Delayed Union, Nonunion, and Malunion

Inadequate response to the fracture injury sometimes occurs, resulting in delayed union or nonunion. Most fractures, if left completely alone, would probably heal but with such malunion that function might be lost. The role of the clinician is to promote functional fracture healing. This chapter is designed to discuss the problems that sometimes occur with fracture treatment, the reasons for these problems, and some methods to overcome them.

Since the time of Hippocrates it has been advocated that immobilization of fractures to some degree or another is advantageous to their eventual union. The type and extent of immobility vary with the form of treatment and may play an important part in the overall result. It has been estimated that of the nearly 2 million fractures that occur yearly in humans, nearly 5% become nonunions. In the dog, no such statistics are available. Clinical practice, however, shows that delayed union and nonunion are not uncommon problems.

Delayed Union

In normal fractures, a certain amount of time is required before bone healing can be expected to occur. This normal time may vary according to age, species, breed, bone involved, level of the fracture, and associated soft tissue injury. Delayed union, by definition, is present when an adequate period of time has elapsed since the initial injury without achieving bone union, taking into account the above variables. (Fig. 38-1) The fact that a bone is delayed in its union does not mean that it will become a nonunion. Nonunion is one end result of a delayed union, and the differentiation between the two is sometimes difficult to make. Classically the stated reasons for delayed union are problems such as inadequate reduction, inadequate immobilization, distraction, loss of blood supply, and infection.

Inadequate reduction of a fracture, regardless of its cause, may be a prime reason for delayed union or nonunion. It usually leads to instability or poor immobilization. In addition, inadequate reduction may be caused by superimposition of soft tissues through the fracture area, which may delay healing. Soft tissue disruption usually leads to loss of vascular supply at the fracture site. In well-muscled areas, this vascular supply may return quickly. In other areas, such as the distal third of the radius and ulna in the dog, in which little muscle is present, this vascular supply may not return.

Inadequate immobilization may result in biomechanical as well as physiologic problems associated with fracture healing (Fig. 38-2). Perren, in a recent publication, states his hypothesis regarding the problems associated with relative motion at the fracture site. (30) His concern about the tolerance of repair tissue to motion, especially elongation (strain), fits into what we know about the normal course of classic fracture healing. The interfragmentary strain levels in the tissues of the healing fracture show that small gaps require very little motion to disrupt the tissue, whereas larger gaps may allow for larger amounts of motion before tissue disruption occurs. This theory accommodates the two types of fracture healing that occur so commonly in veterinary orthopaedics: cast immobilization with relative motion (classic fracture healing) and plate fixation with stable internal fixation (primary fracture healing). In classic fracture healing, the fracture ends are usually immobilized first with a hematoma, which until it is organized is capable of an infinite amount of elongation. As this hematoma organizes into a fibrin clot, granulation tissue appears in the area. Granulation tissue can elongate approximately 100% before rupture, thereby allowing early relative immobilization of these fracture fragment ends. As the granulation tissue is replaced by cartilage, which has an elongation property of approximately 10% to rupture, it can be seen that the fracture must become relatively more stable. Finally, bone, with its elongation of approximately 2% to rupture, fills in the fracture gap, completing bone union. Thus it can be seen that if there is a relatively large gap of many millimeters, this gap can change its dimension initially up to 100% without disrupting the early granulation tissue. If, in fact, the bone is held together with a more rigid plate, the gap would be considerably less. Hence, the motion tolerated at the site of the fracture to provide ingrowth of this granulation would be even more restricted. Therefore, with the small gaps allowed by rigid fixation, small amounts of motion have a much more significant (harmful) effect than the same amount of motion with large gaps. Since the physiology of fracture healing follows this course, which is related to the mechanics of the tissue involved, it is important when dealing with a delayed union or nonunion to ascertain which problems are involved to try to institute changes in the treatment. These changes can be very slight, such as in modification of casts or splints or immobilization of the patient, or they can be the extremes of changing the type of fracture treatment entirely. The fact that fracture healing is delayed and may eventually go on to union is often not sufficient reason to allow treatment to continue as was originally instituted. Many times it will be beneficial to the patient to change the form of treatment so that functional healing can occur more rapidly, thereby returning the animal to a functional life, while at the same time negating some of the problems of prolonged treatment.

FIG. 38-1 Mature canine radius and ulna 6 weeks after displaced fracture and application of plaster cast. (A) Final roentgenograms show external callus traversed by a zone of radiolucency, a typical picture of fibrocartilaginous delayed union. (B) Microangiogram of...
the radial fracture shown in A reveals the avascular zone corresponding to the zone of radiolucency. This represents a plate of fibrocartilage. (original magnification x 4) (C) Photomicrograph of histologic section from a similar area in another experiment shows the very active vascular invasion of the fibrocartilage and the replacement by new bone in the external callus (H & E, x 125). (A. B. Yasuda l: Fundamental aspects of fracture treatment. J Kyoto Med Soc 4:395, 1953; G. Rhinelander FW, Sarory RA: Microangiography in bone healing: Undisplaced closed fractures. J Bone Joint Surg 44A:273, 1962)

FIG. 38-2 Mature canine radius 6 weeks after osteotomy and fixation with a standard four-hole plate and screws. (A) Standard roentgenogram shows extrusion of the two proximal screws with elevation of the plate. The osteotomy site is radiolucent and is bordered by small mounds of external calluses in the cranial-caudal projection. (B) Microangiogram shows loosening and elevation of the plate on the left, with an excellent cortical blood supply, while the vessels in the osteotomy site are a congested mass. The cortex beneath the tight portion of the plate, on the right, contains a few small vessels coming from the medulla. (original magnification x 53) (C) Photomicrographic enlargement of the osteotomy site shows debris and fibrous tissue adjacent to the mass of disorganized blood vessels on the right. (H & E, x 52.5) (A, Rhinelander FW, Wilson JW: Blood supply to developing mature and healing bone. In Sumner-Smith (ed): Bone in Clinical Orthopaedics, Chap 2. Philadelphia, WB Saunders, 1982; B. C. Rhinelander FW: Circulation in bone. In Boume (ed) The Biochemistry and Physiology of Bone, 2nd ed, vol 2. chap 1. New York, Academic Press, 1972)

NONUNION

As stated above, the differentiation between delayed union and nonunion is sometimes difficult. Nonunion is defined as the cessation of all reparative processes of healing without bony union. Since all of the factors discussed under delayed union usually occur to a more severe degree in nonunion, the differentiation between delayed and nonunion is often based on radiographic criteria and time. In humans, failure to show any progressive change in the radiographic appearance for at least 3 months after the period of time during which normal fracture union would be thought to have occurred, is evidence of nonunion. (23) The changes in radiographic appearance may be slight, and therefore radiographs should be scrutinized monthly to see if, in fact, changes have occurred. Personal experiences with an experimental model of delayed union in the adult beagle radius have shown union occurring in all animals between 37 and 52 weeks. No unions occurred before 37 weeks, although radiographic appearance of nonunion was present as described below. Careful radiographic evaluation did show changes over a 3-month period, however. Thus, it is difficult to imagine at what point fracture healing may cease completely.

The clinical diagnosis of nonunion is usually based on the history and physical findings. The animal may have some pain, which is usually mild. The most common sign is nonuse of the extremity, which may also lead to muscle atrophy, joint stiffness, progressive angulation, and malalignment of the bone. Physical examination reveals motion at the fracture site. Sometimes this motion is difficult to appreciate, since the fracture may be in close proximity to the joint and the motion may be thought to be within the joint. Usually when there is a nonunion close to a joint, the joint motion is limited. Deep palpation over the fracture site may yield an expression of pain in the patient, but this is not a constant finding. Radiographically the diagnosis of nonunion is made by the following findings: a radiolucent line through the fracture site, sealing off of the medullary cavity with sclerosis at the edge of the fractured bone, and bony resorption or regional osteoporosis above and below the fracture site. The bone ends may be somewhat rounded, and a large hypertrophic callus may be present. This "elephant foot" appearance of the callus has been thought of as one of the hallmarks of nonunion. Rarely, an atrophic nonunion is seen without any callus at the fractured bone ends. Sometimes a large gap exists between the ends of the bones while the bones themselves may appear to have little callus formation. This is usually more common when associated with severe soft tissue injury or a loss of vascularity in the area. It may be more common when viewing nonunion after internal fixation and open reduction. When in doubt as to the structural rigidity of the fracture, stress films may be taken to show angular deformities that may occur at the fracture site. Once a diagnosis is complete, treatment must be initiated. Before this is done, however, it is important to do a thorough physical examination of the animal and the injured part to ascertain any associated nerve damage or limitations of joints and soft tissues. It is often possible through surgical treatment to turn a nonunion into a strong union that still leaves the animal with a functionless extremity. The purpose of creating a union is for adequate function. If adequate function is not to be expected, the treatment should not be carried out. Functional requirements may dictate the need for other measures such as amputation.

The incidence of nonunion in the dog is unknown. It is well known, however, that the rates of nonunion seem to be higher in small breed rather than large breed dogs and that certain bones predominate. (39) SumnerSmith and Vaughan in two separate studies showed that approximately 60% of all nonunions in the dog occur in the radius and ulna. Twenty-five percent occur in the tibia, and 15% are in the femur. (33,39) There were no humeral nonunions in this study, but they are not rare in our experience. Nonunion can occur at any level in any bone.

TREATMENT

Treatment of nonunion is directed toward improving the local physiological and mechanical environment to allow fracture healing to proceed. This is done in part by addressing all of the problems that cause delayed union and nonunion as described above. Although many forms of treatment for nonunion have been advocated in the past, we use two methods that can accommodate most if not all nonunions.
TRADITIONAL
The first technique is that of compression plating in which an open surgical reduction is made of the nonunion site. If adequate reduction and alignment of the fracture were achieved initially and some callus is evident at the fracture site, the plate may be applied without disturbing the nonunion site. Compression is applied to the bone ends as the plate is applied. This compression of soft tissues lasts only for a short time, but stability at the fracture site is obtained. No additional bone graft is needed and healing is usually seen within 6 to 12 weeks. When the bone alignment at the time of operation was inadequate, the nonunion site is disturbed and the fibrous connective tissue and cartilage are debrided and the bones realigned before plate application. The use of a cancerous bone graft for these cases helps ensure bone healing. When an atrophic nonunion occurs, most commonly in radial and ulnar fractures of the toy breed dogs, it is important to use cancellous bone grafts to help consolidate a union.

Weight bearing seems to play an important role in bone healing. The fact that bones may grow in tissue culture but fractures do not heal in this environment leads one to suggest partial then full weight bearing when treating fractures and especially nonunions. Many clinicians have seen the gradual osteoporosis and resorption of bone in the ulna and radius of small breed dogs subjected to prolonged cast immobilization and nonweight bearing. This problem, once begun, may be very difficult to reverse, especially in an animal that is quite content to walk only on its other three legs. All attempts at fracture treatment and especially nonunion treatment should have as a goal partial then full weight bearing during the treatment period. This dictum mandates some form of stable internal fixation or functional cast treatment of the fracture.

Occasionally, nonunions occur after the use of round intramedullary pins. In such cases the pin maintains reduction, but rotating motion at the level of the fracture site prevents union. Often it may not be necessary to change fixation methods but rather add additional stabilization with a bone graft. The use of an on-edge half-thickness iliac bone graft has been almost universally successful in these cases. No special instrumentation is necessary, and resolution of the fracture usually occurs within 12 weeks. The technique is described in Chapter 39, Bone Grafting.

Often with loose-fitting, round intramedullary pins it is not necessary or desirable to change from an intramedullary device to a periosteal device (plate), since further disruption of the vascular supply to the bone may occur. In these cases the replacement with a tight-fitting intramedullary device plus a bone graft (cancerous or half-thickness on-edge iliac graft) may resolve the problem adequately.

Rectifying the causes of delayed union and nonunion can allow functional fracture healing. Providing stability with weight bearing and the use of bone grafts when necessary will solve most cases of nonunion. Other modes of treatment are becoming more popular in the treatment of nonunions in humans and have been used in animals. Direct electrical stimulation with an electrode placed into the nonunion site as well as noninvasive techniques using electromagnetic fields and capacitive coupling may change the way we treat nonunions in the future. The clinician should be aware of new methods but must try to keep them in perspective, since good results are the objective.

ELECTRICAL STIMULATION
Modern use of electrical energy for the treatment of nonunions had its start in 1953 when Yasuda from Japan demonstrated new-bone formation around the negative electrode (cathode) following application of a small current in the microamperage range, applied continuously for 3 weeks in a rabbit femur. He also described stressgenerated potentials in bone. In the late 1950s Bassett and Becker in the United States reported on similar independent studies with the same result. In the early 1960s Shamos and Lavine, also working in an independent laboratory, reported similar findings. These were signals from viable, nonstressed bone and represented a different electrical potential that was present in bone. Therefore, two separate types of electrical signals or potentials were described in bone: stress-generated or strain-related potentials and bioelectrical or standing potentials.

If bone is stressed, a negative potential may be measured from the concave side or compression side of the bone and a positive potential from the convex side or tension side of the bone. It is important to realize that these potentials are not dependent on cell viability and are produced whenever the bone is stressed. These potentials are still present even if the bone has been decalcified. Therefore, it has been demonstrated that the potential itself originates from the organic and not the mineral component of bone.

Bioelectrical potentials are measured from viable, nonstressed bone. They are absent in dead bone. In a typical long bone, the diaphyseal region exhibits an electronegative charge, while the growth plate metaphyseal region exhibits an electronegative charge. If a fracture is created in the diaphyseal region, the normal electronegative charge reverts to a negative charge and remains electronegative until the fracture heals, when it again becomes electropositive.

Another important discovery was made in the opposite growth plate metaphyseal area, with a fracture in the diaphysis. Under these conditions, the normal electronegative potential is intensified and remains that way until the fracture has healed. It is known clinically that bone overgrowth has been associated with long-bone fractures in children when the fracture surfaces are properly realigned. It is probable that the increased electronegative charge at the growth plate may account for this finding, since it is absent in adult bone.

At the time of preparation of this chapter, there were three major devices on the market for electrical stimulation of nonunion as approved by the Food and Drug Administration (FDA) for use in humans. The first is the direct-current stimulator supplied by Zimmer (Warsaw, Indiana). It was developed by Brighton, Friedenberg, and Black and the research group at the University of Pennsylvania School of Medicine. The second is inductive coupling supplied by Electro-Biology, Inc. (Fairfield, New Jersey). This was developed by Bassett of Columbia University in New York. The third is direct current stimulation by a completely implantable system supplied by Telectronics Proprietary Ltd. (Milwaukee, Wisconsin). It was developed by Dwyer and Wickham of Australia.
Malunion

Malunion is defined as a healing of the bones in an abnormal position; Malunions can be classified as functional or nonfunctional. Functional malunions are usually those that have small deviations from normal axes that do not incapacitate the patient. Some of these functional malunions may be unacceptable in dogs, especially if the animal is a show specimen. Nonfunctional malunions will be discussed in this section. Malunions can occur with both axial deviations and rotational deformities. Axial deformities such as the valgus or lateral deviation of the forepaw that occurs with a poorly set fracture may cause secondary degenerative joint disease of the carpus because of continued weight bearing in an abnormal position. Very often these axial deviation malunions will develop associated joint problems. Fractures associated with physical injuries may also lead to deformities that are usually not classified as malunions. These deformities are associated with premature closure of the growth plate. Very often the deformity in these cases is the same as that of malunion, but it occurred after the time of union because of further growth of one or more bones in relationship to other nongrowing bones. Rotational malunions also occur and are usually those of external rotation. These deformities allow a surprising degree of function in most animal species. Conversely, internal rotational deformities may cause more serious problems but are
uncommon. Most external rotational deformities are not even appreciated if they are less than 10°. It must be remembered when dealing with fractures that some animal breeds (chondrodystrophoid) exhibit skeletal abnormalities in their normal state. Therefore, when reducing fractures in these breeds it is important to match the "normal" deformity of the opposite side.

Most external rotational and lateral axis deformities are associated with the improper positioning of the animal during the application of a cast or splint. Placing the injured leg in an uppermost position when the animal is in lateral recumbency will tend to give an external rotational and lateral deviation deformity when the limb is manipulated. This can easily be corrected by placing casts and splints on animals with the injured limb on the down side. Here extension and manipulation of the limb will be more likely to give a straight limb without this valgus deformity. External rotation may still occur if special attention is not paid when immobilizing radial and ulnar fractures by this method. Rotational deformities are quite common with femoral fractures and usually relate to the muscles that control each end of the fracture fragment. Fractures of the femur usually allow the proximal fracture fragment to be held in external rotation because of spasms and contractions of the iliopsoas muscle. If, when using internal fixation with an intramedullary pin or external fixation with a cast or splint, this external rotation of the proximal femur is not taken into account, the femur will then heal with the proximal fragment in external rotation and the distal fragment in the neutral position. Following union the animal controls the proximal femur through its proper position, thereby giving an internal rotational deformity to the distal femur, resulting in a knock-kneed stance. This is sometimes a disconcerting problem for the dog and may lead to gait abnormalities or lameness. If, in fact, the femoral fracture is approached with the idea that since the proximal fragment is already in external rotation, the distal fragment should be immobilized in external rotation also, this deformity will not occur. At times loose-fitting intramedullary pins allow this deformity to occur.

Correction of malunions is undertaken when the malunion is a functional liability to the animal. Correction of malunions involves osteotomies of bone, which can have all the serious sequela of bone fractures such as delayed union, nonunion, and infection. No osteotomies should be undertaken lightly, although in most animals adequate treatment of a malunion would give a very good result. The techniques used for treatment of malunions are discussed in Chapter 40, Principles and Techniques of Osteotomy.

Most malalignments should be detected before healing occurs. In these cases adequate treatment is undertaken by resolving the axis or rotational deformity that exists, thereby allowing normal union to take place. It is usually better to interrupt the fracture healing at an early stage to correct the deformity than to wait until osteotomy is needed. Proper follow-up of cases after internal fixation or splinting should make the occurrence of malunion very infrequent.

REFERENCES