wedge osteotomy,[21] superimposition of a tracing of the abnormal side over a tracing of the normal side will clarify what correction is needed **(Fig. 5–5A-D).**

Two-plane deformity: Paley[27] has pointed out that in a two-plane deformity, the degree of malalignment documented on standard anteroposterior (AP) and lateral radiographs underestimates the actual deformity. Therefore, a complete workup should include oblique films, which will often identify the true plane of deformity. It may be calculated from the AP and lateral views by plotting the degree of deformity in the coronal plane on the *x*-axis, and the degree of sagittal plane deformity on the *y*-axis. The resultant vector is the degree and direction of the maximal deformity. This can be done fluoroscopically as well by rotating the image intensifier until the deformity demonstrates the greatest magnitude. The plane is then documented from the image intensifier.

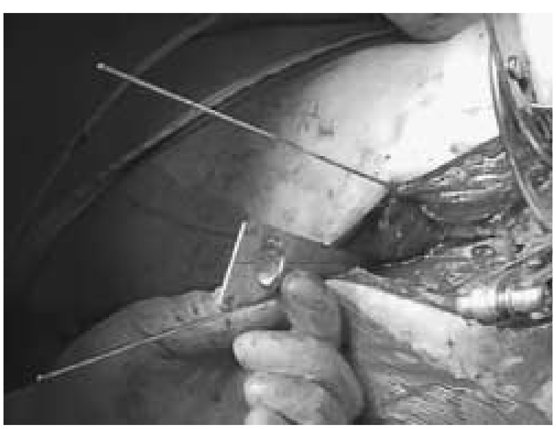
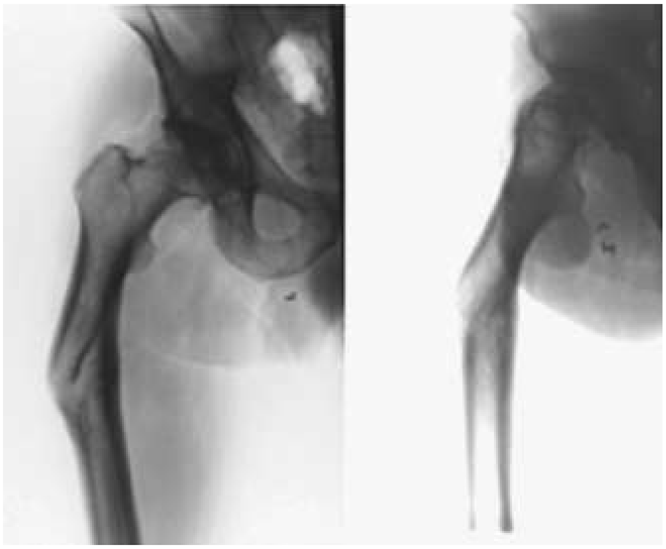


Figure 5–9 K-wire positioned on the proximal and distal fragments mimicking the deformity in preparation for surgical correction.

A closing wedge or single oblique osteotomy is the best option for correction of a two-plane deformity. Treatment with the closing wedge technique requires determination of degree of correction in each plane and resection of a representative trapezoid (**Figs. 5–10A,B; 5–11A,B**). The disadvantage to this technique is the inability to place a lag screw following wedge resection because the resultant osteotomy is transverse. Another disadvantage is the osteotomy leads to additional leg length discrepancy.[28] In contrast, using a single oblique osteotomy[28] allows for lag screw placement and does not increase leg length discrepancy. The plane of the osteotomy cut is perpendicular to the malunion.[17,28]

Three- and Four-Plane Deformities

Three- and four-plane deformities are best managed using a single oblique osteotomy.[17,28] If this method is chosen, trigonometric analysis[17] and the correct orientation of the cut will automatically correct rotation. Closing wedge osteotomy is another option. However, closing wedge osteotomy requires a resection of a trapezoid and it is critical to correct rotation first. Failure to initially correct for rotation



A,B

Figure 5–10 **(A,B)** A proximal femoral malunion. [DE36]

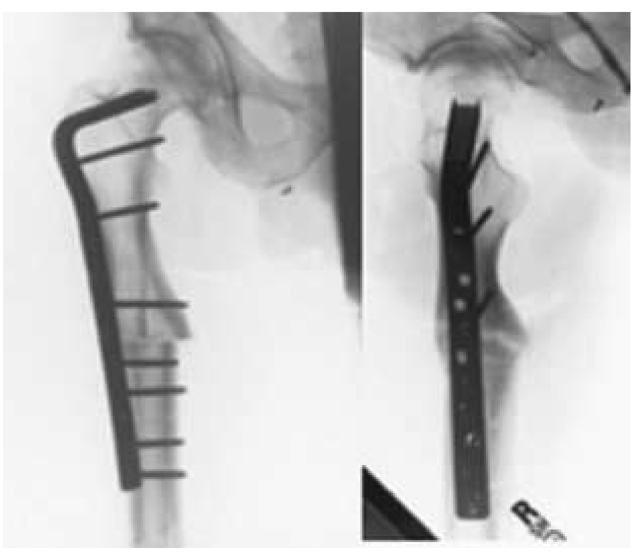
will impact the correction in the sagittal and coronal planes, especially in a curved bone such as the femur. In complex deformities preoperative planning can be aided by making a plastic model simulating the deformity. This will allow the opportunity to make the planned correction prior to surgery.

Osteotomies for Malunion Correction

The practice of malunion correction using an osteotomy requires knowledge of the advantages and disadvantages of the various osteotomy types. Anticipation of and preparation for the limitations of each osteotomy type will minimize complications. Whenever possible, choose an osteotomy that will help create inherent stability, thus protecting the hardware and construct from failure. Deformity correction should preferentially[7,29] take place at the deformity site to avoid creating a deformity to correct one. The exception would be in the case of poor local skin or bone quality where use of virgin skin or bone may be advantageous.[9,22]

Transverse Osteotomy

Transverse osteotomies in the diaphysis are useful for correcting malrotation. Transverse osteotomies are inherently



A,B

Figure 5–11 **(A)** Anteroposterior and **(B)** lateral radiographs after resection of a trapezoid to correct the deformity leaves a residual transverse osteotomy.

Figure 5–12 Radiograph demonstrating invagination of the osteotomy fragments with residual shortening.

unstable in torsion and bending,[30] and therefore are best stabilized with a statically locked intramedullary nail. Care must be used in employing transverse osteotomies in the metaphysis due to the risk of invagination of the cortical step-off, which may lead to overcorrection[12] **(Fig. 5–12).**

Oblique Osteotomy

Oblique osteotomy provides an excellent tool in deformity correction because it can afford length and sagittal plane, in addition to coronal plane, correction. It also offers broader surface areas for healing, superior bending, and rotational stability, and can be compressed with a lag screw. Lag screws placed through the plate increase construct strength by 25%.[21]

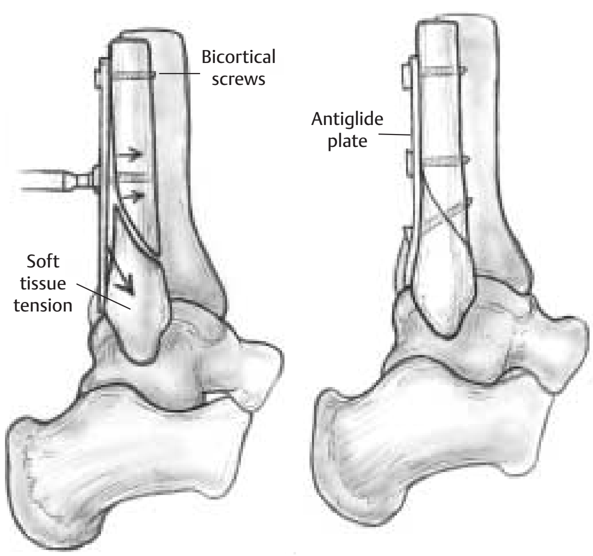
Oblique osteotomies are useful in metaphyseal bone, especially when used with an incomplete cut to create a hinge for increased stability. The surgeon can add or remove wedges to adjust length, mechanical axis, and rotation. Oblique osteotomy also allows the hardware to be placed in a tension band fashion. It is important to make the cut without excessive obliquity to avoid shear unless resisted by an antiglide plate as described by Brunner and Weber[31] **(Fig. 5–13A,B).**

Step-Cut Osteotomies

While seeming attractive during preoperative planning, step cut osteotomies have significant disadvantages, such as requiring increased exposure, allowing only limited fixation, and limiting the potential for angular or rotational correction.

Opening Wedge Osteotomy

In the diaphysis, opening wedge osteotomy allows for axial correction without sacrifice of length. However, opening wedge osteotomies are intrinsically unstable and should be managed with grafting of corticocancellous bone in the newly created defect. In the metaphysis the authors recommend grafting when the opening wedge correction is greater than 5 mm.



A,B

Figure 5–13 (A,B) Oblique osteotomy stabilized with an antegrade plate. [DE37]

Surgical Techniques for Specific Malunions

The goal of malunion reconstruction in the proximal humerus is to reestablish the normal biomechanics of the shoulder. In terms of anatomy, this requires that the tuberosities be fixed to the metaphysis in their normal positions and orienting the articular surface to its normal 125 degrees. Normal alignment is established by taking a radiograph of the uninjured side and comparing tracings of the normal and abnormal side to determine the degree of malalignment. The osteotomy is planned and performed to leave residual obliquity, allowing for lag screw stabilization and also allowing correction of length. The osteotomy is finally stabilized with a plate applied at the end of the osteotomy thus creating the additional structural benefit of an antiglide effect.

Proximal Humerus Malunion

Preoperatively, a radiographic evaluation is facilitated by placing the patient on a radiolucent table with a bump under the affected scapula elevating the patient to approximately a 45 degree angle. The image intensifier is then brought in on the contralateral side and, by performing 45 degree oblique x-rays, one can see an AP view of
[DE7] the glenohumeral joint, as well as a scapular Y view by simply rotating the C-arm. A deltopectoral approach[32] is used for surgical exposure. Once exposure of the proximal humerus is achieved, retractors are placed to expose the malunion. Visualization is usually improved by passing a blunt Homan retractor around the superior and lateral aspects of the proximal humerus. Judicious retraction will prevent injury to the axillary nerve. More distally, exposure may be improved by sharply releasing a portion of the deltoid attachment off the humeral shaft. Threaded K-wires are then drilled in place so as to mimic the area of intended osteotomy **(Fig. 5–14).** After resection of the wedge, the arm is adducted to close the osteotomy gap created. Fixation is performed with a fixed-angle construct such as a blade plate or locking plate and screws so as to assure fixation in the metaphyseal bone. Compression is generated across the osteotomy site by loading the plate distally. Deep and superficial tissues are closed in the standard fashion.

Distal Radius

Distal radial malunions are common in the elderly and usually well tolerated due to the low functional demand in most of these patients. Patients with distal radial malunions experience a loss of strength due to loss of the normal volar tilt. Opening wedge or oblique osteotomy can reestablish the normal volar tilt, normalize the distal radial ulnar joint (DRUJ), and normalize length.

For an opening wedge osteotomy for the distal radius **(Fig. 5–15),** a standard dorsal approach utilizing the fourth

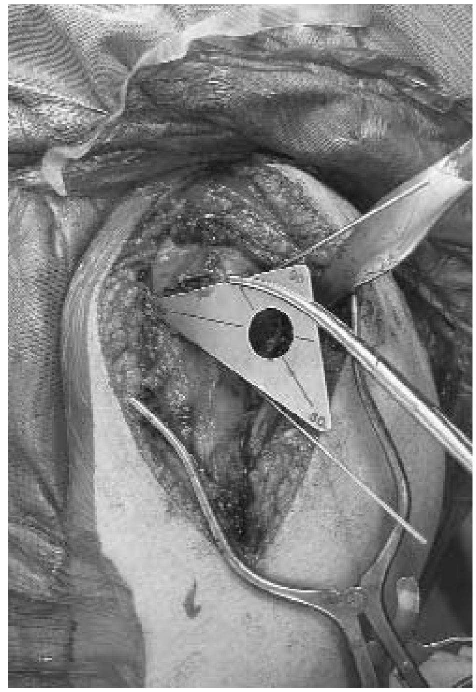
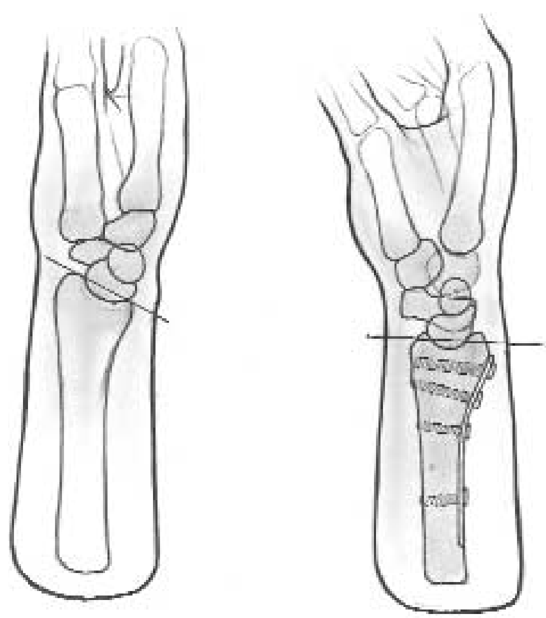
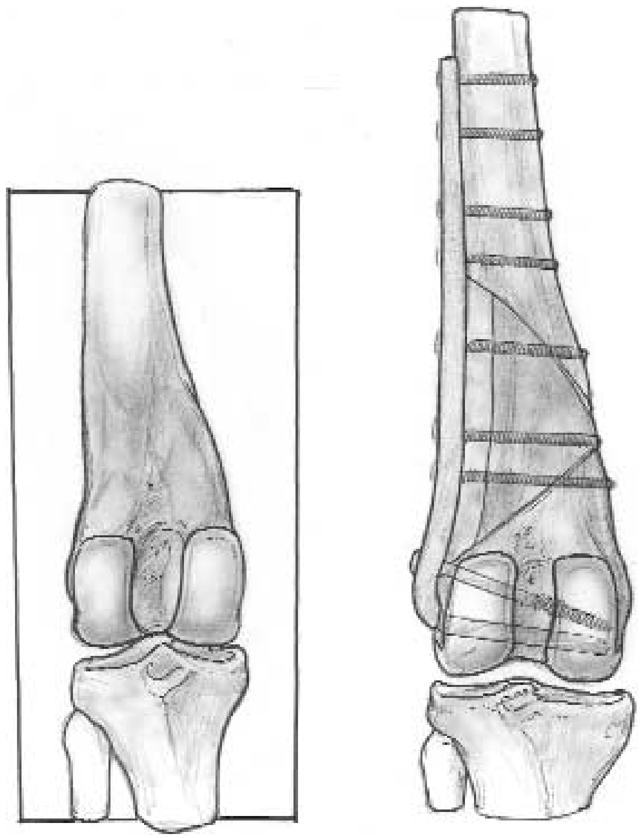


Figure 5–14 Kirschner wires mimicking the intended osteotomy of a proximal humerus malunion.



[p1]

Figure 5–15 Plan for an opening wedge osteotomy of the distal radius with bone grafting.



A,B

Figure 5–16 **(A)** A complex distal femoral malunion. **(B)** Blade plate fixation following double oblique osteotomies.

compartment is preferred. Radial and ulnar dissection will create access to the entire dorsal metaphysis. Once the dorsal radial surface is adequately exposed, threaded Kirschner wires are placed so as to mimic the proposed osteotomy. Proper wire placement is confirmed radiographically. Using a 1 in. microsagittal saw, the osteotomy is performed leaving the volar cortex partially intact. An osteotome is inserted and gently used to lever the osteotomy site open. This will complete the osteotomy at the volar surface, but should be done so as to minimally disturb the soft tissues. Placement of the wrist on several towels will allow it to open on the dorsal surface.

Preoperatively, a tricortical wedge is planned to be taken from the iliac crest. The tricortical graft is planned so that the width of the wedge of crest taken is double the size needed to make the correction. This wedge is then split and each piece inserted to complete the correction. The depth of the graft harvest is the width of the radius on x-ray. One must recognize that measured lengths on nondigitalized plain radiographs have an approximate magnification of 20%. Once the graft is inserted, fixation is by a dorsally applied distal radial plate in compression **(Fig. 5–15).** Closure is performed, with special attention to protecting the extensor pollicis longus from attritional rupture. This may be done by splitting the extensor retinaculum transversely and creating a slip to protect the extensor pollicis longus.

Distal Femur

Malunions of the distal femur are often multidimensional [DE8] and can be in varus, valgus, flexion, or extension, and often have associated shortening **(Fig. 5–16A,B).** Closing wedge osteotomies often exacerbate the shortening; therefore planning should focus on oblique osteotomies, which allow the surgeon to regain length where necessary. Miranda and Mast have used a double oblique osteotomy to correct complex malunions of the distal femur (unpublished series). A case example of this technique is demonstrated in **Figs. 5–16A,B and 5–17A,B.**

The authors prefer the standard lateral approach to the distal femur. Dissection remains extraperiosteal, save for the proposed osteotomy site. Homan retractors are placed to aid visualization and protect neurovascular structures. The leg is placed on a bump or triangle so as to take the tension of the gastrocnemius off the femoral condyles. A

A B

Figure 5–17 **(A)** A clinical photograph demonstrating the channel for the blade plate. **(B)** A clinical photo demonstrating use of the articulating tensioning device.

95 degree angle blade plate is the preferred implant because the placement of the angle blade plate parallel to the joint will re-create normal alignment if the osteotomy site is placed in compression.

Initially, Kirschner wires are placed mimicking the osteotomy cuts. The chisel is then used to create a channel for the blade plate **(Fig. 5–17A).** It is notable that a 1.5 to 2 cm bridge is required between the chisel blade plate channel and the osteotomy site. Once seated, the blade must be loosened prior to the osteotomy cuts or the chisel will be difficult to unseat. Once loosened the cuts may be made. Next seat the blade plate. At this point, using a Verbrugge clamp and the articulating tensioning device **(Fig. 5–17B**), the distal fragment is distracted and the intermediary segment is mobilized medially. Once in satisfactory position, the articulating tensioner is used to compress across the osteotomy sites. The Articulating Tensioning Device is employed to gain better than 100 kPa of compression. The intermediary segment will need to be stabilized or it will lateralize down the decline plane. Wherever possible, lag screws are placed across the osteotomy site to further enhance stability. Postoperatively the patient ambulates with foot flat, touch down weight bearing. Active and passive ranges of motions are encouraged. No bracing or splinting is necessary.

Proximal Tibia

The goal of treatment of proximal tibial malunions is to minimize intra-articular step-off **(Fig. 5–2A,B)** and reestablish the normal mechanical alignment of the knee with a joint line that is parallel to the floor.

The surgical technique for an extra-articular proximal tibia malunion **(Fig. 5–18)** uses a medial approach, which allows adequate exposure for the osteotomy. The patient is positioned supine, a tourniquet is inflated to 250 mm Hg, and the knee is positioned in flexion by using a bump under the knee. A medial approach allows adequate exposure for the osteotomy. Using the image intensifier, the malunion is identified and the intended line of osteotomy is noted and marked. Osteotomy is performed by using an osteotome. The surgeon should be sure that the meniscus is not trapped in the previous fracture site. A Kerrison [DE9] rongeur is employed proximally and posteriorly so as to avoid injury to the posterior neurovascular structures. Fixation is with screws placed across the osteotomy in

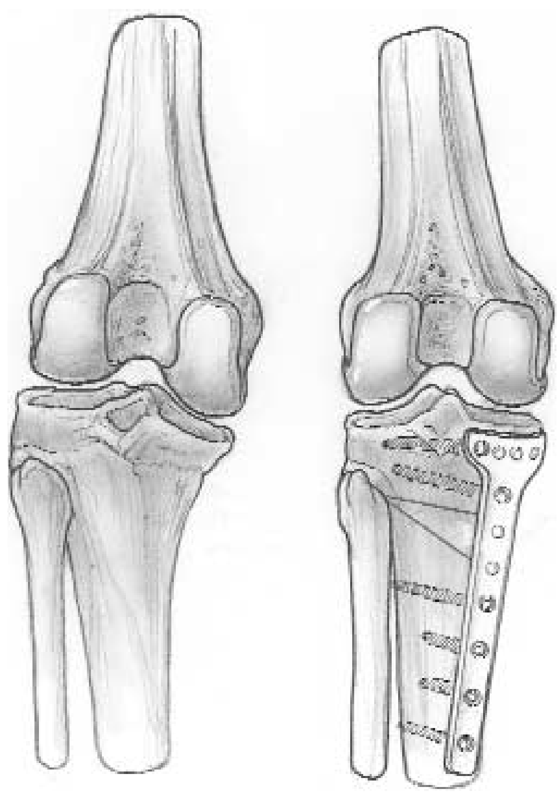


Figure 5–18 Illustration of a proximal tibia malunion treated by a medial opening wedge osteotomy.

[p3]

A,B

Figure 5–19 (A,B) Postoperative radiographs after correction of the [DE38] proximal tibial malunion.

compression using lag technique, followed by buttress plate application **(Fig. 5–19A,B).**

Tips and Tricks for Malunions

- Make sure that the adjacent joints near a malunion are mobile.
- Joint contracture may limit functional outcome and cause nonunion of the osteotomy.
- Place hardware so as to minimize irritation—especially around the shoulder, ankle, and knee.
- Success in malunion surgery directly relates to a preoperative plan where bony stability is achieved.
- Preoperatively make sure the proposed plan is viable by performing cut-outs of the tracings and matching it with the desired end result.
- Focus the plan on the exact mechanism for reduction.
- Lastly, intraoperatively the reduction may require several attempts to achieve the correction; patient determination will assure success.

New Techniques for Malunion Correction

Correction of complex malunions with a Taylor Spatial Frame (Smith & Nephew, Memphis, Tennessee), a relatively new development, allows correction in all three dimensions using a series of struts and a computer-controlled program that is downloaded from the manufacturer. The correction is automatically applied via the programmed system in a very gradual fashion. The early reports with this system are very encouraging, correcting complex deformities in all three planes with impressive accuracy.

Outcomes of Malunion Correction

Modern series of deformity correction show rates of success of 84 to 100% at correction of complex malunions.[18,20,22.29] Sanders et al[28] reviewed a series of 12 patients treated with oblique osteotomies of the tibia. In the patients who were compliant, all had excellent results. Sangeorzan et al[17] reported on four patients with tibial malunions. He described 100% union without complications after osteotomy. Ciodo et al[33] performed oblique osteotomies in [DE10] six patients. They reported excellent results with all deformities corrected to less than 10 degrees variance with the intact side. There were no major complications and no patient required additional surgery.

Complications of Malunion

The most common complications associated with malunion surgery are under- or overcorrection (0 to 15%), nonunion (0 to 12%), nerve palsy (0 to 8%), infection (1 to 3%), delayed union (3 to 5%), and thromboembolism (2 to 4%).

Examination Pearls for Malunions

- The most common (up to 15%) complication associated with surgical correction of malunions is failure to achieve correct anatomical alignment.
- You need to have good joint motion above and below a malunion to achieve a good functional result.
- Most malunions do not occur in strictly orthogonal planes. Make certain you have oblique radiographs to fully evaluate the deformity.

Epidemiology of Nonunions

Bhandari and Schemitsch[34] characterized the status of nonunions well. The published rates after long-bone fractures in the lower extremity range from 3 to 48%.[35] They pointed out that fracture healing is estimated to be delayed in 600,000 patients per year in the United States.[36] Approximately 100,000 of these fractures annually proceed to nonunion.[37] Risk factors associated with nonunion include fracture characteristics such as fracture displacement and segmental loss[37–40]; high-energy mechanism of injury[38]; severe soft tissue injuries[41,42]; and patient characteristics; for example, diabetes,[43,44] alcohol consumption,[45] smoking,[46,47] specific medications (steroids and nonsteroidal anti-inflammatories,[48–50] anticonvulsants,[51] antibiotics,[52] and anticoagulants)[53,54]; and vasculopathy and vascular injuries.[55] Infection is an important and often catastrophic cause of nonunion.

Einhorn describes nonunion as the "cessation of all healing processes and union has not occurred."[56] Delayed union is defined as a continuation of healing processes, with union not occurring in the expected time and uncertainty regarding union.[56] In most instances a nonunion has been established when a fracture has not healed during the expected 3 to 9 months. Radiographically this has been defined as a lack of bridging callus across the fracture site. Although bulky callus is reassuring on follow-up evaluation, cortical continuity has been found to be the single best predictor of fracture torsional strength, and callus size and area to be the least important indicator of union.[57]

Metaphyseal nonunions can be difficult to diagnose.[58] Exuberant callus is common with metaphyseal nonunions. This callus is a result of either motion or bone graft from previous surgery.[58] In actuality, metaphyseal healing takes place by the formation of new bone on existing trabecular bone at the fracture site. This mechanism means that there should be little callus formation seen on x-ray film. Again cortical continuity is the most important radiographic indicator of healing.

Classification of Nonunions

Nonunions can be classified as either hypertrophic or avascular, each with additional subtypes[58] **(Fig. 5–20).** Hypertrophic nonunions have an adequate blood supply but lack sufficient stability to generate union. The hypertrophic subtypes described by Weber and Cech[59] reflect the radiographic appearance of the nonunion. The elephant foot is rich in callous, usually caused by poor fracture stability in a milieu rich in blood supply. The next subtype is the horse-hoof nonunion. This subtype occurs as a result of moderately secure fixation with adequate blood supply. Radiographically, the horse-hoof nonunion has little

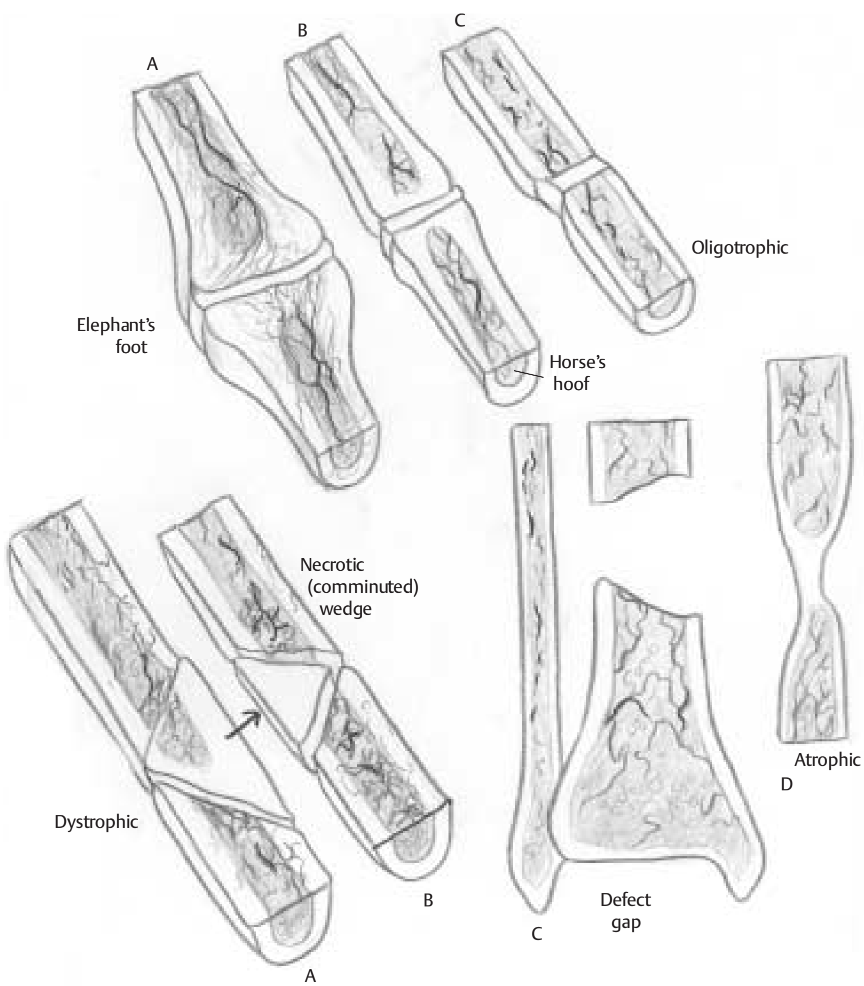


Figure 5–20 Classifications of nonunions.

callous and mild sclerosis. Last in this group is the oligotrophic nonunion, which has no callus and no hypertrophy. This subtype usually reflects fragment distraction or internal fixation without opposition.

Avascular nonunions lack blood supply but may also lack stability. Avascular nonunions are further divided into four subtypes. The first two subtypes identify nonunions with an intermediate fragment of decreased (torsion wedge) or absent blood supply (comminuted). The third subtype is nonunion where there is an absence of diaphyseal bone; these must be treated using a graft. The fourth subtype is the atrophic nonunion, which is the longstanding nonunion with osteoporotic ends lacking in osteogenic potential.

Evaluation of Nonunions

The initial evaluation of patients with a nonunion is detailed earlier in this chapter. Nonunion-specific laboratory workup should include complete blood count (CBC), erythrocyte sedimentation rate, and C-reactive protein. One should be careful, however, because in chronic conditions these laboratory studies can normalize. They are more useful when they are followed over time and a trend is established. Aspiration of a nonunion site suspected of infection can be helpful, but swabbing of open wounds and skin tracts is not usually accurate in identifying the infectious pathogens. The only accurate way to identify an infectious agent is by an open biopsy.

Radiographic evaluation specific for nonunions should include AP, lateral, and oblique views.[39] Stress radiographs are helpful to evaluate instability. MRI, especially when enhanced by intravenous gadolinium, is very accurate for evaluating pathological changes in bone and soft tissue. However, it is not as accurate for differentiating between edema, infection, and postoperative changes. MRI is also limited by any metallic implants in the region being evaluated. CT can be used in those patients with metallic implants and is helpful in evaluating the degree of union, subtle bone changes, sequestra, and devitalized bone.

Nuclear medicine scans are frequently used to evaluate for either acute or chronic infection. There are several radiopharmaceuticals available, each having different characteristics. Indium-labeled leukocyte scintigraphy,
[DE11] 99m-Tc-ABs immunoscintigraphy, and 99m-Tc-labeled nanocolloids are useful in the evaluation of infection, especially during the first year postoperatively, and when metallic implants are present. Suspected chronic, low-grade
[DE12] infections may be best evaluated by 111-In-leukocyte scintigraphy because it tracks cell migration over a 48 hour period.

Surgical Treatment of Nonunions

The principle of nonunion treatment lies in reestablishing the environment required for healing a fracture. In other words, treatment requires assuring the availability of the mesenchymal cells found in the periosteum of live bone, the bone growth factors needed to evolve them, and an adequately vascularized environment with sufficient immobilization of the fracture fragments.[60–64] Preoperative evaluation should determine if each of these factors is available and also if there are factors that will negate their efficacy once the healing process has started. In the case of patients with an infection associated with a nonunion, adequate control of the infection is necessary to achieve union. Infection impacts on union by creating instability from bone as bone is reabsorbed by cytokines released during the acute inflammatory process.

With the exception of femoral and tibial nonunions, all other nonunions should be treated with a technique to generate compression across the nonunion site. Hypertrophic nonunions are typically the result of inadequate immobilization. Stable fixation without further disruption of the blood supply typically results in union in these cases. Tension band plating with interfragmentary screw fixation using indirect reduction[65] is an excellent approach to hypertrophic nonunions.

Atrophic nonunions are the result of an inadequate blood supply to the bone. Causes can include nonviable bone, bone stripped of its periosteum yielding insufficient potential bone-forming cells, and inadequate immobilization of the fracture.[59] These conditions can be precipitated by severe displacement of fracture fragments where the bone ends are not in continuity, high-energy injuries, after internal fixation where the vascular supply is damaged, or with infection. In these situations, it is necessary to resect nonviable bone down to bleeding bone, place the fragments in compression, and then add bone graft to provide osteoinductive factors. In the case of nonunions where the surrounding soft tissue has little vascularity (e.g., the distal tibia), soft tissue transfer may be necessary.

Weber and Cech's defect nonunions require bone grafting or bone transport to achieve union. This type of nonunion can be found in patients having multiple prior procedures, prior infection, or extensive boney injury.[59] Failed internal fixation can also cause significant defects requiring grafting. Bone grafting should be supplemented by decortication, petaling, or shingling of the bone **(Fig. 5–21A,B).** Wave plate fixation[66,67] employs a plate contoured so that it stands away from the bone at the site of the nonunion **(Fig. 5–22)** so as to minimally interfere with vascular access or egress. Theoretically, this allows for more rapid and predictable incorporation of even large bone grafts in complex femoral[66] and humeral nonunions.[23]

Transfer of vascularized fibular autograph offers advantages because it creates immediate and lasting structural support.[68] This is in contrast to cancellous bone graft that is replaced by creeping substitution and weakens before union can be achieved. The disadvantage of vascularized fibular grafting is that it is time consuming and technically difficult. Distraction osteogenesis allows

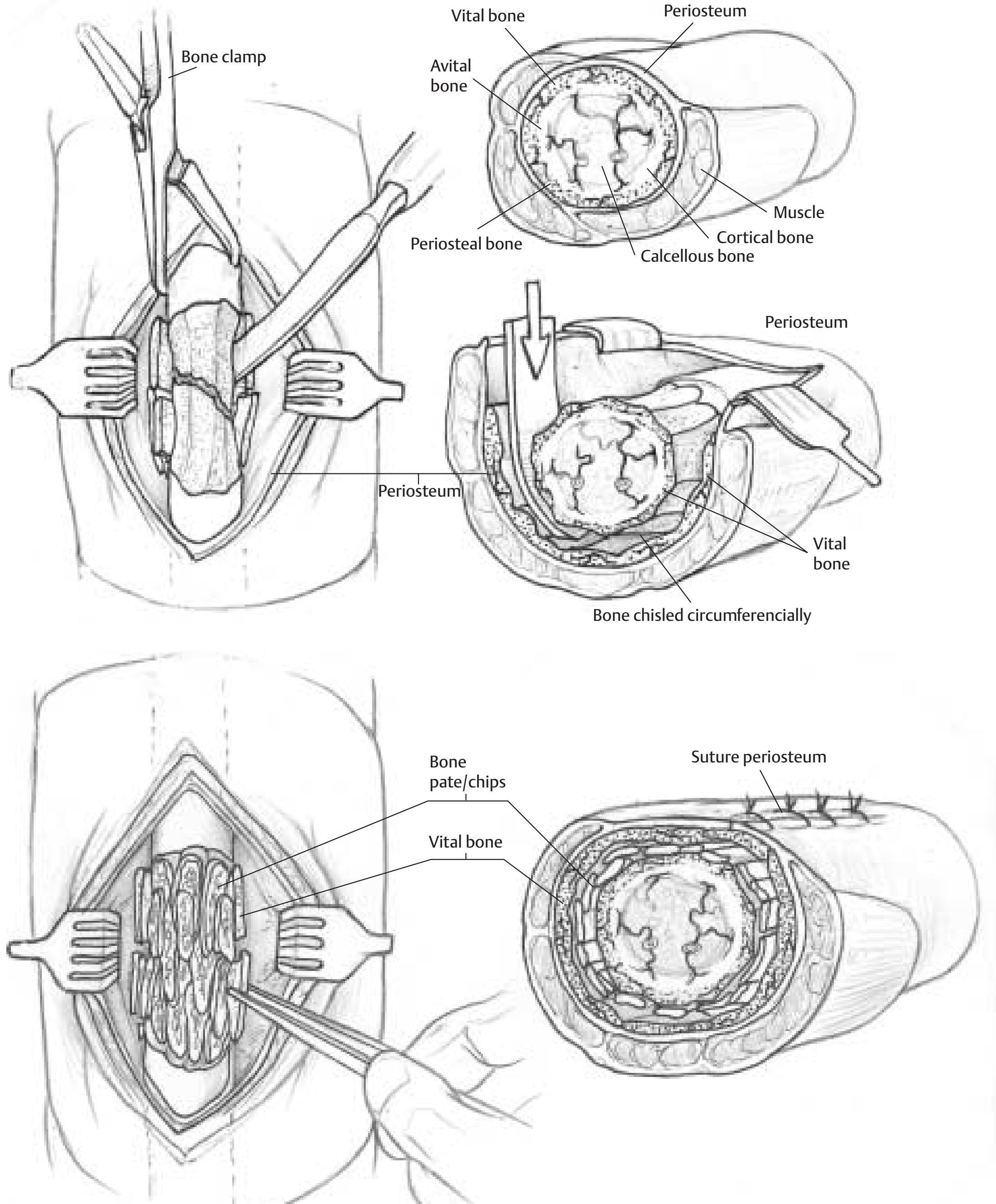


Figure 5–21 **(A)** Shingling the bone with an osteotome to expose vital bone. **(B)** Placing bone chips around the vital bone to obtain union.

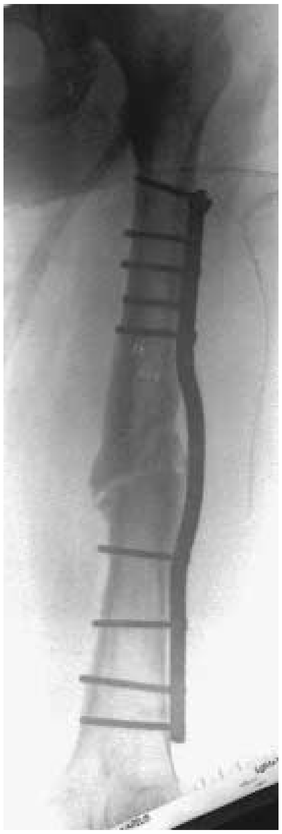


Figure 5–22 A "wave" plate applied to the diaphysis of the femur.

transportation of bone into the defect. The soft tissues are lengthened simultaneously, thereby limiting the necessity for soft tissue transfer. The drawbacks of this approach are that it is time and resource intensive and has a high complication rate.[69]

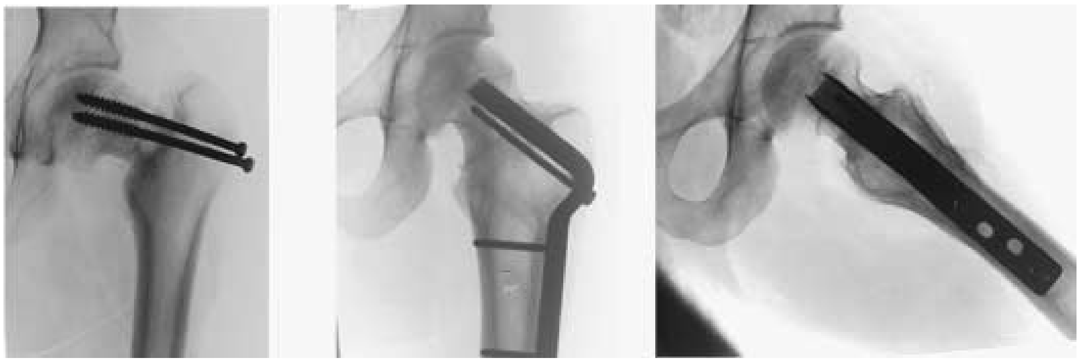
Electrical or ultrasound bone stimulators have been recommended for the treatment of well-vascularized nonunions.[70,71] The disadvantage of this approach is the inability to address deformity and the associated requirement of prolonged immobilization of the limb with the attendant complications of atrophy and contracture.

Femoral and tibial diaphyseal nonunions can be treated with an intramedullary rod. In such cases the medullary canal is accessed via the usual entry portals and reamed to a large size, permitting more secure fixation. The act of reaming causes a periosteal vascular reaction that stimulates bone formation.[72] Reaming also allows the deposition of bone at the nonunion site without stripping the nonunion site. In the instance where an intramedullary rod is fractured in situ, exposure of the nonunion site for extraction of the rod and debridement of devascularized tissues may be necessary. In this setting, plate fixation may be less traumatic than placement of another intramedullary rod.

Intertrochanteric Osteotomy for Femoral Neck Nonunion

Intertrochanteric osteotomy, as described by Pauwels, is a reliable and consistent method for treatment of nonunions of the femoral neck.[2] Preoperative plain radiographs of the hip in internal and external rotation, as well as a lateral view, are required for preoperative planning. The osteotomy planning described here is adapted from Müller.[13] The first step is to establish the inclination of the femoral neck nonunion. Using an AP film of the hip, the surgeon can draw a perpendicular line to the femoral shaft above the hip joint. A second line is drawn parallel to the femoral neck nonunion. The angle created by the intersection of these two lines is the angle of the femoral neck nonunion. The size or degree of closing wedge resected from the intertrochanteric area is the difference between the angle of nonunion and 25 degrees, which is the ideal angle for maximal joint reaction force across the nonunion.

The patient is placed in the supine position. The author's preferred approach is a direct lateral approach with the variation of taking down the vastus lateralis proximally off the trochanteric ridge in a horizontal T so [DE13]
that the vastus fascia may be closed over the implant. A 95 degree angled blade plate or the adult osteotomy plate (Synthes USA, Paoli, Pennsylvania) is the preferred im- [DE14]
plant in these cases. Initially, Kirschner wires are placed to mimic the osteotomy cut planned. Next, we prepare the proximal femur for the seating chisel by identifying the appropriate starting hole and then using the triple drill guide in the angled blade plate set to establish a channel for the blade. The author finds it helpful to insert three 4.5 mm drill bits in the guide and then check radiographs in both AP and lateral views with the three drill bits placed at 2 to 3 cm beyond the opening cortex. Radiographically, this will give an indication of the ultimate position of the blade. Once the seating chisel is placed across the nonunion and satisfactorily positioned on AP and lateral radiographs, the chisel is backed out and loosened prior to making the osteotomy cuts. When the osteotomy cuts are made and the wedge resected, the blade plate itself is seated. Please note that the blade should be seated with room to place the resected wedge between the blade and proximal fragment. This will lateralize the femur so as to avoid inadvertent valgus alignment at the knee. Once the blade is fixed to the proximal fragment, the shaft is abducted until it meets the plate. One will note that the shaft has migrated proximally and that a mismatch has been created. Insertion of the distal screw of the plate fixes the shaft to the plate. Insertion of the most proximal screw will draw the shaft to the blade. As the screw is advanced, the oblique surface of the shaft



A–C

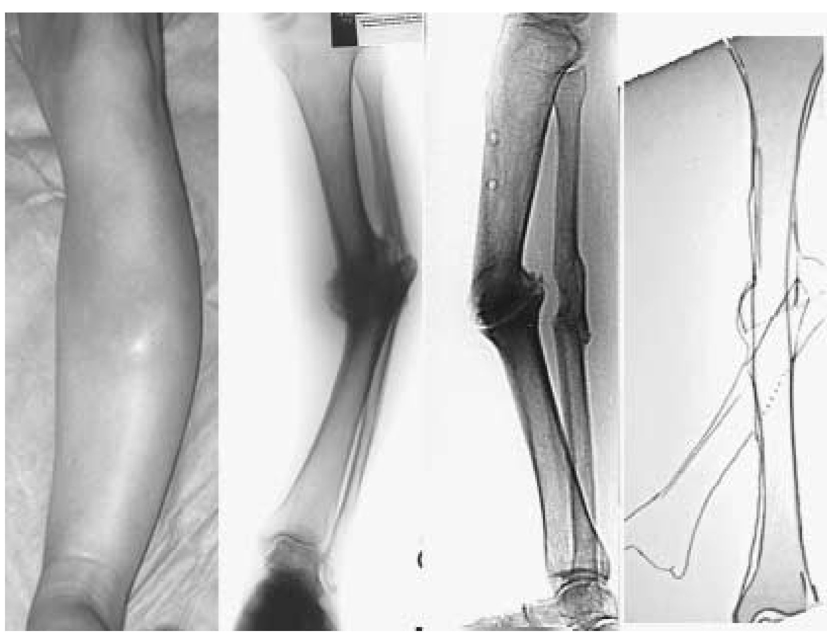
Figure 5–23 **(A)** Femoral neck nonunion following screw fixation. **(B,C)** Postoperative radiographs with 3 year follow-up using a blade plate to treat a femoral neck nonunion.

[DE39]

contacts the proximal fragment with increasing compression. This increases the stability and stiffness of the construct. Due to the force generated by this technique, one must assure that entrance for the osteotomy chisel is at least 1.5 to 2 cm away from the osteotomy site, or cut-out will occur **(Fig. 5–7). Fig. 5–23A–C** demonstrates a femoral neck nonunion and the 3 year follow-up results following an intertrochanteric osteotomy.

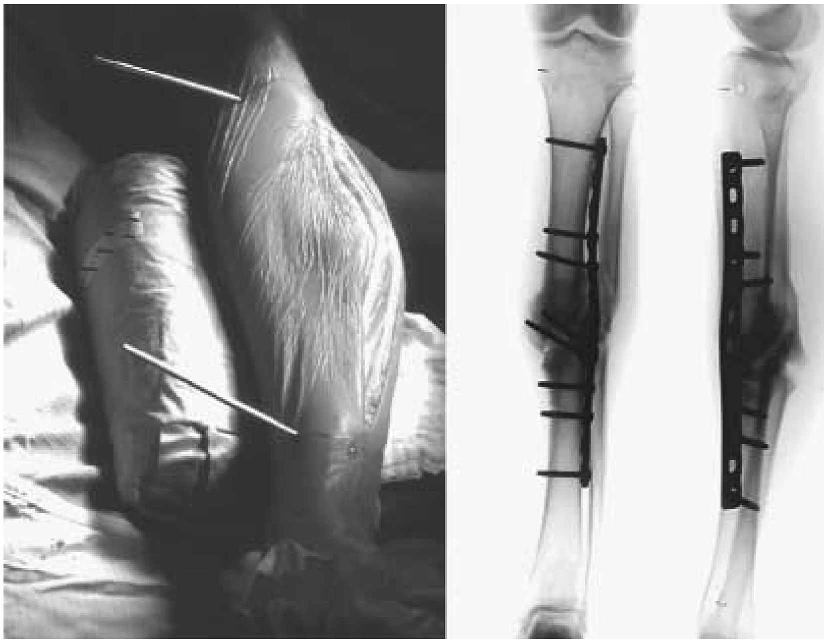
Hypertrophic Tibial Shaft Nonunion

Hypertrophic nonunion treatment has as its goal to increase the stiffness and stability of the nonunion, preferably in compression. An anterior approach is performed with careful dissection around the nonunion site. My initial approach relies on determining the true plane of the nonunion. This is done by evaluating the radiographs preoperatively or by using fluoroscopy intraoperatively. Once the plane is established, the approach is planned so as to place the plate on the tension side of the deformity. Dissection is performed in an extraperiosteal fashion. Homan retractors are placed around the nonunion. An osteotome is then driven across the nonunion to assure mobility. Great effort is made to minimize disturbance to the blood supply. Once the alignment is corrected, a lag screw is placed across the nonunion site and a plate is placed orthogonal to it. In serendipitous circumstances, the plate is applied and the lag is placed through the plate. **Figs. 5–24A–D and 5–25A–C** document



A–D

Figure 5–24 **(A)** A clinical photo showing deformity of the leg as a result of the nonunion. **(B)** Anteroposterior radiograph of the nonunion. **(C)** Lateral radiograph of the nonunion. **(D)** Preoperative plan with tracing of the deformity superimposed on a tracing of the contralateral leg.



A–C

Figure 5–25 **(A)** Pin placement for using the large femoral distractor. **(B,C)** Postoperative radiographs following reduction and compression plating of the nonunion.

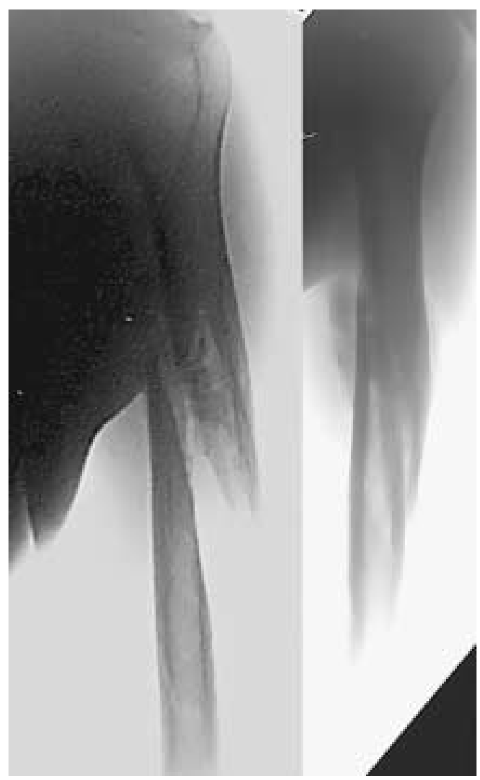
[DE40]

the case of a 33-year-old woman with a hypertrophic nonunion of 13 years duration.

Humeral Shaft Atrophic Nonunion

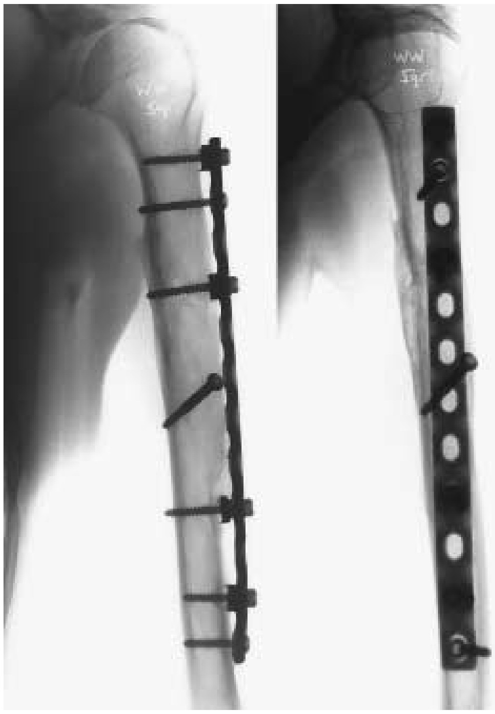
Plate fixation has a higher success rate than intramedullary nailing for nonunions of the humerus.[73] This likely reflects the bony anatomy of the distal humerus. The medullary canal of the distal humerus tapers distally and curves anteriorly, inviting reaming for larger nail placement. However, the cortical nature of the distal humerus causes it to undergo heat necrosis with reaming. **Figs. 5–26A,B and 5–27A,B** demonstrate a nonunion treated by compression plate osteosynthesis.

The coracoid process and deltoid tubercle are palpated and an anterolateral surgical approach is used for this nonunion. Distal extension is continued anterolaterally at the edge of the biceps brachii. Proximally the interval is between the pectoralis major and the deltoid. In the distal portion of the wound the biceps is mobilized medially and the underlying brachii muscle is split. An extraperiosteal approach is used for deep tissue dissection. The dissection is carried proximally and distally enough to allow for plate placement. Once the nonunion is encountered, the periosteum is taken down around the nonunion with a sharp osteotome by flaking off pieces of cortex with it in a process called shingling. Often, the periosteum is absent and the bone ends are covered with fibrous tissue. The bone ends should be exposed and debrided until vascular bone is en-



A B

Figure 5–26 **(A)** Anteroposterior and **(B)** lateral radiographs demonstrating a nonunion of the diaphysis of the humerus.



A B

Figure 5–27 **(A)** Anteroposterior and **(B)** lateral radiographs following compression with a lag screw and placement of a neutralization plate with Schuli washers (Synthes, Paoli, Pennsylvania) to improve fixation and minimize plate disruption of blood flow.

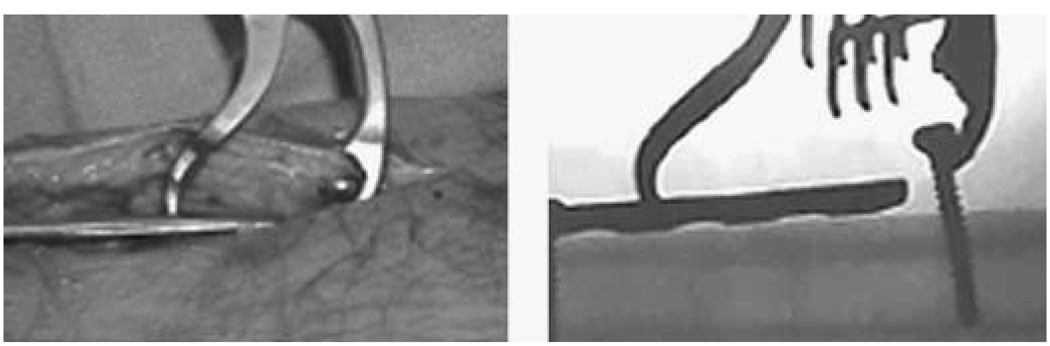
countered as indicated by the appearance of red specks that look like the spice paprika. If possible, shape the bone so it is stable when the bone ends are opposed. Insert bone graft at the nonunion site and around the surrounding tissues. A plate, usually 10 or 12 holes in length, is applied in compression across the nonunion site. Obtaining adequate compression often requires placing a screw outside the plate that is fixed on one side, and use of a Verbrugge clamp **(Fig. 5–28A,B).** Six to eight cortices of fixation are necessary on each side of the nonunion to resist the torsional forces created by the forearm.

Clavicle Nonunion

Clavicle nonunions treated by plate fixation require a transverse incision parallel to the clavicle. Sharp dissection is continued utilizing full-thickness flaps down to the level of the periosteum. An extraperiosteal approach is maintained except at the fracture site. The lateral end of the medial fragment is identified and the bone end is exposed. The medial end of the lateral fragment is approached by carefully dissecting through the zone of nonunion. Once the medial end of the lateral fragment is identified, a small, blunted Homan retractor is slipped over the edge of the fragment and levered against the lateral end of the medial fragment to bring them out to length and into opposition. On occasion, it may be necessary to square off the edges to create stability during this process or in the final reduction. Cancellous autograft is then placed below the nonunion in the defect of soft tissue created by the reduction of the clavicle. An eight- to 10-hole reconstruction plate is placed superiorly and applied in compression. The plate must be twisted to accommodate the change in the anatomy as the superior border of the clavicle extends medial to lateral **(Fig. 5–29A,B)**. Biplanar plate fixation is usually not necessary. Careful soft tissue closure is performed to maximize plate coverage with the full-thickness flaps. If the surgeon is suspicious that there is significant shortening of the clavicle, films of the contralateral clavicle should be taken for comparison and, if necessary, a tricortical iliac crest graft placed to reestablish the normal length.

Rehabilitation from Nonunion Surgery

The rehabilitation of a patient following surgical treatment of a nonunion varies depending on the location of the nonunion, as well as the treatment employed. In gen-



A B

Figure 5–28 **(A)** Clinical photograph and **(B)** radiograph demonstrating the use of the Verbrugge clamp to obtain compression across the nonunion site.

A

B

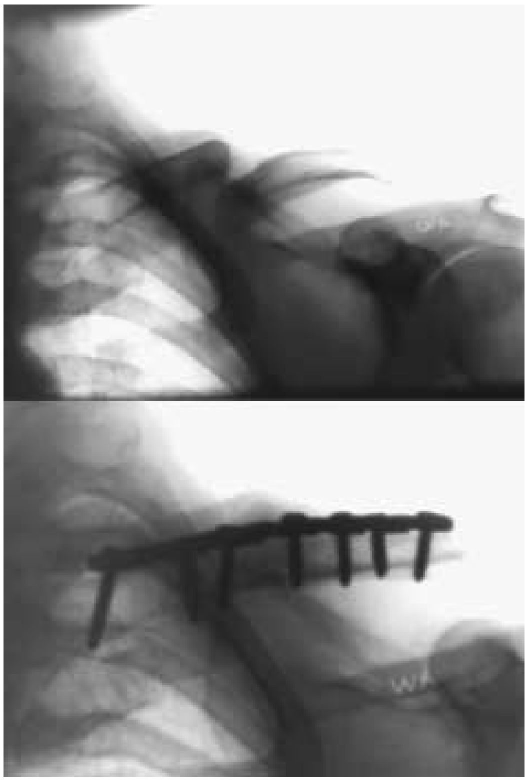


Figure 5–29 (A) Atrophic nonunion of the clavicle 10 months following fracture. **(B)** Healed nonunion 8 months following open reduction and internal fixation of the nonunion.

eral, active range of motion is encouraged immediately postoperatively. Any strength training is deferred until cortical healing is seen on one view during clinical follow-up.

New Techniques for Malunions and Nonunions

Bone Grafts and Bone Graft Substitutes

The use of bone graft and bone graft substitutes to augment stability and achieve union is integral to the treatment of nonunions and malunions. Although autologous bone grafting is the gold standard to which all other grafts are compared, there are circumstances where the appropriate use of allograft and bone graft substitutes can spare the patient the potential risks and complications of obtaining autograft. Any algorithm for bone graft use hinges on an understanding of when and what type of graft is necessary. A detailed description of all of the options currently available is beyond the scope of this chapter, but we will discuss the general principles and choices.

The biochemical and cellular environment of bone defects in fresh fractures differs greatly from nonacute scenarios. In the treatment of nonacute fractures, the surgeon must re-create the biochemical and cellular environment of the fresh fracture to generate union. Bone graft can provide the mesenchymal cells found in the periosteum of live [DE16]
bone and the bone growth factors needed to generate them. Bone graft can also be used to improve structural stability in large or diaphyseal defects. Both these circumstances necessitate that the mechanical environment has been optimized by creating sound bony fixation.[74] Assuming that stability has been created, then the size and location of the defect as well as the biological environment must be considered.

Diaphyseal defects less than 6 cm in a stable mechanical environment need both the scaffolding for osteoconduction and the cellular and chemical components to generate healing. Therefore, cancellous autograft is the best option. Cancellous allograft with bone marrow aspirate may yield similar rates of union, but this has not been clearly demonstrated in human prospective clinical studies.

For diaphyseal defects greater than 6 cm, a cortical autograft or allograft may be needed to provide structural stability. Vascularized cortical autografts are advantageous over nonvascularized autografts or allografts because of their more rapid and complete incorporation, as well as their ability to hypertrophy.[74] However, Finkemeier[74] points out that cortical allografts are best utilized in areas of excellent blood supply, such as the metaphyseal locations, or around the femur with its heavy muscular coat. In bony areas with

Tips and Tricks

- Successful nonunion treatment requires that compression be generated across the fragments.
- In addition to eccentric screw placement, there are three ways of generating compression for nonunions: a Verbrugge clamp, the Articulating Tensioning Device (Synthes), and the femoral distractor (Synthes). The latter two are useful for generating compression and distraction. The color guide in the Articulating Tensioning Device yields the surgeon feedback about how much compression is being generated.
- We recommend the use of long plates to treat nonunions (80% of bone length).
- Whenever possible we use blade plate fixation or locked screws when working in the metaphyseal region.
- Lastly, we harvest bone graft using an acetabular reamer on the lateral cortex of the ilium. This is done through a vertical incision overlying the gluteal pillar just superior and posterior to the acetabulum. This will often generate 40 to 75 cc of graft easily **(Fig. 5–30).** [DE15]

[p2]

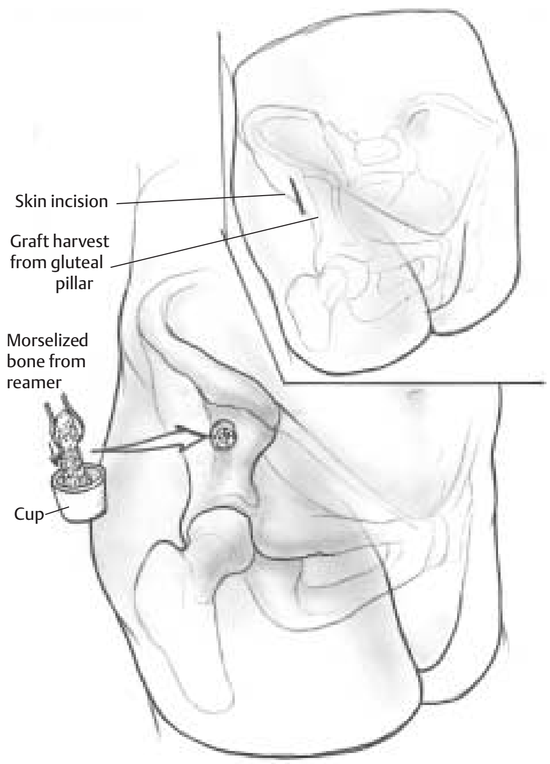


Figure 5–30 Harvest of bone graft with an acetabular reamer on the lateral cortex of the ilium.

poor or disrupted flow the surgeon should strongly consider using vascularized autografts to achieve union.

Metaphyseal defects associated with nonunion are best treated with cancellous autograft for its osteoinductive properties. Those metaphyseal defects from impaction or cysts with a good vascular supply can be adequately treated with bone-graft substitutes or corticocancellous allograft. Skeletal Repair System (SRS; Norian, Cupertino, California) stands out from other bone graft substitutes in
[DE17] that after 12 hours, this material hardens to form dahlite
[DE18] with a compressive strength of 55 Mpa; and, because of its crystalline structure, it can eventually be resorbed and replaced by the host. This creates immediate stability as opposed to cancellous allograft, which will weaken with time as it is absorbed by creeping substitution.

Fracture healing is a complex process utilizing local and systemic regulatory factors. Bench and clinical research has begun to evaluate if the addition of some of these factors [e.g., bone morphogenetic proteins (BMPs), transforming growth factor-β (TGF-β), platelet-derived growth factor (PDGF), insulin-like growth factor (IGF), and fibroblast growth factor (FGF)] will improve union or can substitute for autograft. At present BMP 7 has been shown to yield results approaching autograft. The Food and Drug Administration (FDA) has concluded that, although the OP-1 implant (Howmedica Rutherford, New Jersey) was an effective treatment for nonunions, BMP was not as effective as autograft. The FDA product labeling states that the commercially available BMP OP-1 is indicated "for use as an alternative to autograft in recalcitrant long bone nonunions where use of autograft is unfeasible and alternative treatments have failed."

Outcomes of Nonunion Surgery

The outcomes for nonunions vary remarkably depending on patient comorbidities, available blood supply, index injury energy, and location of the nonunion. Ring et al[75] were able to unite a series of 14 recalcitrant nonunions (> 10 years) in an average of 4 months. These long bones included clavicle (two cases), humerus (five), femur (three), and tibial (four) nonunions. We believe that this demonstrates the excellent potential for long bones to heal with appropriate treatment.

Complications of Nonunion Surgery

Common complications[62,63,72,74] in nonunion surgery include persistent nonunion (0 to 20%), wound dehiscence (0 to 15%), and infection (0 to 3%).The harvesting of autologous bone is associated with a rate of major complications of 8.6% and a rate of minor complications of 20.6%.[75]

Examination Pearls for Nonunions

- Delayed union occurs in 600,000 patients in the United States per year.
- Nonunion occurs in 100,000 fractures in the United States per year.
- Risk factors for nonunion include initial displacement, smoking, segmental bone loss, high energy mechanism of injury, degree of soft tissue injury, diabetes, excessive alcohol consumption, vasculopathy, and certain medications.
- Elephant/horse-hoof nonunions are associated with unstable fixation.
- Oligotrophic nonunion is associated with distraction.
- Atrophic nonunions are associated with tissue interposition.
- Comminuted avascular nonunions are associated with sequestrum interposition.
- Two-part surgical neck fractures are the most common proximal humeral nonunion.
- Cortical continuity is the single best predictor of fracture torsional strength and callus size and area to be the least important indicator of union.
- The complication rate from the harvest of autologous bone is 8.6% major complications and 20.6% minor complications.

On the DVDs

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