CHAPTER 17

MANAGMENT OF DELAYED UNIONS AND NONUNIONS

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Regardless of the skill level of a surgeon, every practitioner will be faced with the management of delayed unions and nonunions. In the management of fractures and osteotomies, the occurrence of a delayed union, nonunion, or an infected nonunion can be particularly troublesome.

In terms of definitions, delayed union generally refers to a fracture or osteotomy that takes longer than usual to heal for a particular location. For example, an osteotomy's healing might be considered delayed at several weeks for a first metatarsal osteotomy, but might not be considered delayed for a naviculocuneiform fusion or tibial osteotomy. Therefore, the definition is specifically related to the location of the fracture or osteotomy. Similarly, for a nonunion, the definition also relates to the particular location of the osteotomy or fracture. Nonunion can be defined as a cessation of healing in a given osteotomy or fracture. Often, an arbitrary definition of approximately eight months is given. Some authors further describe pseudoarthrosis as a sub-category of nonunions, where synovial-lined tissue is formed between the bony fragments.

Delayed unions or nonunions can be further sub-categorized as septic or clean. Septic nonunions are even more difficult to manage, and represent a special category in and of themselves.

PATHOLOGY

Why does a fracture or osteotomy fail to heal? Essentially, the notion that excessive motion between bony fragments contributes to a delay in healing has been held for many years. Von Volkman stated "the speed of reunion of bone is in direct ratio to the rigidity with which the two pieces are placed together." In addition to motion, loss of vascular supply to the fragments is another primary reason for failure of bones to heal. In order to understand this pathology, it is helpful to review normal bone healing, which is categorized into secondary healing, primary healing, and gap healing.

Secondary bone healing is what most commonly occurs after a fracture or osteotomy has been performed, and there is still some motion between the fragments. The four basic steps of secondary bone healing can be categorized as vascular and cellular invasion, formation of fibrous tissue, the formation of cartilage exocallus, and the formation of bone. The formation of the callus is dependent upon the rigidity of the interfragmentary strain. The vascular and cellular invasion phase begins with the release of histamine, kinins, and other factors affecting capillary permeability. Hematoma then forms, and a cellular invasion occurs with macrophages, endothelial cells, and fibroblasts. Initially, the hematoma releases platelet derived growth factor. This growth factor attracts macrophages which release macrophage-derived growth factor. Macrophages help to debride the wound, and the growth factor attracts fibroblasts which lay down the fibrous tissue that forms the second stage of secondary bone healing. After the cellular invasion phase, the reconstructive proliferative stage begins. This stage occurs when the fibroblasts lay down fibrous tissue. As the rigidity between the fragments increases, fibrocartilage forms, followed by more dense fibrocartilage and hyaline cartilage.

The periosteum forms a fragment of bone collar and the endosteum forms a more stable internal bone cylinder. The progression of these stages is governed by strain tolerance of the repair tissue. Tissue can be formed in the gap between fragments only if this tissue can tolerate the amount of strain present between the fragments. For example, fibrous tissue will deform significantly with load, whereas fibrocartilage and bone will be able to tolerate significantly less deformation. Therefore, in order for mature bone to form, the fragments must be immobilized enough to prevent continual breakdown which leads to the formation of fibrous tissue. This occurs with the formation of the provisional callus, which consists of randomly-organized fibrous bone. This periosteal callus formation forms a scaffold. Finally, as this periosteal callus further stabilizes the fracture, mature bone will replace this provisional callus matrix. Mature reorganized bone then forms with continual remodeling.

Primary bone healing consists of the direct formation of lamellar bone traversing the site of a fracture from the Haversian systems of adjacent cortices, without the intervening step of callus formation. Schenk and Willenegger advanced the understanding of the histology of primary bone healing when they defined it as perfect anatomical reduction which occurs at the microscopic level. Primary bone healing is dependent upon anatomic reduction, mechanical stability, and intact vascularity. Primary bone healing occurs parallel to the long axis of bone. It occurs only when a defect is extremely fine, without the penetration of cells or blood vessels.

Gap healing is a common type of healing that occurs in a stable environment. This type of healing occurs in the majority of osteotomies. When the gap is less than 0.5 millimeters, there is a direct formation of lamellar bone. The bone is deposited perpendicular to the long axis of the bone and originates from the marrow and the periosteum. When the gap is 0.5 to 2.4 millimeters, the initial source of the tissue is the marrow, and it begins with vascular and cellular invasion by undifferentiated cells. The scaffold then forms woven bone at the periphery of the cortex by differentiating cells. Cellular alignment then occurs with osteoblasts forming irregular lacunae on this woven matrix. Osteoid is then synthesized in lamellar conformation. The long axis of the repair tissue is perpendicular to the long axis of the bone. Remodeling occurs over a period of months by means of cutting cones.

Primary versus secondary bone healing can be simply contrasted in the following way: primary bone healing forgoes the intermediate stages of healing and is more efficient; secondary bone healing involves interchondral ossification first, but is nonetheless faster. Gap healing versus primary bone healing is contrasted as follows: gap healing has less strength and is formed in a perpendicular direction, whereas primary bone healing has more strength and is formed in a longitudinal direction. The healing of bone fractures and osteotomies is delicate and easily interrupted by two primary factors: movement of the fragments, and loss of intact vascular supply to the fragments.

EVALUATION OF DELAYED UNIONS AND NONUNIONS

Evaluation of delayed unions and nonunions can be divided into several categories. Initially, one must recognize that union has not occurred. This is primarily accomplished through clinical evaluation and conventional radiographs. When union is incomplete, persistent swelling will be present. Radiographs will fail to show trabeculation across the osteotomy or fracture. Further evaluation can also be performed with computerized tomography (CT) or magnetic resonance imaging (MRI). The use of a CT scan with surrounding internal fixation can be difficult to interpret, due to the starburst pattern created by the metallic fragments. Otherwise, a CT scan is a good way of accurately determining how much of a given osteotomy or fracture has healed.

It is also important to classify the nonunion as either avascular or hypervascular. A majority of nonunions are hypervascular in etiology. This can be confirmed by use of a three-phase technetium bone scan. If increased activity is demonstrated at the fracture ends as well as the interposed area, the nonunion can be categorized as hypervascular. If, however, there is a gap of activity, then the classification is more appropriately called avascular. The significance of this distinction relates to the decision as to whether or not an area needs autogenous bone grafting. Unfortunately, the resolution of the technetium bone scan is somewhat finite. In the small bones of the foot, it can be difficult to determine whether or not a gap is present. The morphologic character of the fracture ends can also be misleading, since there are hypervascular nonunions which will not have the classic elephant-foot appearance. The classic morphologic appearance of an avascular nonunion is generally one of the following four patterns: a fracture with a butterfly fragment and partial necrosis of the fragment, a wedge-type fragment with total necrosis of the fragment, a nonunion with a defect, or atrophic and nonvital fragment ends.

MANAGEMENT OF DELAYED UNIONS OR NONUNIONS

When a fracture or osteotomy's healing is delayed but there is continuing progress, conservative measures can usually be employed. Assuming that the fracture or osteotomy has remained in the desired position and is still in good alignment, continued immobilization will allow the delayed union to progress to complete healing. If the delayed union occurred when the patient was immobilized in a surgical shoe, (ex: capital metatarsal osteotomy), then immobilization of the delayed union should consist of a more rigid type of casting. If the delayed union is in poor alignment, then a more subjective decision must be made as to whether or not the alignment is poor enough to warrant surgical intervention. When the overall goal is optimal function, then clearly the alignment of the fracture osteotomy is critical, and mere completion of bone healing is an inadequate result.

With regards to a nonunion, the treatment options are specific for both the hypervascular and avascular nonunion. In either event, there are three basic choices available: immobilization or stabilization (externally by means of a cast, or internally with screws and plates); electrical stimulation; or bone grafting.

For the hypervascular nonunion, the surgeon has the choice of electrical stimulation or rigid fixation. In a well-aligned, well-vascularized nonunion, electrical stimulation may prove to be the most efficacious therapy. In this case, bone healing can be accomplished without additional surgical intervention, and with decreased risk to the patient. Early therapy with electrical stimulation consisted of direct current therapy through implantable electrodes. The majority of external electrical stimulation is now accomplished with pulsing electromagnetic fields in a non-invasive fashion. However, direct current therapy is still available either non-invasively or through an implantable device. Pulsing electromagnetic fields are generated through coils placed directly over the nonunion site. The usual treatment time is 8–10 hours per day, which can be conveniently performed while the patient is sleeping, or divided into multiple shorter segments of time during the day. An implantable direct current stimulator is also available. This has a wire cathode which is placed directly across the non-union site, and a remote battery which is buried in muscle tissue. The battery lasts approximately 6 months, and can be removed through a small incision by snapping the wire at the area of the previous nonunion, and leaving the cathode wire buried deep.

A non-invasive direct current stimulator is also available which is small and easy to use. A disadvantage is that it does require continuous contact with the skin, which can be irritating in a hypersensitive patient. Electrical stimulation can be used in conjunction with other therapies as well. It can be used as the primary therapy for the treatment of a hypervascular nonunion in good position. It can be also be used secondarily as an adjunct to therapy in the treatment of hypervascular or avascular nonunions, in conjunction with bone grafting or rigid fixation. The primary contraindications to electrical stimulation include the presence of a large gap or interposed synovial tissue, or the presence of malignancy. Many studies have demonstrated very good results with electrical bone stimulation, supporting its use as the primary therapy for well-aligned hypervascular nonunions.

In poorly-aligned hypervascular nonunions, operative reduction with internal fixation should be performed. Significant stabilization can be achieved with the use of plates and screws. Additional augmentation can be performed through the use of an autogenous cancellous bone graft. A secondary treatment with electrical stimulation (either by invasive or non-invasive means) can also be used. The fixation used for a nonunion repair must be stable. In general, it might require more stabilization than an ordinary fracture or osteotomy in the same location.

Bone grafting can also be used in the management of nonunions. Cancellous autograft is typically the material of choice, since it provides the highest cellular content. In situations where the graft is interpositional and must be more mechanically stable, then a component of cortical bone is also necessary. The iliac crest is ideal for this kind of material. The calcaneus also can be used quite effectively to procure smaller amounts of cortico-cancellous autograft. Although there may be situations in which allogeneic bone might be used in conjunction with a nonunion repair, autograft material is generally preferred. Since this is an osteotomy or a fracture that has already had one non-healing episode, logic would seem to dictate that every effort be made to give the osteotomy or fracture the best possible chance at healing. This can best be done with autogenous rather than allogeneic bone.

POSTOPERATIVE CARE

Following any type of surgical intervention for a nonunion, the anatomic area must be protected. Most of the time this will involve a non-weight-bearing fiberglass cast. However, if the nonunion is adequately stabilized, then the use of a removable cast or splint can provide for a more functional aftercare program. Some stimulation of the osteotomy or nonunion site can be helpful. This is accomplished through the gradual introduction of bearing weight on the limb. Evaluating the progress of a nonunion can be difficult. Usually multiple serial x-rays is the most effective way of accomplishing this. A nonunion must be protected for a long period of time, particularly if a bone graft has been used. It takes a graft a significant period of time to be fully mechanically integrated into the surrounding bone structure. Therefore, some element of protection is necessary during the several months of bone remodeling. In the forefoot, this may consist of a balanced insole or a stiff-soled shoe. In whatever way it is accomplished, the objective is to protect the graft until it is fully mechanically incorporated into the surrounding bone.

SUMMARY

The management of delayed unions and nonunions is a clinical challenge. Frequently, delayed unions and nonunions occur in the course of elective surgery. Despite informed consent, the patient is often quite concerned when a bone does not heal in the usual time frame. It is important to be able to give these patients perspective and to be able to assure them that the end result can be accomplished even though the time frame may be somewhat longer. It is particularly important to insure that the patient understands the importance of compliance.

The treatment principles regarding delayed unions and nonunions are relatively straightforward. In the case of a delayed union with good alignment, increase the immobilization or add electrical stimulation. In the case of a delayed union where the alignment has been lost, open reduction with internal fixation is an effective way to manage the condition. In hypervascular nonunions with good alignment, electrical stimulation is often a good choice. A second surgical procedure with internal fixation, the possible use of supplemental autogenous cancellous bone, or the use of internal fixation, can be quite helpful. In avascular nonunions, autogenous bone grafting with stable fixation is the preferred method of treatment. Electrical stimulation may also be used as a secondary therapy.