CHAPTER 39
BONE GRAFTING

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The use of bone grafts in veterinary medicine is widespread. It is a common procedure for treatment of various delayed unions and nonunions, as well as for the treatment of fresh fractures to help ensure union. Although it has been estimated that more than 200,000 bone grafts per year are used in the United States in humans, there are no accurate estimates for the use of bone grafts in veterinary surgery.(22) By reviewing the veterinary literature it can be seen that by the time veterinary orthopaedics was being discussed in the early 1940s, bone grafts were already a part of that discussion.(35) Since then, the changes in grafting have swung back and forth through a great variety of techniques and materials. It is the purpose of this chapter to discuss a rational method for the present use of bone grafts.

TERMINOLOGY

Although transplantation terminology has been established for many years, continued use of old nomenclature has thrived in the literature.(27)

The autograft is tissue from one person or animal that is transferred from one portion of the body to another. The isograft is material that is taken from one individual and transplanted into another genetically identical individual, such as an identical twin. In this case the donor and the recipient must have the same genotype. The allograft (formerly called a homograft) is tissue that is transferred from one individual to another individual of the same species. The xenograft (formerly known as a heterograft) is tissue that is taken from one individual and transferred to another individual of a different species.

Bone grafts may be either cortical or cancellous in nature. Furthermore the bone that is being transferred may be either dead or alive. Sometimes the nonviability of the transplant is known, such as when using a frozen allograft, but at other times the viability may be in doubt. A great deal of controversy exists regarding the transplantation of live bone and its ability to survive.(1,3-5,10,13,16,23 26,28 31,33,38) The greatest chance for the successful transplantation of live bone is with a cancellous autograft or with the vascularized pedical cortical autograft. Both of these grafts must be recognized by the recipient as self,(15,17)

Osteoconduction is the process by which capillary ingrowth into the graft occurs from the recipient bed. This may take place on a framework or scaffold of the dead graft itself or, as in the case of a fresh autograft, may be accomplished in concert with the viable cells that remain within the graft.(9)

Osteoinduction represents a process of cellular interaction in which unspecialized mesenchymal cells may differentiate into bone.(35,39) This production of bone requires an environment that is conducive to bone formation as well as some osteostimulating substance. These substances may be osteogenic cells or other materials such as bone morphogenic protein.(35) The mechanism of bone induction is presently unknown.

Creeping substitution, the process of bone remodeling by osteoclastic resorption and creation of new vascular channels with osteoblastic bone formation resulting in new haversian systems, is the method by which strong cortical bone is formed from grafted material.

BONE GRAFT INCORPORATION

The biology of bone graft incorporation involves many factors. To look at these factors we will need to examine several types of grafts.

The fresh autograft is an attempt to transplant living bone that can survive and add to the bone volume and eventually the bone strength. When fresh autograft is added to a recipient site, the incorporation of the graft relates to the recipient site cells as well as to the remaining viable cells within the graft itself. The cellular response seems to be different when using a cancellous graft as opposed to using a cortical one. Cancellous autografts as well as fresh cortical autografts begin their incorporation in much the same way.(1,2,5,19) Blood clot and hematoma provide the initial environment for the new graft. An inflammatory response then prevails and vascular granulation tissue invades the area. By the end of the second week, in the dog the response is that of a fibrous granulation tissue, and cellular death occurs within the graft, which has not yet been reached by the vascular response.(20) At this point the differences of graft incorporation between cortical and cancerous grafts become evident.

In cancellous autografts the vascular response is much greater than in cortical grafts. The entire cancellous bed may be completely revascularized within approximately l to 2 weeks (Fig. 39-1).(19) The cell population of this environment comprises predominantly osteoblasts. It is not known if these cells are produced from the recipient site or if they are the descendants of cells transplanted with the graft itself.(9) In any case these cells line the scaffold presented by the trabeculae of the graft and deposit a seam of osteoid that surrounds and entraps the original dead bone. This entrapped dead bone is eventually resorbed by osteoclasts. Radiographically the cancerous bone first becomes more dense as the new bone forms on the old trabeculae and then becomes less dense as the osteoclastic remodeling takes place. It would appear that in the dog the cancerous graft is completely remodeled and replaced by new bone (Fig. 39-2). Fig. 39-3 shows a similar situation with a frozen cancerous allograft. Here, however, the vascular response is less and the cells of the transplanted bone are dead initially.

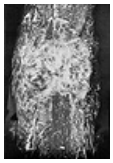

FIG. 39-1 Mature canine ulnar diaphysis one week after insertion of fresh autogenous iliac cancerous chip grafts into a l-cm complete defect. Microangiogram shows very active vascularization of the entire graft recipient site. (original magnification x 5.5) (Rhinelander FW: Circulation in bone. In Bourne (ed): The Biochemistry and Physiology of Bone, vol 2, chap 1. New York, Academic Press, 1972)

In the cortical autograft the main differences revolve around the amount of revascularization and the completeness of the remodeling.(20,29) The cortical bone may not be revascularized as quickly as the cancellous graft. Revascularization takes about 2 months and is caused by the structure of the cortical graft, which does not allow as large a contact area for vascular penetration between the graft and the host.(1,19,20) Revascularization is accomplished through the old haversian and Volkmann canals. Following the revascularity of the periphery of the graft, the interior follows suit quickly. Interior revascularization of a cortical bone graft will start the process of creeping substitution, which first resorbs bone stock before replacement with new viable bone stock. In studies in the dog the resorptive phase was seen to be increased over normal levels at 2 weeks, steadily increasing for the next 4 weeks, and then diminishing toward normal by one year. The histologic evaluation of this data showed that the resorption process progressed so that the peripheral haversian systems and their adjacent interstitial lamellae were remodeled first and then the interior haversian systems were remodeled without their corresponding interstitial lamellae, thereby leaving areas of dead cortical bone mixed in with the newly remodeled bone. The overall results showed that the bone at the ends of the graft was more completely remodeled than the bone in the center of the graft. The completeness and rate of repair seemed to be related to the remodeling activity of the animal, with greater repair associated with more active remodeling.(29) The relationship of this remodeling rate to weight-bearing stresses is unclear.

The incorporation of cortical allografts differs slightly from that of cortical autografts. In general the revascularization is much slower and the bone formation is less extensive.(11,12,15,16,30,35,43) Resorption may play a much larger part in the graft incorporation. The temporal sequence of the cortical bone allograft shows an inflammatory response for several weeks. The major cell type at this time is the lymphocyte. The inflammatory response lasts for another month or two, during which time a fibrous Encapsulation of the allograft takes place. Gradually the graft may be incorporated into the host tissue. The time period associated with the incorporation of the allograft is one indication of the acceptance or rejection of the graft. Callus formation is a good sign but may not be present to any great extent if rigid internal fixation is used. In one study in dogs using allografts of the fibula,three basic results were seen. In 20% of the dogs, healing was complete in that the graft was united with the host by 16 weeks. The remodeling resembled that of autografts. Sixty percent of the animals in the study were seen to have problems related to delayed unions and nonunions, with loss of graft diameter and decreases in the mechanical strength of the grafted bone. The other 20% of the animals in this study showed complete bone resorption with no evidence of healing.(9)

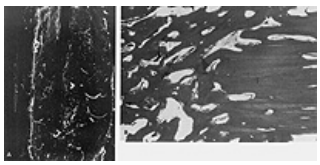

FIG. 39-2 Mature canine ulnar diaphysis 12 weeks after insertion of fresh autogenous cancerous iliac chip grafts into a l-cm complete defect. (A) Microangiogram shows marked incession m vascularization of the grafted area and surrounding host bone in comparison with the situation at one week as illustrated in Figure 39-1. (original magnification x 6) (a) Photomicrograph of histologic section corresponding to A shows advanced new-bone formation in the grafted area and secure union with the host cortex on the right. (H & E, x 50) (C) Roentgenograms of radius and ulna show the advanced healing of the ulnar discontinuity. After removal of the pin, only viable host tissue will remain. (Rhinelander FW: Circulation in bone. In Bourne (ed): The Biochemistry and Physiology of Bone, vol 2, chap 1. New York, Academic Press, 1972)

The mechanism of allograft rejection seems to be related most strongly to cellular rather than humoral immunity.(8,15,18,23) This cellular type of immune reaction is thought to have its source mainly in the bone marrow.

The mature cell type is that of the lymphocyte. The cellular component of the graft is antigenic, while the bone matrix seems to play a lesser role. For this reason many of the allografts that are used have the marrow elements removed or rendered less important by freezing, freeze-drying, or deproteinization.(8) Other methods of reducing antigenicity such as boiling or heat sterilization have been used, but the grafting of boiled bone is one of the least successful methods; mainly because the boiling leads to denaturation of bone collagen(15,17) In autografts the coagulation of protein elements within the haversian system leads to the nonrecognition of the denatured protein as self, with subsequent rejection of the original bone that was really self. However, the literature does describe many successful uses of boiled grafts, including xenografts.(9) Two or three megarads of irradiation can be used as a method of destroying the antigens that are involved in bone rejections Studies using this method have shown that the loss of mechanical strength and inductive properties (protein denaturation) that takes

place makes this a less acceptable alternative to other methods. The use of decalcified grafts has also been studied, but the results seem equivocal Most studies have shown that decalcified grafts are more successful than inorganic grafts. It should be remembered that the most successful graft is an autograft, and the most completely incorporated autograft is a cancerous graft.

One of the other problems of bone grafting, in addition to incorporation, is bone strength.(6,7,20,42) Fatigue fractures are a common problem when using cortical allografts in humans, and many of the failures of bone grafts deal with mechanical problems that are related to the biologic incorporation of the graft. Cancerous grafts initially strengthen by appositional new-bone formation. Remodeling of this graft then yields normal strength. Cortical bone, however, is first resorbed, and hence weakened, before the creeping substitution can replace the bone through the haversian remodeling process. Studies in the dog using cortical autografts of the fibula have shown that torsional strengths decreased sharply at 6 weeks and remained low through 24 weeks but returned to normal strength by 48 weeks. The relationship between the mechanical strength data and graft incorporation is striking. The initial decrease in strength was associated with the increasing porosity associated with creeping substitution. At the end of this experiment at 48 weeks only 60% of the graft has been remodeled, but the strength parameters had returned to normal.(20) This showed that the strength of the graft is related to porosity and not to bone viability. It can be surmised from these data that fatigue fractures in the dog should occur between 6 and 40 weeks, after which fatigue fractures would be unusual.

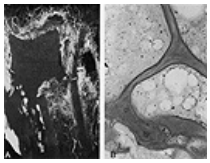

FIG. 39-3 Mature canine proximal tibial metaphysis one week after insertion of frozen homogeneous cancerous chip grafts into complete bone defect. (A) Microangiogram shows injected blood vessels in only a narrow zone around the periphery of the graft site. (original magnification (x 7) (B) Photomicrograph of histologic enlargement from center of grafted area shows grafts with empty lacunae and no surrounding cells of any type. (H&F, x 160) (A, Rhinelander FW: Circulation in bone. In Bourne led): The Biochemistry and Physiology of Bone, vol 2, chap 1. New York, Academic Press, 1972)

BANKING BONE

Bone banks have been used in veterinary orthopaedics for many years and were strongly advocated by Brinker. This banking procedure requires adequate planning and attention to detail. The specimens are collected in sterile containers and deep frozen. The retardation of autolysis by cooling would suggest that the lower the temperature the longer the graft would remain useful.(37) Grafts frozen to - 70¡C have been used successfully up to 2 years after collection. Theoretically freeze-drying should lengthen the useful life of the graft infinitely. Careful attention to sterility in the collection process is mandatory. Nothing is worse than having an infected fracture or nonunion that is related to the interposition of a contaminated graft. Careful donor selection is necessary to ensure that the donor is not going to transfer its disease condition to the recipient. One has only to remember the transfer of rabies via a corneal transplant in a human to recognize the potential catastrophy. Luckily the selection of the donor does not usually represent the same type of legal problem that occurs in humans. This should ensure that only healthy donors are chosen. Bone is collected using aseptic techniques, with special attention paid to the skin preparation. The most common bacterial contaminant of the graft is usually traced to an organism on the skin. It is wise to culture all specimens at the time of collection to help ensure quality control. Reculture at the time of implantation is also recommended. At the time of surgery the graft is usually warmed at room temperature and may be placed in a physiologic solution such as Ringer's. Antibiotics are sometimes added to this solution, but no firm guidelines can be given in this regards

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DONOR SITES

In the dog and cat various locations can be used as sites to obtain autograft tissue. Cancellous grafts are the most common form of autograft and can be obtained from the wing of the ilium, the proximal tibia, and the proximal humerus. Sometimes the amount of graft that is needed may demand that more than one site be used.

The approach to the wing of the ilium is easy and straight-forward. A 2-cm long incision is made over and parallel to the wing of the ilium. The skin and subcutaneous tissue are retracted and the fascia of the middle gluteal muscle is incised along the rim of the ilium. A periosteal elevator can be employed to separate the muscle from the bone. A rongeur is used to open the medullary cavity of the bone and a curette is inserted to scoop the cancerous bone out of the cavity; it is placed within a blood-soaked sponge or in a basin. The bone is best kept moist using the patient's own blood. The viability of the graft cells are best ensured by disturbing them as little as possible. The use of saline-soaked sponges would be detrimental in this regard.(14)

The graft is obtained from the tibia via the proximal medial surface just caudal to the tibial tuberosity and distal to the physeal line. The incision is made through the skin down to the bone. A hole is drilled through the cortex with a large Steinmann pin inserted into a Jacob's chuck. The graft material is then removed with a curette.

Obtaining a graft from the proximal humerus is very similar to the tibial procedure. The skin incision is made over the proximal cranial aspect of the humerus just distal to the greater tubercle. The hole is drilled and the graft is taken as described above.

RECIPIENT SITES

In fresh fractures the recipient site is usually easily defined. The cancerous graft is placed into and around the defect being grafted. The application of the graft may be thought of as placement of the callus. The bone graft will form the scaffold for further bone production so that adequate bridging of the defect will help ensure bone union.

When dealing with delayed unions or nonunions, the application site of the graft may be more difficult to determine. The fibrous connective tissue that surrounds the old fracture site may not allow the placement of the graft where needed. In these cases the fibrous connective tissue must be removed so that the graft can come into contact with the bone fragments and the surrounding vascularized tissues.

GRAFTS ASSOCIATED WITH OPEN FRACTURES AND INFECTION

In general, only cancerous bone autografts are used safely when dealing with open fractures and certainly when dealing with infected fractures. (14) The use of cortical bone grafts in association with open fractures and osteomyelitis will allow the formation of infected sequestra or an involucrum. When dealing with open fractures, grafting may have to be delayed because of inadequate vascularity at the recipient site. Often a bed of granulation tissue covering the lining of the wound is necessary to allow the revascularization of the cancerous graft to occur. This may mean that bone grafting will be delayed 10 to 14 days after the initial reduction and fixation. If a cancerous bone graft fails because of infection, the graft undergoes coagulation necrosis and will flow from the wound, usually without leaving an infected sequestrum. Regrafting may be tried after the infection is under control and the vascularity of the area can support a graft.

Extensive wounds associated with comminuted fractures and delayed unions or nonunions in combination with infections are often amenable to massive cancellous bone grafts employing Papineau's technique,(40) which uses cancellous autograft material for bone and cutaneous healing. This is accomplished through two successive operations. The first procedure comprises adequate debridement with stabilization of the fracture, usually with external skeletal fixation, leaving a clean, largely open wound that can fill with granulation tissue. It is important not to leave any pockets in the wound that can fill with fluid. This process is closely related to bone saucerization but includes the soft tissue as well as the bone. The wound is then packed open with thick dressings. We use sterile Vaseline-impregnated gauze as the packing material. The second surgical procedure is done approximately 14 to 21 days later and involves filling the entire wound with a cancerous graft over the granulation tissue bed. The graft is placed right up to the skin edges, and the graft and wound are covered with a dressing. This dressing is changed daily, with gentle cleansing of the wound edges. In our experience with this technique in the dog, the bone goes on to union and the skin closes spontaneously. The duration of healing is prolonged (many months), but the lesions that are treated in this manner are not handled easily by other methods.

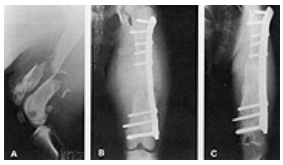

FIG. 39-4 A comminuted fracture in a large breed dog (A) was treated using a cancellous autograft to fill the large gap after internal fixation with a plate and screws (B). Radiographic consolidator of the fracture occurred in 8 weeks (C).

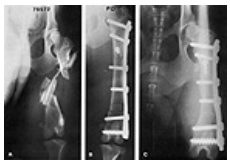

FIG. 39-5 (A) A 2-year-old dog was brought for treatment with a comminuted femoral fracture. (B) The fracture was treated with a segmental cortical allograft and fixed with a plate and seven screws. (C) Radiographic healing is seen at 8 months following surgery. (Courtesy of Dr. W. D. Hoefle)

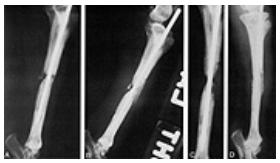

FIG. 39-6 (A) A nonunion of 6 months' duration is seen with an intramedullary pin for fixation. On physical examination 90¡ of rotation was felt. An on-edge half-thickness iliac bone graft was applied (B) and films were taken again at 4 weeks (C) and at 8 weeks (D), at which time union had occurred.

SPECIAL GRAFT TECHNIQUES

Cortical grafts can be used as onlay grafts, inlay grafts, and segmental grafts. The onlay and inlay grafts may be autografts but are often allografts. Segmental grafts are almost always allografts when used in clinical situations in the dog and cat. The use and success of cancellous autograft has lessened the use of onlay and inlay grafts (Fig.39-4). Segmental grafts are used for the replacement of long defects associated with severely comminuted fractures (Fig. 39-5). Rigid internal fixation with a plate and screws is used when dealing with a segmental graft.

On-edge half-thickness iliac bone grafting is a useful but seldom used technique in veterinary surgery.(34) The principle of the technique involves the grafting across some form of instability with cancellous bone while incurring some stability associated with the cortical component of the wing of the ilium. The technique is used in our clinic for nonunions associated with intramedullary pinning and for arthrodesis of the talocrural joint (Fig. 39-6). The technique consists of creating at least two canals across the part to be stabilized using a Hall drill. These canals are the width of the onehalf thickness of the ilium and are about 2 cm long. The graft is taken from the dorsal rim of the ilium; it is removed en bloc and then split down the middle of the marrow cavity, leaving one surface cancellous and the other surface cortical. The graft is then taken and tapped into the canal that was made in the recipient site. Each piece is placed in one of two canals that are about 120¡ apart. The extremity is usually placed in some form of external fixation, and the union may occur within 6 to 12 weeks. This type of bone graft is extremely useful and can often be used in place of a major new internal fixation procedure when alignment is already satisfactory.

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