Delayed Union and Nonunion of Fractures

Each year, approximately 2 million long bone fractures are treated in the United States. Of these, Heppenstall estimated that 5% result in nonunions, and even more result in delayed unions.

More aggressive treatment of acute fractures has decreased the incidences of delayed union and nonunion; however, paradoxically, it has increased the incidences in some types of fractures, especially tibial fractures.

Delayed unions and nonunions remain a challenge for treating physicians.

DELAYED UNION

Union is considered delayed when healing has not advanced at the average rate for the location and type of fracture (usually 3 to 6 months).

Delayed union often can be treated successfully by an efficient cast that allows as much function as possible.

in the lower extremity, weight bearing in a snug walking cast often hastens union.

This conservative treatment can be continued for 4 to 12 additional weeks; if the fracture is still ununited, a decision must be made.

External ultrasound and electrical stimulation may be considered as nonoperative options if it seems that union will be delayed.

Open reduction to remove interposed tissue and to appose widely separated fragments is necessary when delayed union follows poor reduction.

NONUNION

A diagnosis of nonunion is unjustified, however, until clinical or radiographic evidence shows healing has ceased and that union is highly improbable.

In 1986, for purposes of testing bone-healing devices, a U.S. Food and Drug Administration panel defined nonunion as “established when a minimum of 9 months has elapsed since injury and the fracture shows no visible progressive signs of healing for 3 months.”

This criterion cannot be applied to every fracture, however.

A fracture of the shaft of a long bone should not be considered a nonunion until at least 6 months after the injury because often union requires more time, especially after some local complication, such as an infection.

In contrast, a fracture of the femoral neck sometimes can be defined as a nonunion after only 3 months.

Although the exact causes of delayed union and nonunion are unknown, systemic and local factors are thought to contribute to their development. Systemic factors include the patient's metabolic and nutritional status, and activity level general health.

The use of tobacco has been implicated in the development of nonunions.

Castillo et al. found that nicotine decreased vascularization at fracture sites and increased the chances for the development of osteomyelitis.

It has been shown that smokers have a decreased oxygen level in the cutaneous and subcutaneous tissues, which leads to poor wound healing.

Even though approximately 50% of smokers return to their habit, it is best for healing of bone and soft tissue if they can abstain while being treated for their injury.

Additionally, nonsteroidal antiinflammatory drugs (NSAIDs) have been found to decrease fracture healing in multiple animal studies.

Several studies have found delayed healing in human subjects who were taking NSAIDs, whereas many other studies refute the hypothesis that NSAIDs delay fracture healing.

We suggest that patients with a delayed union or nonunion abstain from using NSAIDs or steroids, if possible, during their fracture treatment.

Local factors were defined in a review at this clinic of 842 patients with nonunions of long bones.

Boyd, Lipinski, and Wiley found that nonunion was more common when the fractures were :

1-open

2-infected

3- segmental, with impaired blood supply, usually to the middle fragment;

4- comminuted by severe trauma;

5- insecurely fixed;

6- immobilized for an insufficient time;

7- treated by ill-advised open reduction;

8- distracted either by traction or by a plate and screws;

9- irradiated bone.

Heppenstall et al., in a study of 185 nonunions of the tibia, found that 92.4% had an initial delay in weight bearing of more than 6 weeks.

The severity of the injury, infection after primary closure of open injuries, an intact fibula, and fracture in the distal third of the tibia also were important factors in the development of nonunion in their series.

In our experience with more than 2500 femoral fractures and 800 tibial fractures treated with intramedullary nails, the rates of nonunion are low: approximately 1% after femoral fractures and 2% after tibial fractures.

The incidence of nonunion in the long bones varies with each bone and with methods of treating acute fractures.

More recently, with the frequent use of interlocking intramedullary nails for acute fracture management, nonunions after femoral fractures have become rare, and because of the frequency of severe open tibial fractures with concurrent soft-tissue injury, the tibia probably is the most frequent site of nonunion.

Considerations before Surgery

Status of Soft Tissues and Neurovascular Structures :

With current techniques of bone grafting and internal and external fixation, definitive surgery in many instances can be performed earlier, and rehabilitation of the joints and soft tissues can be started earlier.

Unyielding scar tissues, especially on the concave side of a deformity, may result in skin necrosis.

Deep scarring may prevent bone transport or grafting, and the need for skin grafting or flap coverage may influence treatment selection.

A significant vascular abnormality may limit treatment methods and fracture healing. Vascular abnormalities should be corrected.

Any nerve injuries should be carefully evaluated; if possible, the nerve should be repaired.

Occasionally, an extremity must be shortened to gain length in repairing a nerve defect.

To avoid nerve damage, the Ilizarov technique may be considered for gradual lengthening and treatment of the nonunion.

When the nerves are so damaged that sensation and muscle power in a lower extremity are permanently lost, amputation usually is the practical choice.

Status of Bones :

The status of the bones, especially at the nonunion, depends on the type and duration of the fracture and the method of any previous treatment.

Judet, Müller, Weber and Cech, and others classified nonunions into two types according to the viability of the ends of the fragments:

In the first type, the nonunion is hypervascular (hypertrophic) or viable and is capable of biological reaction.

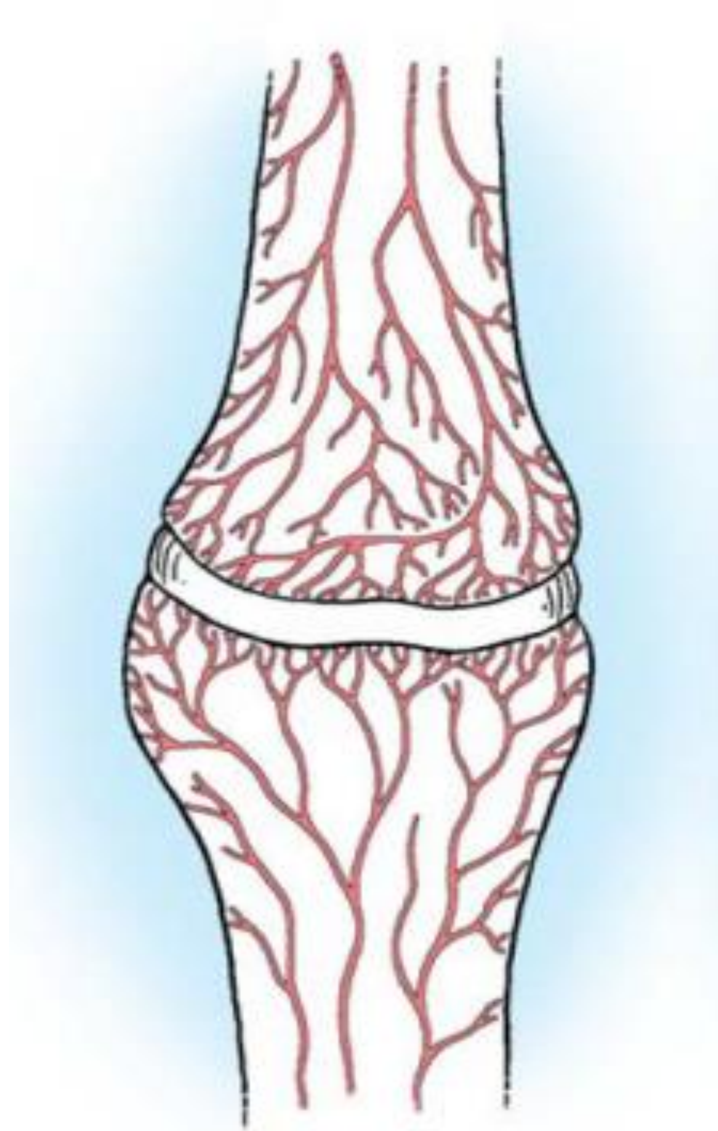
The second type of nonunions are classified as avascular (atrophic) or inert and are not capable of uniting without intervention.

Hypervascular nonunions have shown uptake of strontium-85, which indicates a rich blood supply in the ends of the fragments.
Hypervascular nonunions are subdivided as follows:

1. “Elephant foot” nonunions .

These are hypertrophic and rich in callus.

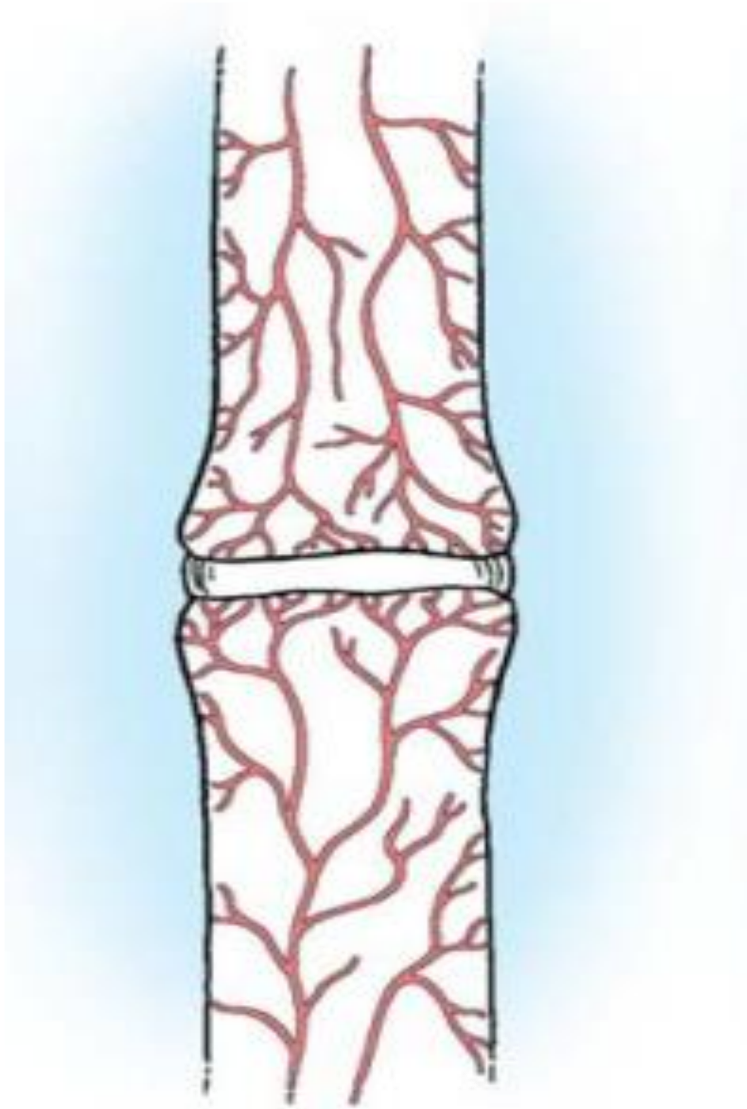
They result from insecure fixation, inadequate immobilization, or premature weight bearing in a reduced fracture with viable fragments.


A

2. “Horse hoof” nonunions

These are mildly hypertrophic and poor in callus.

They typically occur after a moderately unstable fixation with plate and screws. The ends of the fragments show some callus, insufficient for union, and possibly a little sclerosis.



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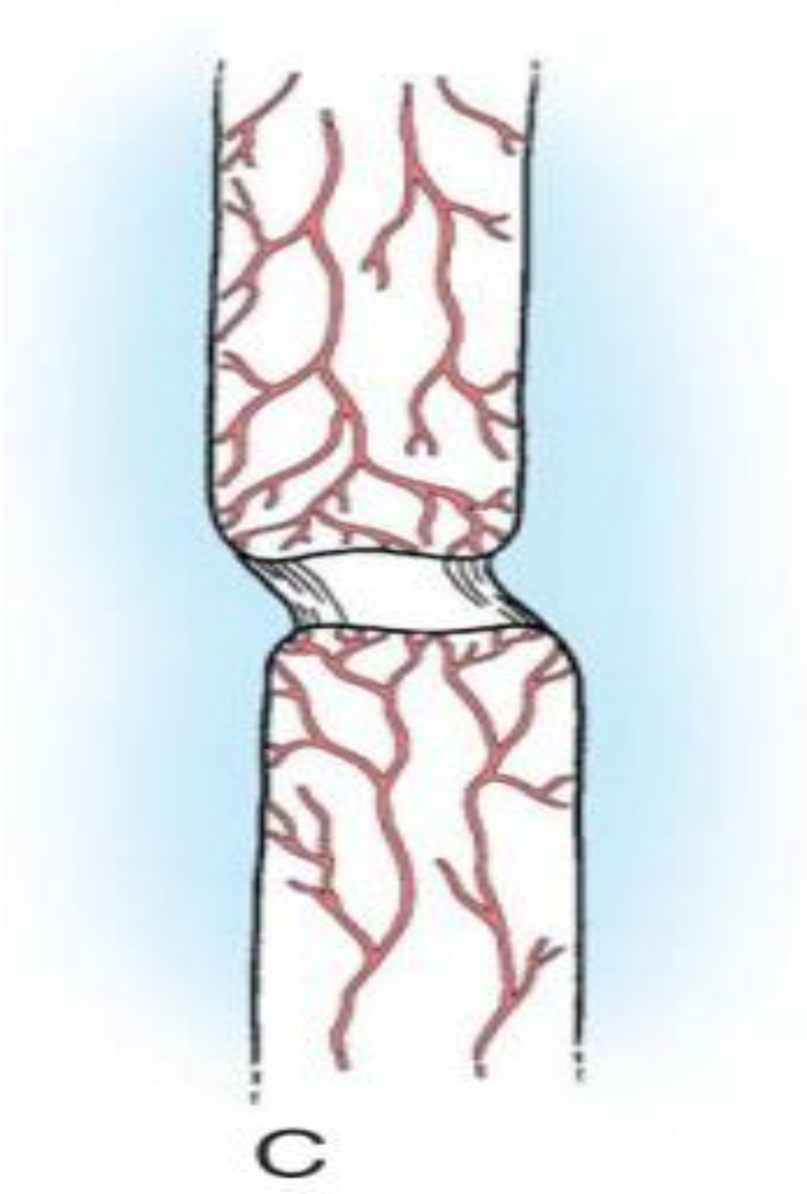
3. Oligotrophic nonunions

These are not hypertrophic, but are vascular, and callus is absent.

They typically occur after major displacement of a fracture, distraction of the fragments, or internal fixation without accurate apposition of the fragments.



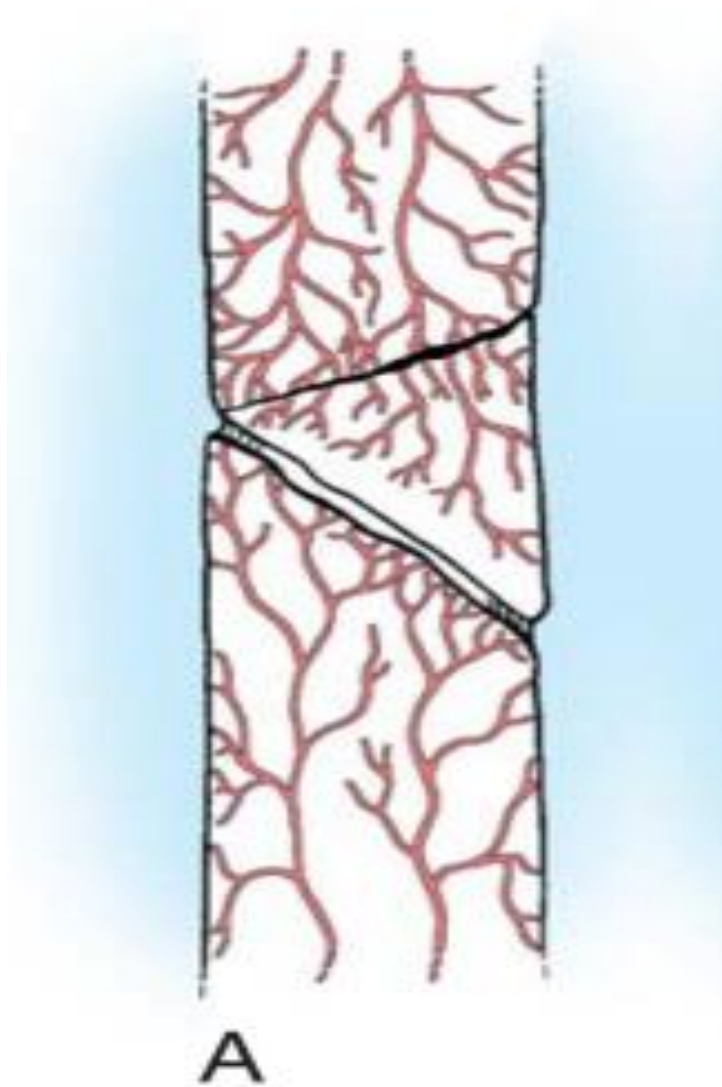
The second type of nonunion is avascular (atrophic) or inert and is incapable of biological reaction. Studies of strontium-85 uptake in these nonunions indicate a poor blood supply in the ends of the fragments.

Avascular nonunions are subdivided as follows:

1. Torsion wedge nonunions

These are characterized by the presence of an intermediate fragment in which the blood supply is decreased or absent.

The intermediate fragment has healed to one main fragment, but not to the other. These typically are seen in tibial fractures treated by plate and screws.

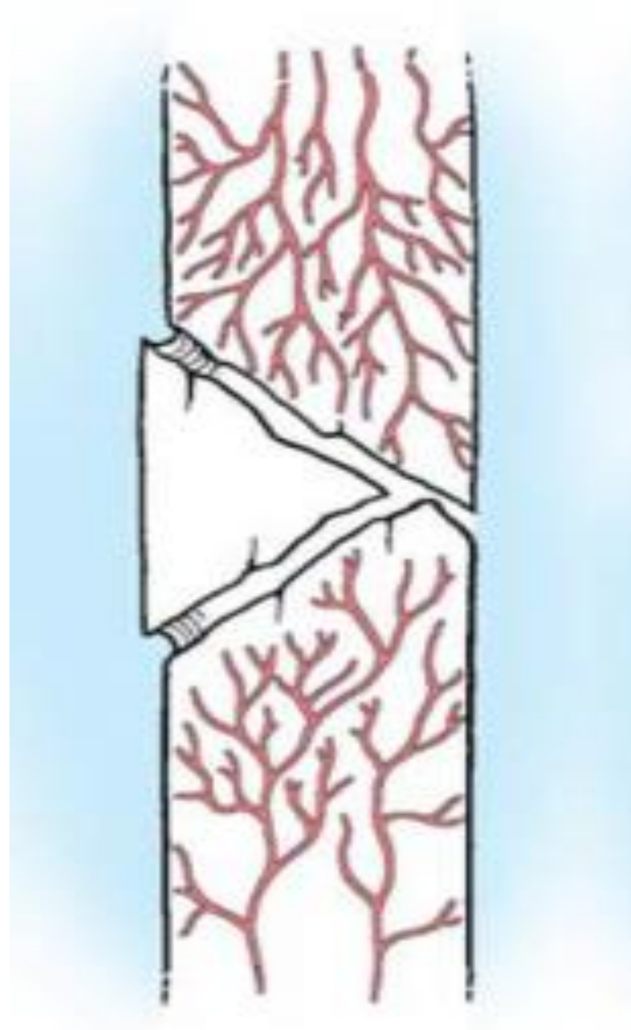


2. Comminuted nonunions

These are characterized by the presence of one or more intermediate fragments that are necrotic.

The radiographs show absence of any sign of callus formation.

Typically, these nonunions result from the breakage of any plate used in stabilizing the acute fracture.



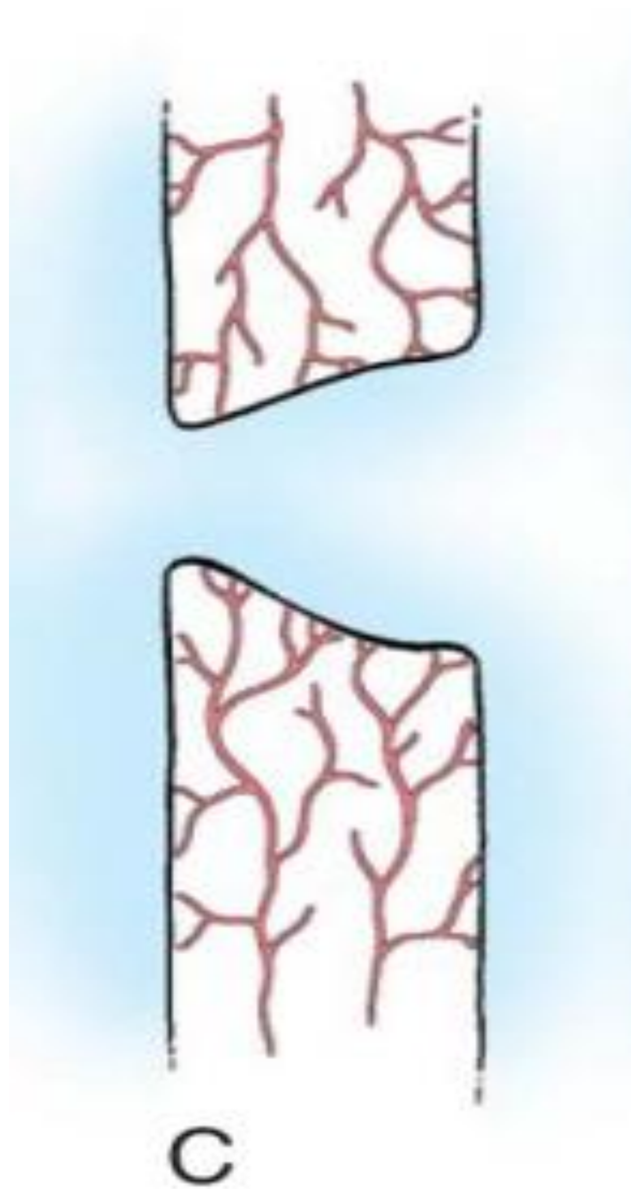
B

3. Defect nonunions

These are characterized by the loss of a fragment of the diaphysis of a bone. The ends of the fragments are viable, but union across the defect is impossible.

As time passes, the ends of the fragments become atrophic.

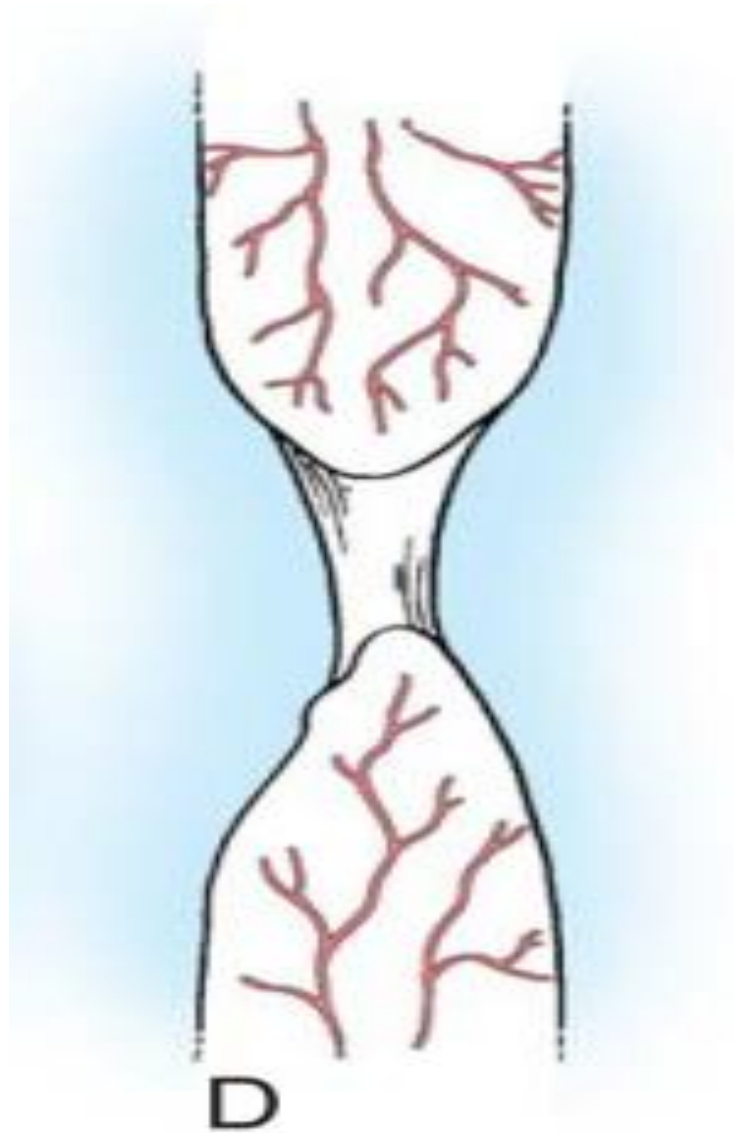
These nonunions occur after open fractures, sequestrectomy in osteomyelitis, and resection of tumors.



4. Atrophic nonunions

These usually are the final result when intermediate fragments are missing, and scar tissue that lacks osteogenic potential is left in their place.

The ends of the fragments have become osteoporotic and atrophic.



Paley et al. described a classification of nonunions of the tibia that can be applied to nonunions of other bones.

They divided nonunions, clinically and radiographically, into two major types:

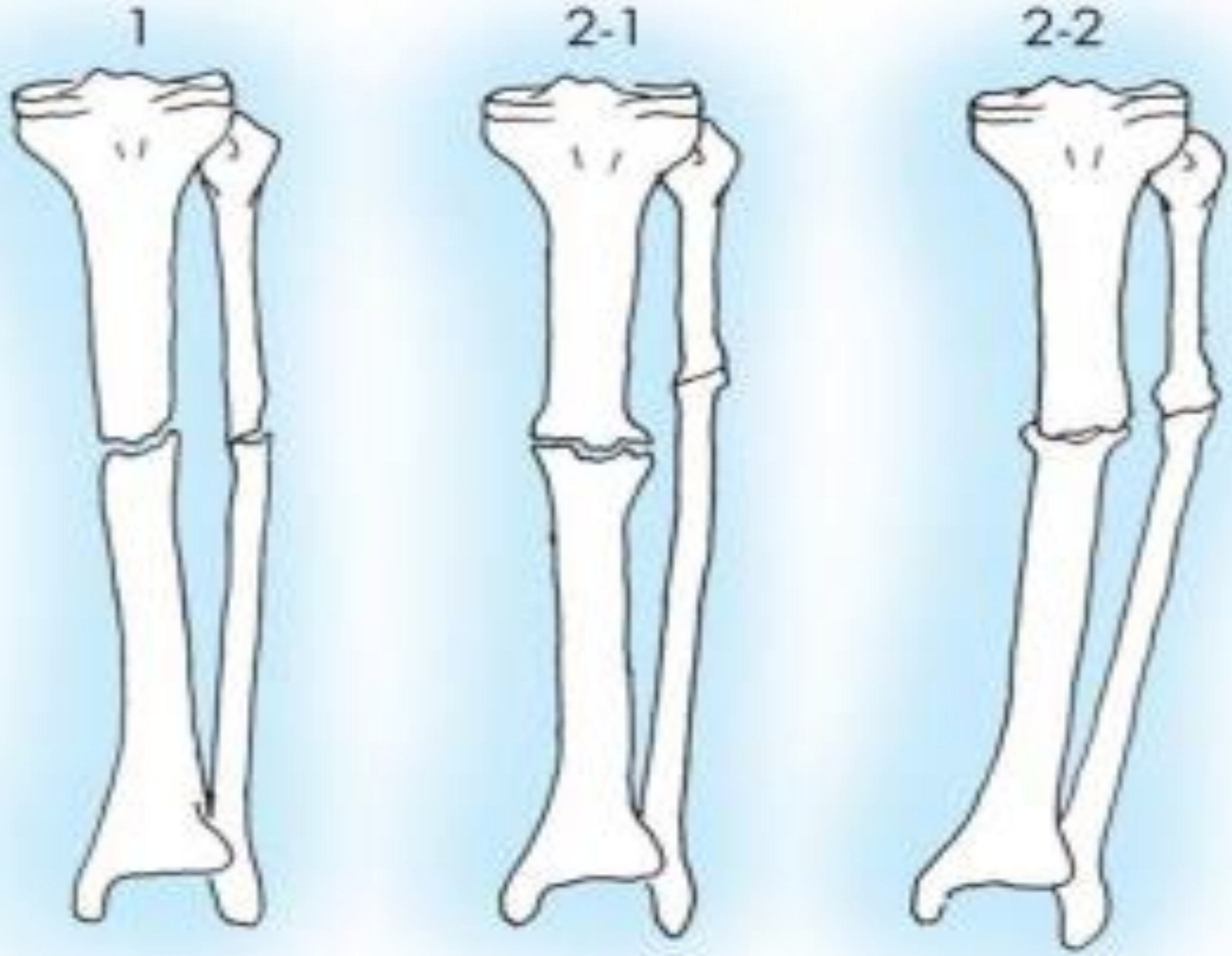
nonunions with bone loss of less than 1 cm (type A) and those with more bone loss (type B).

Type A nonunions are subdivided into nonunions with a mobile deformity (type A1) and those with a fixed deformity (type A2).

Type A2 is subdivided further into type A2-1, a stiff nonunion without deformity, and type A2-2, a stiff nonunion with a fixed deformity.

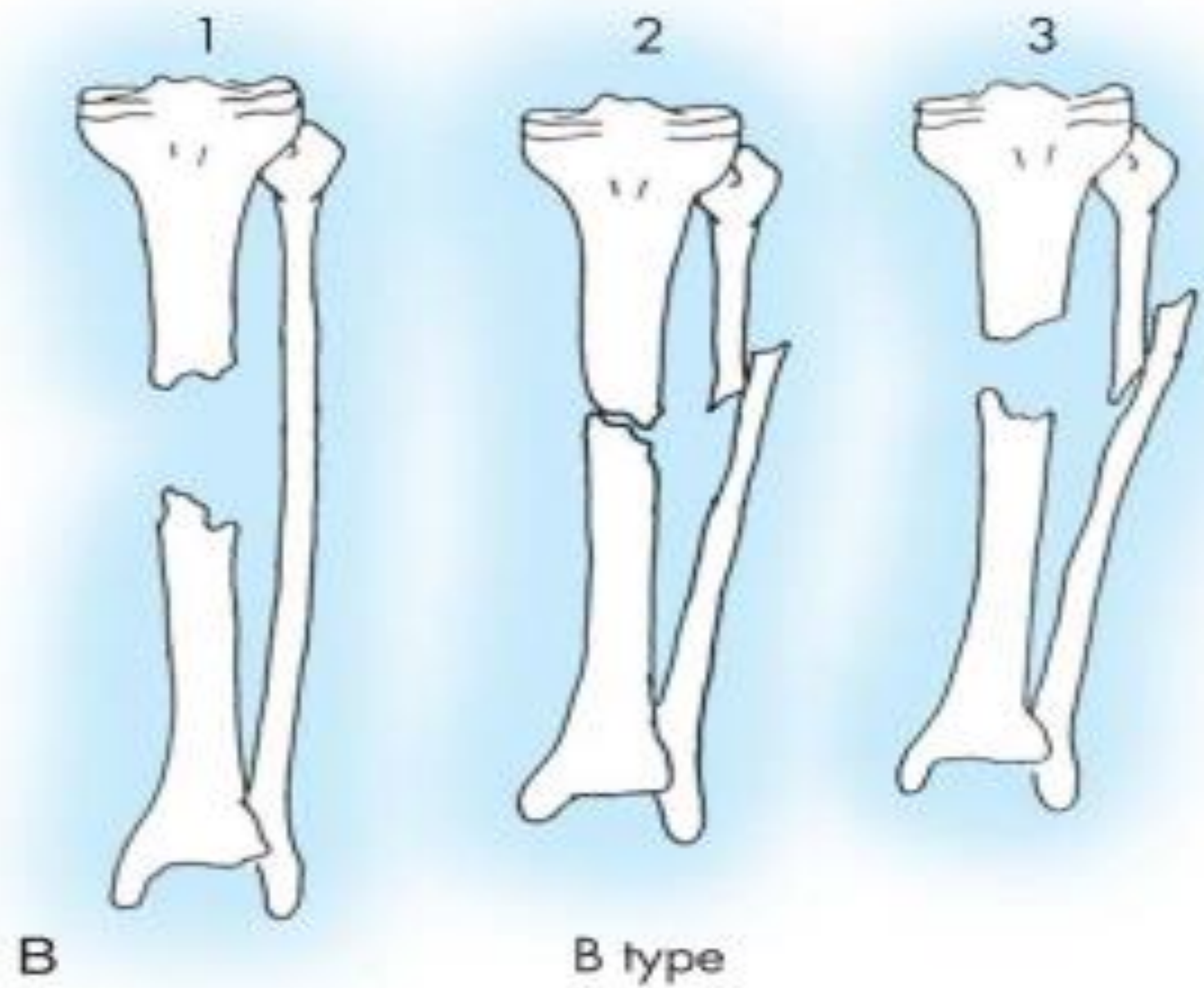
Type B nonunions are subdivided into nonunions with a bony defect (type B1), loss of bone length (type B2), or both (type B3).

Both of these classification systems can be modified further by the presence or absence of infection.



A

A type


1
2
3
B
B type

General Treatment of Nonunions

Orthopaedic surgeons can choose from numerous surgical and nonsurgical methods that vary greatly in their invasiveness and propensity for minor and catastrophic complications.

The treatment of nonunion has advanced with improvements in electrical and electromagnetic stimulation, ultrasound, and bone grafting.

The Ilizarov external fixator continues to be an effective and versatile method for treatment of difficult nonunions complicated by complex deformity, infection, and bone loss.

Improvements in internal fixation systems have provided sufficiently stable fixation to allow active and passive range of motion of adjacent joints, promoting complete functional recovery in addition to bony union.

Research also continues in the use of bone grafts, bone graft substitutes, bone morphogenetic protein (BMP), and new materials for the regeneration of bone .

Successful treatment of a nonunion rarely consists of only one method or surgical technique, and the surgeon must anticipate the next step that may be necessary.

Generally, the method chosen should allow for the potential use of as many other methods as possible.

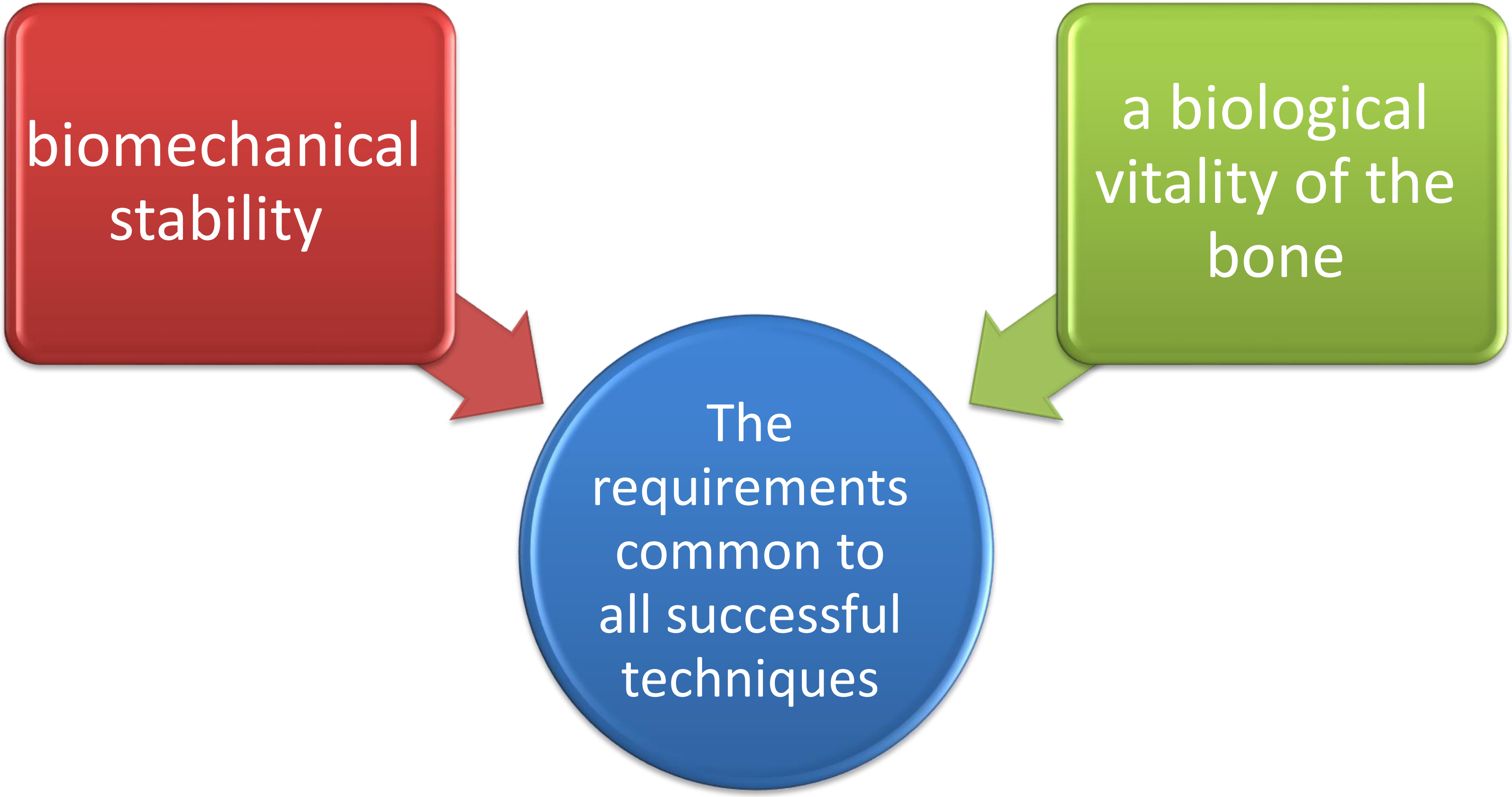
Operations for nonunions are relatively extensive and should be recommended only after nonunion has been shown clinically and radiographically, and when union is improbable or obviously impossible without a change in treatment.

The increasing severity of nonunions outlined in the classification systems of Judet and Judet; Müller, Weber, and Cech; and Paley et al. dictate more extensive surgical methods.

Hypertrophic (hypervascular) nonunions often can be treated by stable fixation of the fragments alone, whereas atrophic (avascular) nonunions require decortication and bone grafting for healing.

According to the classification of Paley et al., most type A nonunions can be treated with restoration of alignment, followed by compression.

Type B nonunions may require additional cortical osteotomy and either internal bone transport or overall lengthening to obtain the original bone length.


biomechanical stability
a biological vitality of the bone
The requirements common to all successful techniques

These can be obtained through good reduction, sufficient bone grafting, and firm stabilization of the fragments.

Reduction of Fragments :

When the fragments are in good position, but are separated by fibrous tissue, extensive dissection usually is undesirable.

Leaving the periosteum, callus, and fibrous tissue intact around the major fragments preserves their vascularity and stability. Using a bridging graft, the intervening fibrous tissue and callus ossify resulting in union of the fracture.

Displaced, and especially bayonet, nonunions of any long bone can be approximately reduced by gradual traction using a simple pin fixator before closed intramedullary nailing.

In cooperative patients, posttraumatic shortening usually can be corrected rapidly; we have been able to obtain lengthening of 1 cm per day in divided increments.

The external fixator is applied for a few days to restore length, the fixator is removed, and closed intramedullary nailing is performed.

We have had no problems with infections after a brief period of external fixation. Alternatively, an Ilizarov frame can be used to restore length, appose fragments, and stabilize the fragments until union.

Plating and bone grafting of displaced nonunions of most long bones require a more extensive operation.

Scar tissue around the nonunion must be excised so that the grafts can be covered by relatively normal tissue.

The fragments are mobilized, preserving their normal soft-tissue attachments as much as possible; their rounded ends are resected so that contact is maximal; their medullary canals are cleared of fibrous tissue to aid in medullary osteogenesis; and they are apposed as closely as possible.

Bone Grafting :

For many years, the most frequently used method of treatment of nonunions has been bone grafting.

Autogenous cancellous bone, although limited in quantity and associated with significant donor site morbidity, remains the “gold standard” in grafting material.

Its osteoconductive (matrix) and osteoinductive (protein) properties and its osteoprogenitor cells make it an ideal substance for nonstructural grafting.

Cancellous autogenous grafts are obtained from the proximal tibia, distal radius, and ilium.

Fresh or refrigerated allogenic bone for grafting can be used when the source of fresh autogenous bone is inadequate or inaccessible. Clinical and experimental data show, however, that the osteogenic properties of allogenic bone are inferior to the osteogenic properties of fresh autogenous bone.

If mixed with autogenous bone or host bone marrow, cancellous allograft can be used in nonstructural applications with excellent results.

For structural applications, autologous cortical grafts, except from the fibula, are now rarely used because of donor site morbidity.

Frozen or freeze-dried cortical allografts provide the greatest structural strength, but their osteogenic properties are limited.

Ceramics (hydroxyapatite, tricalcium phosphate, or some combination of the two) have osteoconductive properties and avoid problems with donor site morbidity, but are extremely brittle, and the results of their use at this institution have been disappointing.

Work in combining ceramics with bone morphogenetic protein or other osteoinductive protein is currently under way.

Particulate ceramic also can be mixed with bone marrow to add osteoprogenitor cells or with a limited volume of cancellous autograft to improve its osteoinductive capability.

Onlay Bone Graft :

Massive cortical grafts combine fixation and osteogenesis in treating nonunions of the long bones.

The onlay bone graft was used for nonunions of the shaft of any long bone, and the technique was similar for all; only the size of the graft and the number of screws were modified to suit the individual bones.

Phemister described a technique of onlay bone grafting for established nonunions in which the graft is placed subperiosteally across the fragments without mobilizing the fragments.

Besides being simple to do, its advantages were that the blood supply of the fragments and the normal impacting forces of the fracture were not disturbed.

Because union in congenital pseudarthrosis of the tibia is difficult to obtain, in 1941 Boyd devised an operation for this condition in which dual grafts are used.

Two cortical onlay grafts are placed opposite each other on the host bone across the nonunion and are fixed with the same set of screws;

they grip the fragments like a vise.

Any intervening space at the bone ends is filled with cancellous chips.

Dual grafts have been used to fix a nonunited fracture near a joint firmly with a short, osteoporotic fragment.

A

B

C

Dual grafts also have been used in elderly patients with old nonunions of the shafts of long bones when the cortex of the fragments is thin and osteoporotic.

The fragments are compressed between the grafts resulting in stable fixation of the fragments.

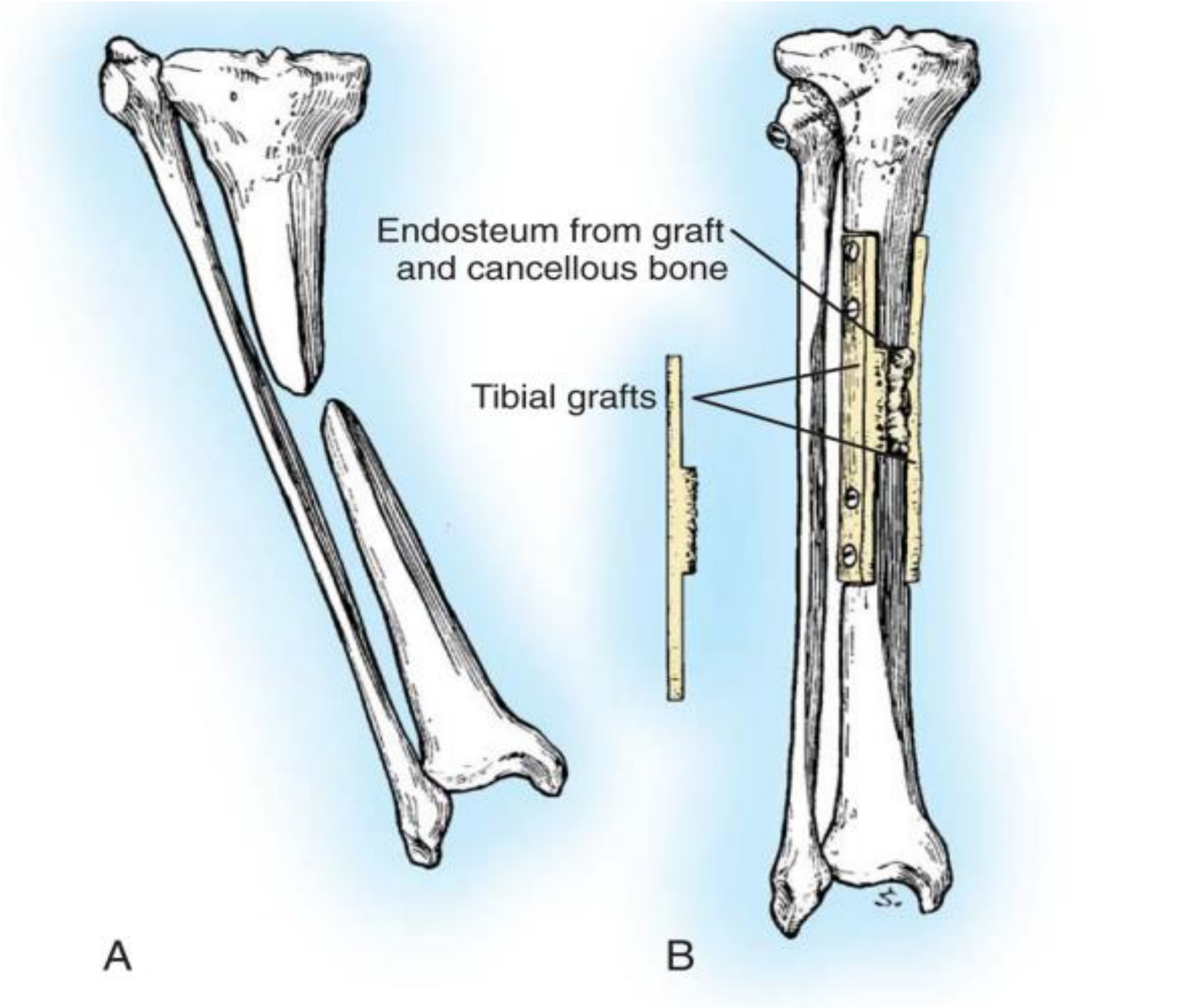


Fig. 56-5 Boyd dual onlay grafts. **A,** Before surgery. **B,** After application of grafts and fusion of proximal tibiofibular joint.

Cancellous Insert Grafts :

Nicoll described a technique of bridging gaps in long bones with solid blocks of cancellous bone and fixing the fragments with metal plates.

This procedure has been useful in patients with defects less than 2.5 cm long.

We have used ordinary plates, wedging the graft in position as described by Nicoll; however, we believe compression plates are usually preferable.

Massive Sliding Graft :

Gill devised a technique that uses a sliding graft about one half the circumference of the bone and 10 to 15 cm long .

Flanagan and Burem revised and improved this technique for nonunion of the tibia and femur; their procedure has been useful for bridging bone defects, but when a massive sliding graft fails, later grafting is difficult.

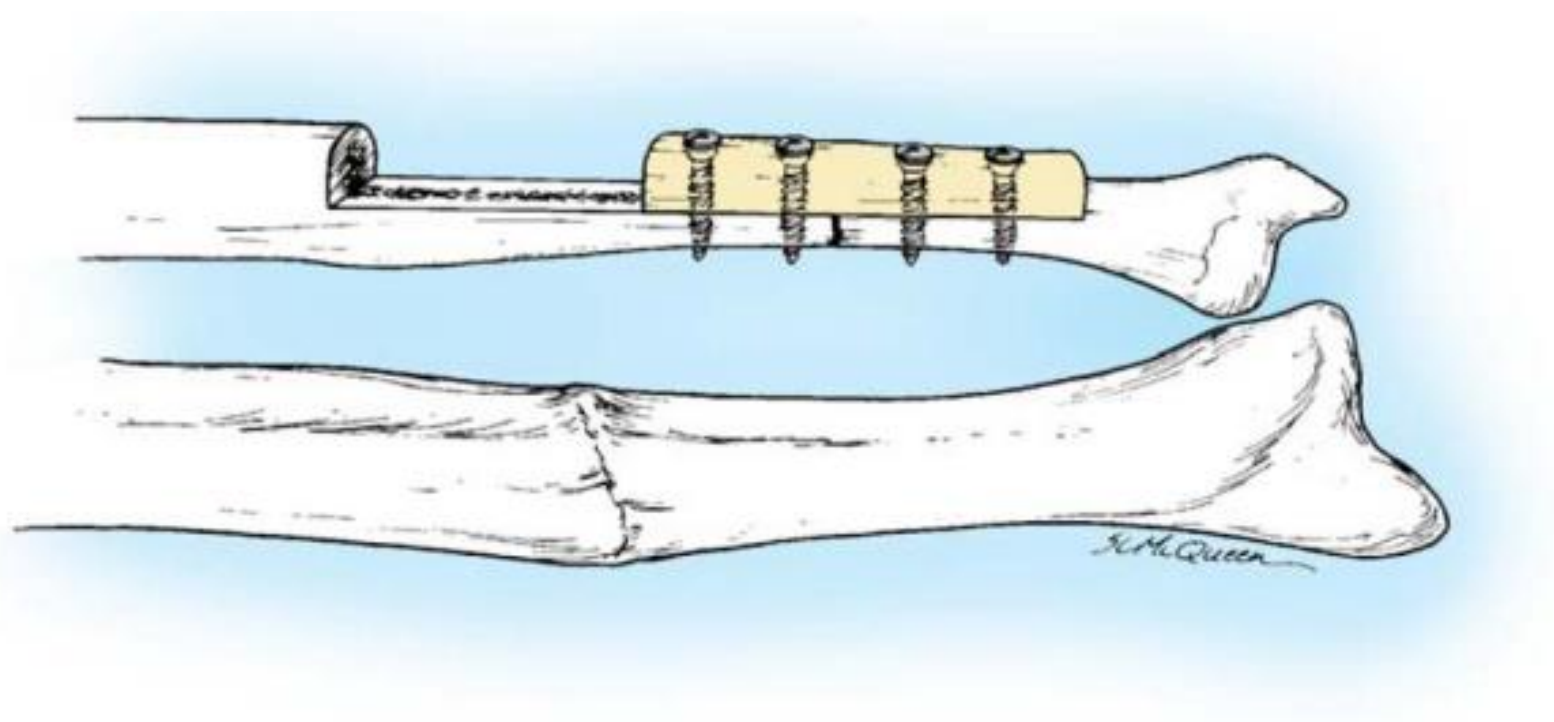


Fig. 56-6 Gill massive sliding graft (see text).

Whole Fibular Transplants :

whole fibular transplant may be useful for bridging defects in the radius or ulna.

Because it is tubular, it is stronger than a tibial graft with the same amount of cortical bone and need not be as large; the tissues of the forearm are not unduly crowded by it, and closing the wound is easier.


A
B
C

Elsewhere, fibular transplants are limited in usefulness by their size. They have been used to bridge defects in the humeral shaft, but in adults they do not hypertrophy enough and are likely to fracture, so we do not recommend them for this location.

They are useful in the distal humerus if a large amount of iliac bone is added to help reconstruct the expansion of the metaphysis.

They are too small to use for tibial defects in adults, but in children they usually hypertrophy enough to approach the size and strength of a normal tibia. The amount of hypertrophy is about proportional to the years of growth after grafting.

Vascularized Free Fibular Graft :

The use of vascularized free fibular grafts has been advocated by some for treatment of osteonecrosis of the femoral head.

Others have used it to treat defects associated with tumor resections.

Duffy et al. reported success using vascularized free fibular grafting for nonunions of shaft fractures of bones that had been irradiated to treat a malignancy .

A B

Fig. 56-8 Posteroanterior **(A)** and lateral **(B)** radiographs made 3 years after fibular transfer, showing excellent remodeling with fracture healing.

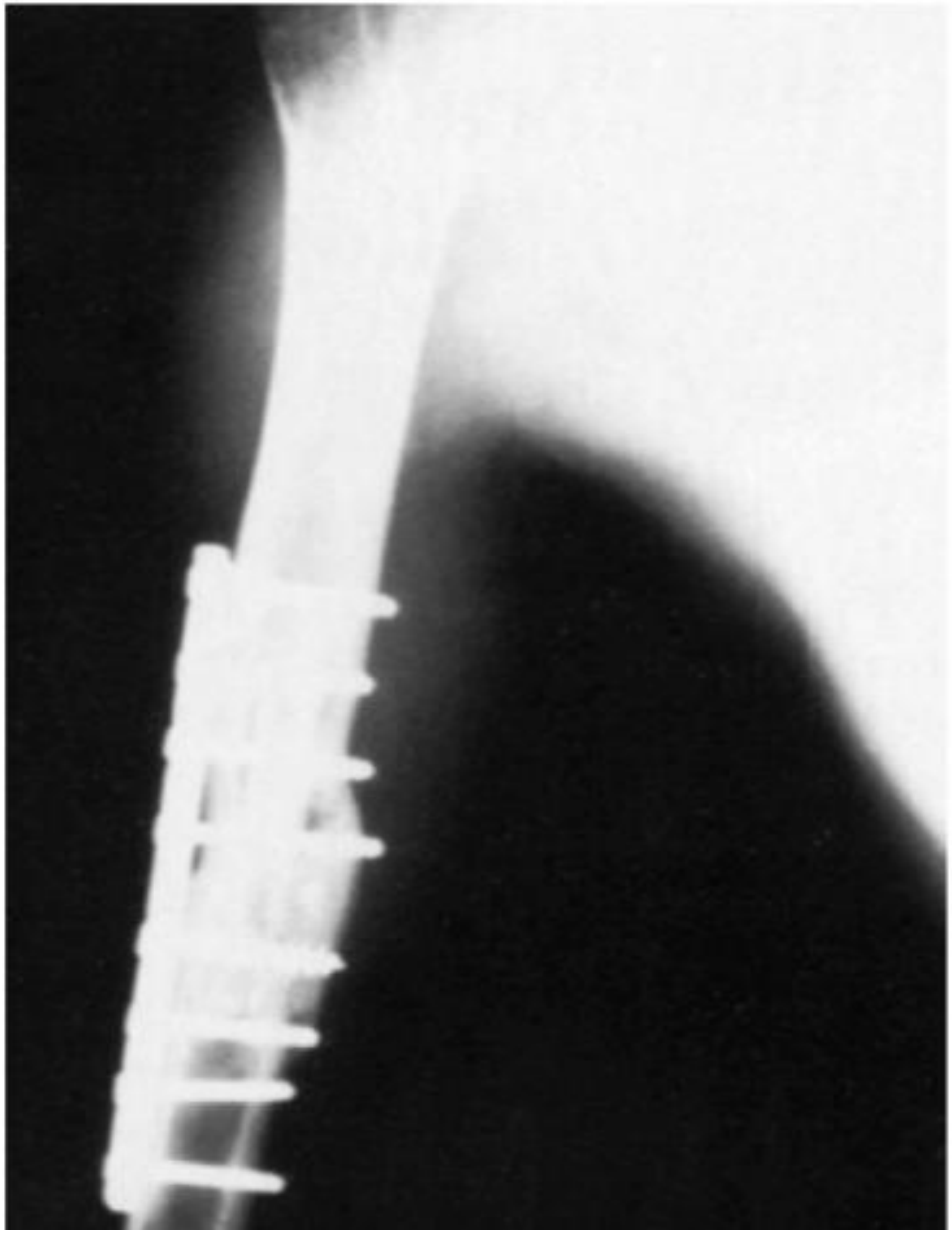
Duffy et al. reported success using vascularized free fibular grafting for nonunions of shaft fractures of bones that had been irradiated to treat a malignancy.

A B

Intramedullary Fibular Allografts:

Muramatsu et al. used vascular bone grafts successfully to treat 23 nonunions of the humerus. They used vascularized fibular grafts in 10 patients with large bone defects; femoral and scapular grafts were used in 13 patients with small or no bone defects.

Wright et al., Miller et al., and Crosby et al. reported a high percentage of good results in humeral nonunions using a technique of intramedullary grafting of the humerus with an allograft fibula and plating with a 4.5-mm compression plate.



Internal Fixation :

Internal fixation in the treatment of nonunions, as in acute fractures, should provide sufficient stability for fracture healing without excessive rigidity.

The choice of internal fixation depends on the type of nonunion, the condition of the soft tissues and bone, the size and position of the bone fragments, and the size of the bony defect.

Plate and screw fixation without bone grafting usually is adequate for hypertrophic nonunions if the bone is not osteoporotic and the fragments are large enough for firm screw fixation.

Intramedullary nailing, especially interlocked nailing, is useful in nonunions of long bones, such as the tibia, femur, and humerus.

Bone grafting usually is not required.

Early weight bearing is possible, and the late effects of stress shielding do not occur.

A relative contraindication for intramedullary nailing is current or prior infection; however, intramedullary nailing frequently is successful as a salvage operation even for infected nonunions.

External Fixation :

The Ilizarov external fixator is a labor-intensive, but very effective, tool in the treatment of nonunions.

It is especially useful in nonunions associated with defects, shortening, and deformities.

External fixation can be used for temporary or definitive stabilization.

One advantage of external fixation is that it is relatively noninvasive and does not disturb soft tissues surrounding the nonunion.

Other advantages are its ability to correct deformity and provide stable fixation.

Low-Intensity Ultrasound :

Some studies showed increases in cellular activity at osteotomy sites and increases in mineralization of the bone and metabolic activity.

It has been theorized that ultrasound stimulation promotes bone healing because it stimulates the genes involved in inflammation and bone regeneration.

Another theory suggests that ultrasound increases blood flow through dilation of capillaries and enhancement of angiogenesis, increasing the flow of nutrients to the fracture site. Yang et al. and Nolte et al. suggested that chondrocyte stimulation also is enhanced by ultrasound, which leads to an increase in enchondral bone formation.

The current protocol is to use the ultrasound equipment for 20 minutes once a day.

Rubin et al. noted in their 2001 review article that double-blind prospective clinical trials showed that healing times of fresh fractures can be reduced 40% with the use of ultrasound.

Electrical and Electromagnetic Stimulation :

External electrical stimulation is especially advantageous in infected nonunion management or when surgical intervention is contraindicated.

At least three electrical and electromagnetic methods are available for the treatment of nonunions.

These methods are either invasive, requiring the implantation of electrodes, or semiinvasive, requiring the percutaneous application of multiple electrodes.

Factors Complicating Nonunion

Nonunions may be complicated by infection, poor soft-tissue quality, short periarticular fragments, or significant deformity.