SAFETY AND PRACTICALITY OF USING THE PROXIMAL TIBIA AS A SOURCE OF AUTOGENOUS CANCELLOUS BONE IN THE HORSE

by

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DVM, Washington State University, 1974

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Surgery and Medicine

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1982

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Acknowledgements

I would like to thank Dr. Jacob E. Mosier, my major professor, and members of my committee: Dr. Mark M. Guffy, Dr. Hugh C. Butler and Dr. Horst Leipold for their guidance during my masters program.

I would also like to thank Dr. J. E. Schneider for sharing his knowledge and experience during my program and for his continued support in the completion of this project.

I am also grateful to Dr. Gordon Baker for his assistance in the completion of this thesis.

The following people have provided invaluable aid for which I am thankful: Dr. Richard and Cindy O. Howard, Dr. Jack Manning, Dr. S. Swartz, Dr. W. M. Haschek-Hock, Karen Killough, S. E. Koenig, Dave Adams, Sam Giannavola, and Midge Hildreth and staff.

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INTRODUCTION

As a result of advances in anesthesia, orthopedic appliances, and surgical techniques many equine orthopedic patients currently receive surgical treatment for conditions which would have led to their destruction or conservative therapy and a poorer prognosis in the past.[3,87] Long bone fractures, however, continue to be a challenge for the equine orthopedic surgeon. Repair of equine long bone fractures is often attempted with orthopedic appliances designed for use in human patients. Although they are a significant improvement over conservative methods in many instances, these appliances are often asked to do more than they were designed to do. The weight of horses and ponies and the need for immediate postoperative ambulation coupled with fracture gap, missing or discarded fragments, or severe comminution, creates potentially unstable conditions which may lead to implant failure. Early callus formation is important in such cases, and the use of autogenous cancellous bone may help stimulate and fortify this early callus formation.

The use of cancellous bone has been recommended in a number of clinical situations: to stimulate callus formation in delayed and nonunions,[5,49,86] to enhance osseous union in arthrodeses,[21,39,77,89] to fill bone defects following sequestrectomy in osteomyelitis or defects from curettage of bone cysts,[34,50,62,63,80] in fresh fractures where there is a defect due to removal of avascular small fragments, or fracture gap due to less than anatomic reduction.[10,49,63,83] It has also been recommended for use in fresh fractures of certain long bones in the adult horse which are slow to heal or in which implant fatigue failure is not uncommon.[83] The early callous formation, which is stimulated by the autogenous cancellous graft, may be the difference between implant failure and successful clinical union in some cases.

Cancellous autographs have been used extensively in human and in small animal surgery, but their use in horses has been limited to date. A limiting factor in the use of cancellous bone grafts in the horse is the time required to obtain the graft material or the need of a second surgery team to harvest the graft. The most common donor site used in the horse is the tuber coxae.[2,3,26] The main advantage of the tuber coxae is the abundance of cancellous bone. However, the tuber coxae requires a larger incision and therefore the approach and closure are more time-consuming than the tibia. Many long bone fractures require double plating. For this procedure the patient is placed in dorsal recumbency in order that both sides of the bone may be approached. Such a procedure makes the tuber coxae donor site inaccessible. The use of the proximal medial tibia as a donor site of the horse has been reported by three surgeons.[14,34,82] Two surgeon indicated no complications,[14,34] while the other noted two instances of fracture through the donor site.[82] It was suggested that the tibia had been significantly weakened by the hole in the cortex and the harvesting of cancellous bone from the area.

Orthopedic procedures performed in adult horses which require cancellous bone graft, such as arthodesis, subchondral bone cysts, and fresh fractures, usually do not require large volumes of cancellous bone. The tibia would be an attractive alternative to the ilium if adequate amounts of graft could be removed efficiently without significant risk of fracture. This is especially true for the surgeon in general practice who is less able to field a second surgery team.

This study was designed to test the safety and practicality of using the proximal medial tibia as a source of autogenous cancellous bone in the horse.

The study was approached from two aspects. The first involved the use of cancellous bone taken from the proximal medial tibia in a study designed to see if more effective results could be obtained in arthrodesis of the distal intertarsal and tarsal-metatarsal joints. The currently described method for arthrodesis of the two joints has a somewhat varied and prolonged convalescent period and employs the use of exercise prior to osseous union.[1,29] Such exercise is contrary to the accepted orthopedic principles applied to the surgical arthrodesis of other joints.[21,24,39,71,89] The study enabled the practicality of the use of the tibial donor site to be evaluated. The availability of graft material, the clinical course, and healing of both the soft tissue wound, and the osseous defect were monitored. The second part of the study was undertaken to determine if harvesting cancellous bone from the proximal medial tibia would effect the fracture pattern or the torsional load required to fracture the tibia. Previous studies have shown torsional loading to more satisfactorily mimic forces producing clinical fractures than many of the previously described methods of fracture.[16,17]

There are a number of variables in the determination of the fracture strength of bone.[16,36,68] In testing the fracture strength of whole bones loaded in torsion, three important variables are size, hydration state of the specimen, and load rate.[16,36,68] In this study, the load to fracture was the method used to compare the treated tibia to its untreated control to give qualitative data on load strength, fracture configuration, and location. The effects of the variables were minimized by using paired tibias for comparison. The tibias in each of the two groups were stored and handled under similar conditions and all bones were loaded at the same rate.

LITERATURE REVIEW

Classification

Bone grafts are classified from the source of donor graft, the morphological type, and the technical use employed. The current classification of grafts, according to source, defines an autograft as bone from the same individual; an allograft (homograft) being bone from a different individual of the same species; and a xenograft (heterograft) as bone from an individual of another species.[40,47] Bone subjected to devitalizing treatments, such as freeze-drying or decalcifying, is termed an implant. Thus an allograft which has been freeze-dried becomes an alloimplant.[47,67]

Morphologically, bone grafts are classified as cortical, cancellous, or corticocancellous.[47] There are numerous techniques of graft applications. Cancellous bone may be used as chips, strips, or may be compacted into cylindrical plugs.[8,44,67,75,88] Cortical bone has been used in various on-lay and in-lay procedures and as full cortical cylinder grafts for replacing large defects in long bones resulting from tumor resection in man or severe comminution in animals.[53,86,88,89]

Indications

The indications for bone grafts include the following:

1. To promote early callus formation when fracture gaps or severe comminution has created a potentially unstable condition.[3,10,49,62]
2. To fill bone defects such as missing or discarded pieces in comminuted fractures, defects left after curettage of cysts, or following sequestrectomy in osteomyelitis, or resection of tumors.[13,34,43,50,63,80]
3. To promote early fusion in arthodesis.[3,21,24,49,51,52,71,77,86,89]

4. To stimulate bone production in delayed unions and nonunions.[5,26,49,50,54,86]

5. To help provide stability or fixation.[53,64,66,88]

6. To re-establish long bone continuity.[53,88]

No single graft material is ideal for all functions. However combinations of graft materials, such as cortical alloimplants combined with fresh cancellous autografts and the use of graft material in combination with internal fixation, can produce satisfactory results in the above clinical situations if basic orthopedic principles are followed.

The properties or functions of an ideal graft material would be:

1. To supply living osteogenic cells at the implanted site (osteogenesis).[10,13,18,27,45,49]

2. To stimulate pluripotential cells in the host to produce bone at the implanted site (osteoinduction).[6,9,11,19,46]

3. To provide a matrix for rapid in-growth of neovascular and neo-osseous tissue (osteoconduction).[8,11,28,46,49]

4. To provide a mechanical barrier to soft tissue interposition.[46,49]

5. To provide structural support until healing occurs.[53,88]

At the same time the ideal graft must be immunologically acceptable to the host so that an uninterrupted sequence of vascularization and bone production may proceed.[12,28,30,32,48,57] It should also be convenient (aseptic, prepackaged, and easily stored).[24,37,38,52] No graft material, to date, can satisfy all these criteria.

In the past, cortical bone was used extensively to provide structural support and, in some cases, fixation of unstable fractures and nonunions.[67,86]

This function has largely been taken over by metallic implants such as bone plates and intramedullary pins and nails.[5,56,66]

Cortical bone is still used to bridge large defects and provide structural support in severely comminuted fractures and in the resection of tumors of long bones. Frozen, freeze-dried, or gas sterilized alloimplants stored in bone banks are the most common source of cortical bone for this use. When properly stabilized, with metallic bone plates, these alloimplants provide mechanical strength and help maintain the functional integrity of the limb.[37,38,53,88] They are also osteoconductive and osteoinductive.[6,33,45,48] Autogenous cancellous chips may be added to provide cells for early stage healing and a more easily vascularized structure for early bridging callus formation. Cortical autografts in the form of vascular pedicle or muscular pedicle bone grafts are also used in some instances of nonunion and to replace bone defects opposite bone plates.[44]

Autogenous Cancellous Bone

There are many references in the literature describing the fate of the various types of transplanted bone in the host environment. Some of the types and treatments that have been investigated include fresh, frozen, freeze-dried, decalcified, and deproteinized allografts and similarly treated xenografts. The majority of these graft and implant materials follow a similar sequence of events when placed in the host environment. However, they vary in the severity of the host's immune response, the time required for the different stages of bone healing, continuity of the healing process, and ability to induce new bone formation.[20,30,46,59,65,70,72,85] The comparisons will not be discussed except to note that most authors agree that the graft material which is the most potent stimulator of new bone is autogenous cancellous bone.[9,28,31,48,65]

The question and significance of the survival of the donor cells at the host site has been controversial from its first discussion at the end of the nineteeth century to the current day. Numerous experiments have been conducted, using increasingly sophisticated techniques, to establish if cells of the graft survived in the host and if they take an active part in new bone formation. One school of thought supported the idea that the graft cells did not survive and that new bone was formed by metaplasia of cells already in the host site. The other group maintained that a significant number of surface cells remained viable on the graft and these cells produced new bone. Both processes are now known to occur.[6,11,20,27,70,79] The early phase of osteogenesis is seen only in fresh autografts and fresh allografts.[27,28,30,31,48,65] This early stage is important for graft stabilization, vascularization, and early callus formation.[9,31,45,49,65]

Autogenous cancellous bone is the only graft material which provides significant numbers of viable cells to take part in the early phase of osteogenesis.[18,19,20,70,79] It is immunologically acceptable to the host and avoids the prolonged latent period and slow incorporation which characterizes most of the other graft materials.[31,57]

Autogenous cancellous bone is the most widely used type of bone graft in veterinary medicine.[3,25,49,62,73,76,86] It has the highest osteogenic potential due to the large number of pluripotential cells on its surfaces and its ability to stimulate both these cells and cells in the graft bed of the host to form new bone, provided the proper conditions exist in the microenvironment of the host graft site.[7,8] These pluripotential or undifferentiated mesenchymal cells are derived from elements of vessel walls, bone marrow, trabecular surfaces, and the cambium layer of the periosteum.[6,9,11] The large surface area and relatively small particle size of cancellous bone is also important to early graft survival. The large surface area and small particle size allows for more efficient nutrition of cells during the early phases of transplantation when nutrients diffuse via the interstitial fluid. Cancellous bone is also more readily invaded by capillaries from the host vascular bed and provides some protection for these delicate vessels.[9,58,59,67,85]

Initially, fresh allografts are vascularized, show cell proliferation, and new bone formation similiar to autografts. But the vascularity soon diminishes, cell proliferation and new bone formation decreases, and the graft becomes surrounded and infiltrated with round cells.[12,31,78] This rejection phenomenon is greatly reduced or absent in frozen or freeze-dried alloimplants, but these implants are not vascularized as rapidly as fresh autografts, and they lack the early phase of osteogenesis seen in viable autografts.[31,37]

Viable cells in autogenous cancellous bone take part in the early bridging callus along with cells from the host. The early cellular response is the main advantage that autogenous cancellous bone has over other graft materials and allows graft incorporation to proceed at a pace that is three or four weeks ahead of other graft materials.[31,45,48,60,67] This time margin may mean the difference between early union and implant failure. Since these cells are so important, the surgeon must do what he can to insure maximum cellular viability of the graft material at the time of grafting and insure minimal interference with early vascularization.

Graft Incorporation

The initial incorporation of cancellous autografts proceeds in a manner similar to a fresh fracture. In the first three days, there is fibrin deposition and most of the graft becomes necrotic due to lack of blood supply and inadequate nutrition from the surrounding tissues. The only cells that survive are cells within 0.3 mm of the surface.[48] These include cells on the periphery of the marrow, surface cells lining the trabeculae, and some osteocytes on the outer layers of the bone. The surviving marrow cells and surface cells begin multiplying and, together with macrophages and fibroblasts from the host tissues, they begin to invade the necrotic center of the graft. Thus by the third or fourth day, a complex of the surviving cells of the graft and cells from the host bed may be seen in the trabecular spaces on the periphery of the graft. Also by the fourth day, a granulation tissue bed from the host developes around the graft and numerous capillaries proliferate near its surface. During the fifth through the seventh day, proliferation continues and fibroblasts and capillary buds invade the graft.

The first signs of new bone formation may be seen on the surface of the trabecular bone by the seventh day and woven bone may be identified in the tissue forming the host graft interface at fourteen days. By twenty-one days, the graft is anchored by woven bone.[9,31,45,58,65,67,78,79] Depending on the size of the graft and local conditions, the graft may be completely revascularized by three or four weeks.[78]

New bone continues to be formed and the dead bone of the graft is removed by osteoclasts and replaced by osteoblasts. If the autogenous cancellous bone graft was placed in a fracture site in a long bone, then the woven bone will eventually be replaced by osteons of mature lamellar bone orientated parallel to the long axis of the bone as dictated by the mechanical forces acting on the bone.[47]

The mechanical forces produce electrical potentials (stress generated electrical potentials) which stimulate bone formation.[9,54] Bone formation is more active in areas which have a negative potential. Areas of compression have a negative potential relative to areas of tension. It is, therefore, advantageous to place grafts in areas of net compression.[49] Cancellous bone graft placed in a fracture gap opposite a tension band plate in a long bone fracture would be an area of compression when axially loaded.

The survival of donor cells in grafted bone is dependent on the nutrition from the graft recipient site. This will be affected by the overall condition of the host, including diet, parasitism, or concurrent disease.[9,45] Nutrients reach cells by diffusion from the interstitial fluid of the host bed across the host graft interface to the cells of the graft. The effectiveness of this circulation depends upon the distance the cells are from the supplying capillary bed, the diffusion rate of the extracellular space, the interposition of barriers to diffusion (such as inflammatory cells or hematoma formation), the propulsion of the extracellular fluid by cyclic deformation of the tissues surrounding the graft, and by electrical and osmotic forces in the microenvironment.[9,49]

The nutritional, chemical, and mechanical-electrical aspects of the cells microenvironment not only affect cell viability and survival, but also affect the differentiation of pluripotential cells of the graft and the host. Experiments have shown that these undifferentiated cells may become fibroblasts, chondroblasts, or osteoblasts, depending on the microenvironment.[7,9,41]

These cells placed under adequate oxygen, but placed under tension, developed into fibroblasts. If they were placed under compressive forces, but without adequate oxygen, they differentiated into chondroblasts. But when these cells were placed under compression in the presence of adequate oxygen, they developed into bone-producing osteoblasts.[7,9,41]

Rigid fixation of the site to be grafted is also important.[5] Blood vessels of the host cannot invade the graft until the shear forces between the soft tissue and noncompliant bone tissue or between two noncompliant bone tissues are negligible.[9,48,66] If there is interfragmentary motion at the fracture site, then resorption of the fracture ends will occur initially to widen the fracture gap and, therefore, decrease interfragmentary strain.[66] Fibrous callus will be thrown up to increase the cross sectional area. The increased cross sectional area provides better leverage or a higher moment of inertia to resist bending and torque.[37,66] The fibrous tissue callus may limit motion enough to allow cartilage formation since cartilage has a lower strain tolerance than fibrous tissue. The added rigidity of the cartilage may decrease relative motion of the fracture fragments enough to allow formation of bone which has even less strain tolerance. Thus in secondary fracture healing (endochondral ossification), the reduction in fracture mobility is based on the geometry of the callus and the increasing rigidity of the bridging tissues.[37,47,49,66]

Surgical Considerations

The surgeon may have a positive or negative effect on several aspects of graft incorporation. Strict adherence to basic surgical principles will help to insure a positive affect. Rigid fixation of the fracture fragments is important in the case of fractures. Thorough debridement and atraumatic handling of soft tissues in the area will help maintain a good vascular bed and prevent the interposition of necrotic tissue between the graft and the host capillaries. Strict asepsis and hemostasis will prevent hematoma formation or purulent exudate from impeding cell nutrition and closing the soft tissue around the graft will eliminate dead space. It will also help keep the graft material in place and provide intimate contact to the vascular soft tissue.[5,49,61] If dead space cannot be eliminated by wound closure or bandaging, a negative suction drain should be placed in the wound.

The above guidelines should help to establish an optimum recipient bed. It is equally important to handle the graft properly since it is vulnerable to a variety of physical and chemical insults in the time period between removal from the donor site and placement in the recipient site.

The best way to handle the autogenous cancellous graft is to place it in the recipient site immediately after harvesting it from the donor site. Prolonged exposure to physiological saline, exposure to room air for 30 minutes or longer, and temperature elevations above 42 C will decrease the number of viable cells.[9,25,43,49,61] A variety of chemical agents can affect graft viability. These include many cold sterilizing agents, bone wax, and many antibiotics.[9,49]

If positioning of the patient, available help, or the presence of infection in the primary surgery site, make it necessary to harvest the graft prior to use, there are certain precautions that may be taken to help maintain graft ability. The graft material should be placed in a small container, such as a glass beaker or stainless steel container of appropriate size, to decrease the amount of air space. A small amount of blood may be added to percolate down through the graft. The beaker should be covered with a sponge soaked in balanced electrolyte solution and placed away from the heat of the surgical lights until needed.[9,25,49] The lag time between harvesting and implantation must be minimized. Local irrigation of antibiotics or bactericidal solutions should be avoided as they may affect graft viability. If the surgeon feels antibiotics are necessary, they should be given systemically prior to surgery and for a short time thereafter. Antibiotics present at the surgical site following systemic administration will have been buffered by body fluids and are less likely to be in cytotoxic concentrations. Autologous cancellous fragments less than .7 mm should not be used as it has been shown experimentally that they incite a foreign body response and are rejected by host tissues.[9] Graft fragments thicker than 5 mm may well develop necrotic centers.[9,40,78] This may be of little concern when it is necessary to graft large osseous defects since the necrotic bone in the center will still be osteoconductive, osteoinductive, and may eliminate dead space at the site of surgery. Cancellous bone grafted next to cancellous bone will be more rapidly vascularized.[49,78] This may be of little clinical significance since the surgeon must place the grafted material whe.e it is needed. However, it may be advantagous to decorticate cortical bone in the graft area to increase the surface area for the early attachment of the graft.[33,49,75]

Donor Sites

Sites from which autogenous cancellous bone may be obtained include the ilium, tibia, rib, sternum, greater tubercle of the humerus, and the greater trochanter of the femur.[3,49,61,73] In man the iliac crest is preferred as a source of cancellous bone, but the proximal medial tibia, fibula, or ribs may be used for cancellous, cortical, or corticocancellous onlay or inlay grafts.[24,40,47] In small animal surgery both the ilium and the proximal tibia are used as sources of cancellous chips.[50,61,86] The ilium, tibia, rib, and sternum have been used in the horse.[3,34,76,82] The most common donor site used in the horse is the tuber coxae.[73,76,82] Techniques for harvesting cancellous bone from the tuber coxae and ilium have been described for the horse.[73,76] The main advantages of the tuber coxae are that it has an abundance of cancellous bone, it is not a weight-bearing structure, and it can be used in immature animals. However, the tuber coxae requires a larger incision than the tibia and more muscle attachment may be involved. To avoid dehiscence, fascial layers should be closed individually, retention sutures or stent bandages are usually used, and some authors recommend wound drains.[73,76] The use of the proximal tibia as a source of cancellous bone has been reported in the horse by three surgeons.[14,34,82] Two surgeons reported no complications. The other reported two cases of fractures through the donor site.[82] The two cases of fracture through the donor site were in foals.[84]

Complications

Complications which may occur following bone grafting are infection at the recipient site, graft failure, dehiscence or infection at the donor site, and fracture at the donor site. Infection at the recipient site is probably the most common complication.[49,73,76] This may be due to existing osteomyelitis, prolonged surgical procedure, contaminated or traumatized soft tissue, or septicemia. Graft failure may occur from a variety of conditions already discussed, such as instability, infection, physical or chemical insults, and many other factors. Stormy recoveries from anesthesia following prolonged surgical procedures may increase the likelihood of fracture through the donor site.

Stress Concentration

It has been observed clinically that bone with a cortical defect, be it a pocket of fibrosis in a "healed" fracture, a screw hole, tumor, cyst, or donor site altered by removal of material for grafting, may fracture following loads which are significantly below that required to fracture intact healthy bone.[16,22,23,35,55] Experimental studies have demonstrated that a hole drilled through the cortex of a bone or a scoremark in the cortex significantly weakens the bone's ability to withstand tensile bending force and torsional loading.[16,35] These defects decrease the total volume of bone available to resist the loads applied. Except in cases of large defects such as 30 to 50% of the diameter of the bone or more, this loss of bone volume per se is not as significant as the effect this defect has on the distribution of stresses within the bone.[23,36] The result is that stresses are concentrated locally in the area of the defect. Loads which would not be sufficient to cause failure in an intact bone may result in high enough stresses concentrated in the area of the defect to initiate a fracture line which will then propagate and result in fracture failure of whole bone. Thus, these defects are called stress concentrators or stress raisers. The effect has been likened to a boulder in a stream.[35,36] The water which the boulder is diverting may travel two or three times faster as it goes around the rock. The effect can be demonstrated visually by coating the bone with a birefringent compound and utilizing polarized light techniques.[35] The concentration of fringe lines at the hole gives a visual image of the higher strain levels around the hole when torsional load is applied.

Quantitatively, it has been shown that a hole placed in an area of the cortex which will be under maximum tension during bending will decrease the load strength of the bone by 30%.[16,22,55] If the hole is in an area subject to compression, the load strength was unaffected. Studies testing the effect of a drill hole on the energy absorbing capacity of dog and rabbit bone loaded in torsion showed a decrease in energy absorbing capacity of 55.2% and 70%,[16,22] respectively. These fractures still occurred along the planes of maximum tensile stress and the general orientation of fracture lines was not altered. However, there was sufficient localization of stress to cause a decrease in the energy absorbing capacity of the bone and a decrease in the degree of comminution of the fractures as the fracture localized to the region of the hole.

Mechanical Testing of Bone

There are many variables in the determination of the fracture strength of bone.[17,68] Different factors come into play depending on whether the experiment is designed to test bone as a structure or as a material. Bones may be loaded in tension, compression, shear, bending, torsion, or a combination such as bending or torsion combined with compression.[17,22,68]

Tensile and compressive strengths of a material are directly proportional to the cross-sectional areas of the material and are not dependent upon the geometry of the cross section.[17,22,68] Therefore, a hollow cylinder with a larger outside diameter than a solid cylinder would have the same compressive and tensile strength when loaded axially if the cross-sectional area of the material was the same. Results from loading in compression may be influenced by edge effects from the testing machine and by the axiality of the load.[17,22,68] Results from loading in tension may be affected by the gripping device.[17,22,68] To minimize these effects when testing in axial compression or torsion, bone is usually machined to specific shapes with a section which is reduced in size. Thus, the area of failure is determined by the experimental design.

Strength in bending and torsion is affected by the geometry of the bone.[22,68] Again, one can use as an example the two cylinders, one solid and one hollow, but of equal cross-sectional area of material. The one which is hollow will be stronger because its mass is distributed farther from the bending or torsional axis. The tubular structure of bone allows it to be stronger for its weight than it would be if it were a solid structure. The moment of inertia is the quantitative characteristic of bone which takes into account not only the cross-sectional area of material but its distribution in relation to the neutral axis of bending or torsion.[4,22,66]

Bending places the concave side of the specimen in compression and the convex side in tension. Since bone is weaker in tension, the bending test configuration is mainly a measure of the tensile strength of bone.[17] When using bending as a load configuration, it is often the load configuration itself which determines the site of the fracture.[17,68] Three-point bending is an example of this since it uses two supports and a single load point. The position of maximum stress is at the load point. This may be satisfactory for obtaining absolute numerical values for the material strength of a uniform piece of bone but is not satisfactory for trying to determine the weakest point in the whole bone sample. Also, bending strength may be influenced by cross-sectional geometry of the bone since bones do not have a perfectly uniform circular cross-section. This effect is similar to loading a 2 x 4 inch board. It is stronger when loaded in bending on edge, using the 2-wide face as the base, than when it is lying flat with the 4-inch wide face as the base.

Torsion is the most satisfactory load configuration for determining the strength of whole bones and for determining where the weakest point in the bone is located.[17,68] This is because it loads the bone equally throughout its length and is not dependent on the orientation of the bone in the testing apparatus. Also, the configuration of fractures produced by torsional loading is more similar to actual clinical fractures.[17]

In testing the fracture strength of whole bones loaded in torsion, three important variables are size, hydration state of the specimen and the load rate.[17,68] Variations in handling and hydration state of bone used by different investigators have made comparisons of absolute values of mechanical characteristics of bone difficult.

As bone dries the plastic deformation and ultimate strain are decreased. Surface drying times in the order of 30 to 60 seconds can decrease the amount of plastic deformation.[68] This also decreases the ultimate strength and energy absorption before failure. Embalmed specimens and specimens which are allowed to dry and are then rehydrated also behave differently from wet bone. It has been recommended that fresh or fresh-frozen bone be used and that it be kept wet by saline drip during all phases of preparation and testing.[68]

Bones loaded at fast load rates (physiological rates), such as 0.1 sec, absorb more energy, develop more torque, and greater comminution than bones loaded at slower rates.[22,36,68] Bone and other materials whose characteristics change with the load rate are said to be viscoelastic materials.[15,66]

MATERIALS AND METHODS

Part I

Subject Preparation

Nine adult horses ranging in age from 8 to 14 years were used in this study (Table 1). Although the breed was not known for many of the horses in this study, most of the horses were of quarterhorse body-type. There were 3 females and 6 geldings with weights ranging from 800 to 1200 lbs. The horses were held at least 4 weeks prior to surgery and were kept under similar conditions of feed and shelter. Three radiographic views were taken of the tarsus dorso palmar, lateral, and dorso palmar lateral to medial oblique. The horses were divided into 3 groups so they could serve as their own controls in the arthrodesis study. The tarso-metatarsal and distal intertarsal joints of all legs were drilled out and packed with cancellous bone. In addition, a "T" plate was used to stabilize the arthrodesis site in 6 legs and an electrical bone stimulator was used in 6 others. The cancellous bone harvested from the tibias was used to pack the tarso-metatarsal and distal-intertarsal joints of the same leg. Results of the arthodesis experiment are not reported in this study.

Surgical Technique

The horses were held off feed for 12 to 18 hours prior to surgery. Water was not withheld. The horses were given 20,000 units/kg/procaine pencillin G IM, 4 to 6 hours presurgically. The horses were premedicated with 0.3 mg/lb of Xylazine i.v. and induced with a mixture of 500 cc of 5% guaifenesin and 3 gm thiamylal sodium given to effect. The horse was then intubated and maintained on halothane. The horse was placed in lateral recumbency on a waterbed on a hydraulic surgery table. The waterbed was filled with water until the animal just floated free of the table. The bladder was catheterized in all geldings and a purse string suture was placed in the prepuce to prevent leakage of urine. The catheter was diverted away from the site of the surgery.

The medial aspect of the tibia was prepared for orthopedic surgery in a routine manner using povidine iodine scrub, 70% ethyl alcohol, and povidine iodine spray. A plastic drape was put under the leg, 4 surgical towels were placed around the surgical site on the proximal medial tibia. The toweled area was covered by a cloth eye drape with a 5 cm diameter hole. A sterile towel was placed over the opening in the eye drape and the lower half of the drape was folded over the surgery site. The surgical site for the arthodesis was draped and the horse was covered with sterile body drapes.

Once the tarso-metatarsal and distal intertarsal joints were drilled and flushed, the graft donor site on the tibia was exposed. The groove for the middle patellar ligament was palpated cranially and the caudal border of the tibia was palpated caudally. The incision was started from a point half-way between the middle patellar groove and the caudo-medial border of the proximal tibia at the level of the distal aspect of the groove for the middle patellar ligament. From this point the incision was extended 3 cm distally. The incision was carried through the subcutaneous tissue, tendinous insertion of the gracilis muscle, and the periosteum. The periosteum was elevated and reflected. A 4.5 mm drill bit was then used to drill 2 adjacent holes through the cortex. A number 4 bone currette was then used to join the 2 holes and was enlarged sufficiently to accommodate the currette. The resulting hole was approximately 1 cm. in diameter.

Cancellous bone was then removed and placed in a sterile 10 ml glass beaker. Once the beaker was filled 2 or 3 curettes of blood were placed on top of the graft and allowed to percolate down through the graft. A saline soaked sponge was then placed over the beaker and the beaker was placed to the side where it was out of the direct heat from the surgical lights. The 2 drilled out joints were flushed again to remove any blood clots or remaining debris. The cancellous bone was then placed into the tarso-metatarsal and distal-intertarsal joints. If additional graft was needed it was taken directly from the tibia and placed in the joint where it was needed. A sterile moistened surgery towel was then placed over the donor site which was closed after completion of the arthrodesis. In some cases the donor site was closed by an assistant while the arthrodesis was being completed.

The donor site was closed in 3 layers; the aponeurosis of the gracilis and periosteum were closed together using 2 or 3 cruciate sutures of 2-0 braided polyglycolic acid suture. The subcutaneous tissue was closed with a simple continuous pattern of 2-0 using the same suture material and the skin was closed with horizontal mattress sutures of 2-0 monofilament nylon.

Aftercare and Monitoring

The horses were maintained on 20,000 units per kg of procaine penicillin G i.m. b.i.d. for 5 days. The clinical course of the heading process was monitored daily and the sutures were removed 12 to 14 days post operatively.

Radiology

Radiographs were taken 1 to 3 days postoperatively, at 2 weeks, and 4 weeks, and monthly thereafter. A 125 kvp, 50 mas capacity discharge machine was used to take the radiographs. The film was Chronex IV with high plus screens and an 8 to 1 grid. Machine settings were 100 kvp and 24 mas. The films were developed with an automatic processor.

Necropsy and Histopathology

Bone samples were taken from both tibias of horses which died or were euthanatized. The legs were disarticulated at the femorotibial joint. The soft tissues were removed from the proximal tibia and the proximal tibia was cut transversely with a bandsaw approximately 5.0 cm below the graft donor site. These bone ends were then cut longitudinally in sections approximately 8.0 mm thick. The sections were separated by paper towels, reassembled, tied together, and placed in a sealed bucket of 10% buffered neutral formalin. These sections were stored until the completion of the study and all the tissues were processed at one time. Fixed specimens were selected from each tibia to include the area which contained the hole in the cortex and the healing cavity where the cancellous bones had been removed. These sections were trimmed and each cavity was divided into 4 quadrants for decalcification, tissue block preparation, sectioning, and staining. The samples were decalcified and embedded in paraffin blocks. Eight micron sections were then sliced on a microtome and stained with hematoxylin and eosin using standard techniques.

Part II

Specimen Preparation

Twelve pairs of equine tibias were obtained from an abattoir. Those selected were all mature tibias (closed physes) and were of medium or smaller size. Some of the larger tibias were too large for the end brackets which were used to hold the bones in the torsion machine.

The majority of the soft tissue had been removed from the tibias at the abattoir. Additional soft tissue was removed at the proximal and distal ends of the tibias to facilitate molding of the ends of the bones. The ends of the bones were cut with a band saw perpendicular to the long axis of the bone just enough so that the bone would stand free on either end. This facilitated molding the ends of the bones to fit the holding brackets (Figure 1). When

Figure 1. The distal ends of the tibia are set in wooden forms corresponding to the size of the holding bracket. Both ends of the tibias were cut so they would stand free.

Fig.1

Figure 2. A tibia is shown with both ends molded and the corresponding brackets are present at either end.

Fig. 2

not being handled the bones were packed in saline moistened cotton, placed in plastic garbage bags, and the bags were placed in sealed plastic garbage cans. These containers were then placed in the refrigerated cooler.

The bones were placed in molds corresponding to the size of the holding brackets (Figures 1 and 2). Several molding compounds, including plastic autobody putty, anchoring cement, mortar, and concrete were used during pilot studies, but were found unsatisfactory because they would fracture or crumble before the bone. The compound selected for use consisted of 2 parts epoxy resin mixture to 3 parts oven dried silica sand.

Treatment

Two groups each containing six pairs of tibias were fractured. In group 1, cancellous bone was removed from the left tibia of each pair. A 4.5 mm drill bit was used to drill two adjacent holes midway between the posterior medial border of the tibia and the groove of the middle patellar ligament at the level of the distal end of the groove. The holes were then joined and enlarged with a bone currette so that cancellous bone could be removed through the hole. Due to the variation in size of the tibias, no predetermined amount of cancellous bone to remove was set. Instead, the volume of bone removed was that amount of cancellous bone which could readily be removed under usual clinical conditions from a bone of similar size (Figure 3). This amount was measured in a graduated glass beaker and recorded.

Testing

A Tinius Olsen torsion machine was used to fracture the bones (Figure 4). This machine measured the torsional load required to fracture the bone. An attempt was made to measure the degrees of torsional deformity at the time of fracture by recording the number of degrees of rotation at the time the

Figure 3. The cavity created by harvesting the cancellous bone from the proximal medial tibia can be seen. Note the abundance of cancellous bone still available.

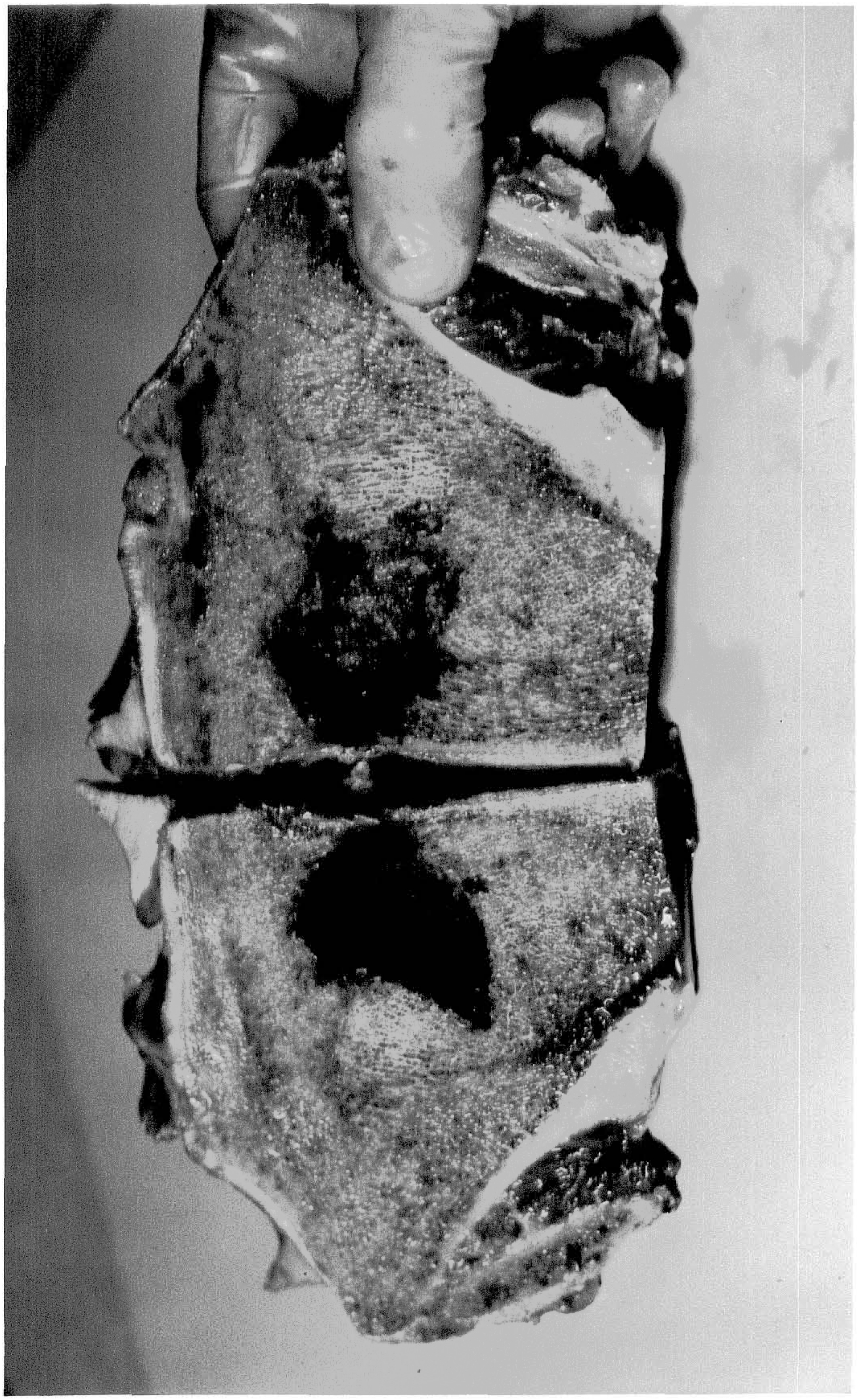

Fig. 3

Figure 4. The Tinius Olson torsion machine set up for testing. A sheet of rubber was taped around the bone to contain fragments.

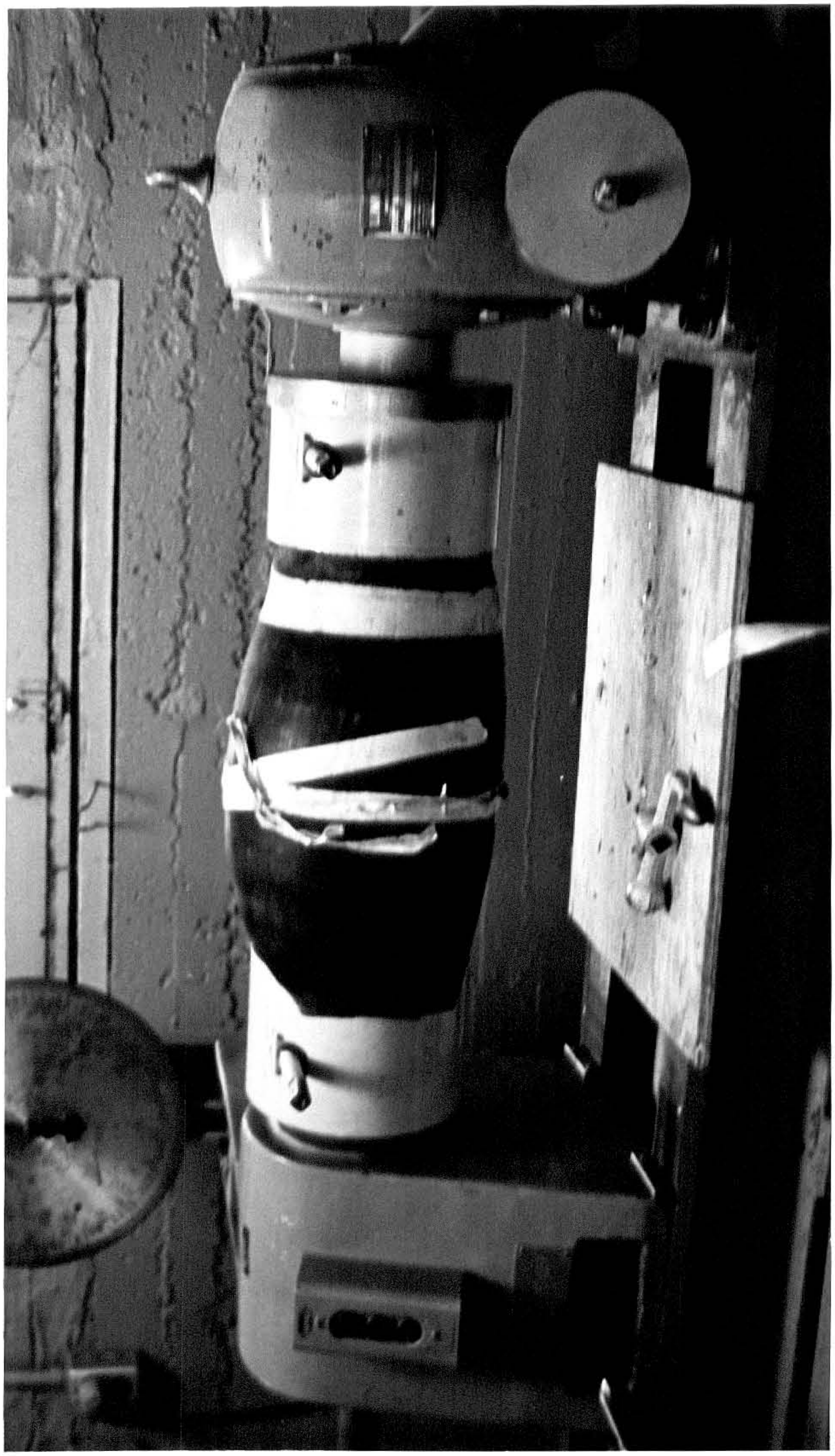

Fig. 4

maximum torsional load was reached. This measurement is not reported as it was subject to error because the machine had to be read while it was moving and the load failure pattern varied somewhat between bones.

In group 1, the tibial crests were rotated laterally about the long axis of the bone as viewed from the proximal end. Group 2 was treated similarly except that the cancellous bone was harvested from the right leg and an effort was made to remove a larger amount of cancellous bone relative to size than in group 1. The tibial crests in this group were rotated medially.

The load required to fracture the bones was recorded in inch-pounds. The general pattern of the fracture was recorded and whether or not the fracture line entered the graft donor site or the hole in the cortex. Black and white photographs of each pair of bones in group 2 were taken following fracture.

RESULTS

Part I

Clinical Observations

An adequate amount of cancellous bone (10-30 ml) to fill the drilled out joint spaces on the site of arthrodesis was obtained in all cases. The approach to the donor site was straightforward. The close proximity of the donor site to the site of arthrodesis made transfer of the graft material convenient.

The length of follow-up on these horses was variable due to complications associated with the arthrodesis experiment. Since both legs were operated on during the same anesthesia period, the anesthesia time was prolonged. Horses (9 and 12) had violent recoveries and were euthanatized in the recovery stall. Both horses were in the group which received a "T" plate on one side and an electrical stimulator on the other leg. This group required the longest anesthesia period. Horse number 9 fractured a third metatarsal bone down the line of screw holes in the side that had a "T" plate applied. Horse number 12 had severe pulmonary and cerebral edema and myositis. Since these two horses were euthanatized in the immediate postoperative period, the clinical observation on the tibial graft sites were limited to the availability of adequate graft material, the convenience of the surgical approach and closure, and the ability of donor site to hold up under the forces applied during two rough recoveries.

Horses number 1 and number 8 were the first 2 horses in the series to undergo surgery. Both horses died of renal failure of undetermined etiology at 10 and 12 days, respectively following surgery. In addition to the previous observations, the donor site incisions were followed and were observed to be healing satisfactorily at the time of death.

Two horses (3 and 6) were euthanatized 7 weeks postoperatively due to instability or infection at one or more of the arthrodesis surgery sites. Horse number 6 underwent a second surgery at 3 weeks on one side in an attempt to clear up an ascending infection from the electrode wires. An additional cancellous graft was removed distal to the original donor site on the right leg during the second surgery. No complications were noted on any of the graft donor incisions on either of these horses, including the tibial graft site which was operated on twice.

Horse number 7 was the only horse to have a donor site incision dehisce. This horse was painful postoperatively from the arthrodesis. He spent most of his time down and would urinate on his down leg. He developed an ascending infection, and dehisced on the 13th postoperative day. The wound was almost completely healed by second intention when the horse developed acute diarrhea and endotoxic shock 4 weeks postsurgery. The horse was reported to have a ruptured branch of the cranial mesenteric artery and midzonal liver necrosis at necropsy.

Horse number 11 was closed by an assistant who only closed the subcutaneous tissue and skin. This horse developed bilateral seromas at the graft donor site. The seromas were drained twice with hypodermic needle and healed without further complications. This horse developed hypoproteinemia and peritonitis 4 weeks postoperatively but responded to therapy.

Horse number 2 had no complications.

Radiology

A defect in the cortex approximately 1 cm in diameter was evident on the initial postoperative radiographs. The cavity where the cancellous bone had been removed was seen as an irregular decrease in density and did not have

Figure 5. The left tibial donor site of horse number 11 is seen at 3 days (A), 1 month (B), 3 months (C), and 6 months (D). At 1 month and 3 months there is increased density in the cavity at the donor site, but little change in the diameter of the cortical defect. At 6 months the cortical defect is smaller and the trabecular bone appears to be remodelling.

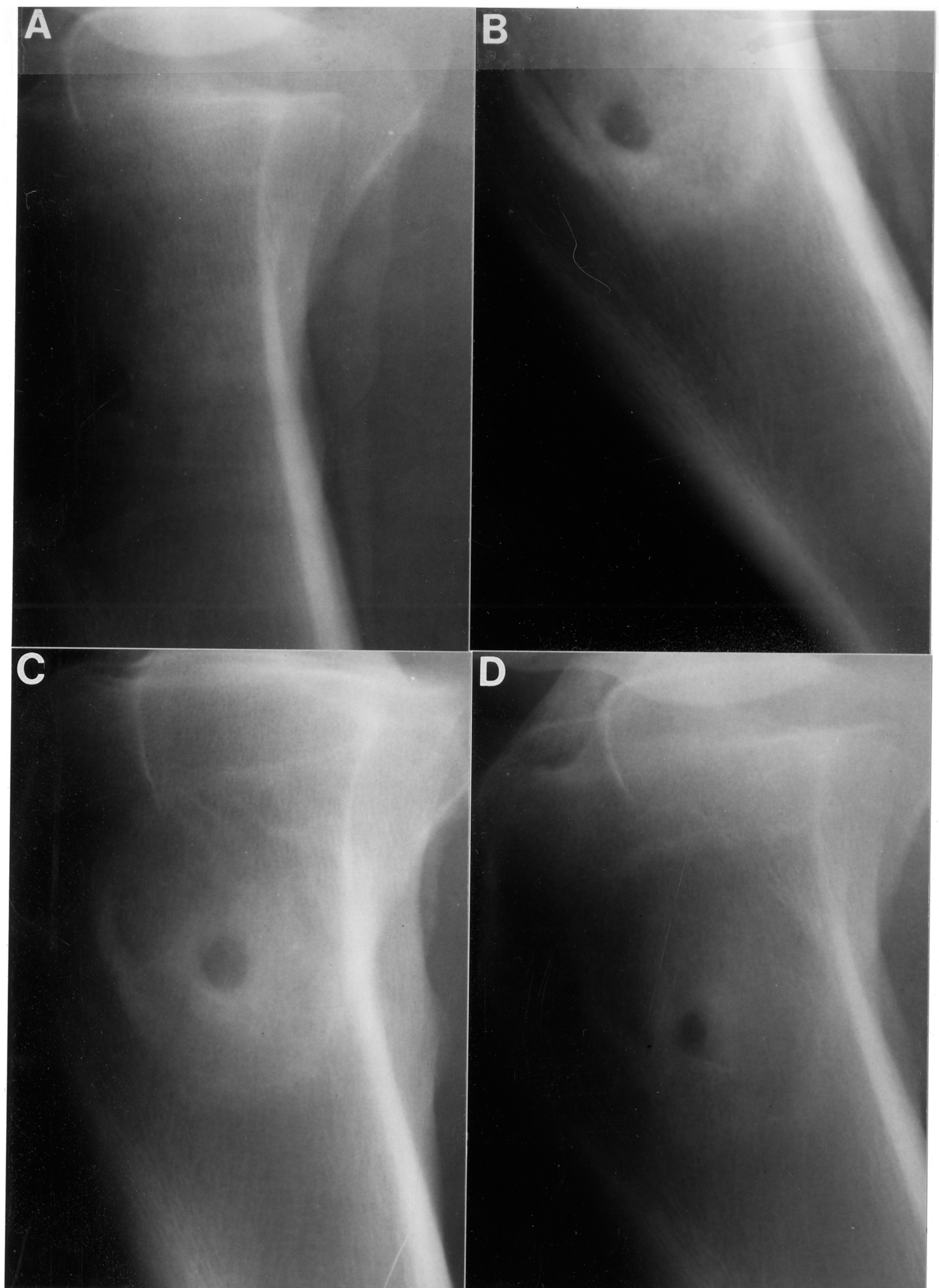

Fig. 5

sharply demarcated borders. By the 2 week film, the cavity in the cancellous bone was outlined by a narrow zone of sclerosis. The outline of the cortical defect was not as sharp, indicating some initial lysis of the cortical edges. The 1-, 2-, and 3-month radiographs show widening of the zone of sclerosis around the outline of the cavity in the cancellous bone and an increase in density throughout the cavity which lacked a distinct trabecular pattern as viewed on the lateral projection. The cortical defect showed little change. At 5 and 6 months, the cavity was still noticeably more dense than the surrounding area of cancellous bone, but it appeared to be remodelling at this stage as the trabecular pattern was becoming more distinct. The cortical defect was noticeably smaller at this stage, especially in horse number 11 but it was not completely filled in (Figure 5).

Histopathology

Histopathology was obtained on 5 horses. Horses 2 and 11 were 6 months post surgery, horses 3 and 6 were 7 weeks post surgery, and horse number 7 was 4 weeks post surgery when the specimens were obtained.

In horse 2 the defect in the cortex was still identifiable in the section through the hole. Mature fibrous connective tissue from the soft tissue scar was continuous into the defect in the cortex. A mature periosteal membrane lined the hole and was continuous with the periosteum of the outside cortex. As the fibrous connective tissue were moved deeper into the center of the cavity, it became broken up by clusters of fat cells. Trabecular bone formed an irregular border to the cavity, but there were few osteoclasts seen. Osteoblasts lining the trabecular surfaces were flat and were not numerous. The overall impression was that of a mature fibrous connective tissue scar with little activity.

The sections from horse number 11 have the same general appearance on scanning power as that of horse number 2. The fibrous connective tissue of the soft tissue was entering the hole and penetrating into the cavity. However, on closer examination there were more islands of trabecular bone throughout the cavity. The periosteum of the outer cortex did not penetrate and line the hole in the same manner as horse number 2. A larger number of osteoclasts was visible on the surface of the trabecular bone and osteoblasts were more numerous and more cuboidal than those seen in horse number 2. There were fat cells in the center of the cavity, but there were more islands of trabecular bone present throughout the cavity and the overall cellularity was increased over that seen in horse number 2.

Horses 3 and 6 were both 7 weeks post surgery. Sections of horse number 3 were similar to horse number 2, even though there was 4 months difference in the duration of healing. Horse number 3 did not show the periosteum lining the hole, but the overall impression was that of mature fibrous connective tissue and there was little cellular activity on the trabecular surfaces.

Sections from horse number 6 appeared similar to those of horse number 11. There were multiple islands of trabecular bone throughout the cavity. Trabecular surfaces were more cellular than in horse number 3.

Horse number 7 was 4 weeks post surgery at the time of collection. The sections from this horse showed more evidence of inflammation. There were multifocal areas of highly cellular clusters of neutrophils, mononuclear cells, and multi-nucleated osteoclasts. Small fragments of necrotic bone were identifiable in some of these areas. Trabecular surfaces appeared quite active with osteoclasts and osteoblasts. The overall impression was one of active healing and an inflammatory response due to necrotic debris still present at the site.

Part II

Mechanical Testing of Tibias

The torsional loads required to fracture the tibias in both groups are given in Tables III and IV. These values were analyzed using the paired T test. The value for the paired T test was 0.927. This value demonstrates there was no significant difference between the treated and control groups.

All fractures were spiral oblique fractures. Although the obliquity and comminution varied (Figures 6 and 7). The second group, which had been stored longer, showed more comminution as a whole than the first group. Tibia number 2 was the only tibia that the fracture line extend as far proximally as the donor site and that bone required a slightly greater load to fracture than its intact control. Bone number 12R broke lower than the other bones and with less comminution than the other bones in this group.

Figure 6. A typical spiral oblique fracture in the machine, immediately post fracture.

Fig. 6

Figure 7. Fracture configuration of pair 11.

Fig. 7

DISCUSSION

The merits of fresh autogenous cancellous bone grafts in orthopedic surgery have been discussed in the introduction and literature review. It is a well recognized tool of operative orthopedics regardless of the species. In the repair of equine long bone fractures the race between osseous union and implant failure is often close under the best of circumstances and the equine surgeon should use every measure available to increase the chances of a successful outcome. Although the advantages of autogenous cancellous bone grafts in stimulating early callus formation are well established, the surgeon must weigh these advantages against other factors such as the length of the anesthesia period, the length of time the surgical wound is open to possible airborne contamination, and the practical limitations of available facilities and personnel.

The clinical part of this experiment was designed to test some of the practical aspects of using the tibia as a source of cancellous bone in a procedure for which it might be indicated. The tibia was found to have several advantages making it an attractive site for the removal of cancellous bone. It is accessible in either dorsal or lateral recumbency. The approach is simple and straightforward and it is in an area where there are no major vessels or nerves and minimal soft tissue. The incision required is small in comparison to other techniques described for removal of cancellous bone from the ilium or tuber coxae and the closure is quick and simple. Although this experiment was not designed to compare the surgical times between the ilium and tibia for harvesting cancellous bone the tibia required significantly less time for the total graft harvesting procedure.

Complications were seen in three of 16 incisions followed for 10 days or longer. Horse number 11, the one case of bilateral seroma formation at the donor site is attributable to surgical technique. The incision was closed in only 2 layers, the subcutaneous layer and skin. Although some temporary edema was present in other incisions, no incisions which were closed in 3 layers developed seromas. The only dehiscence in the series was in horse number 7 which spent most of his time down and contaminated the incision with urine repeatedly. The incision developed an infection and dehisced on the 13th day postoperatively.

Complications involving the arthrodesis experiment affected the clinical follow-up of the graft donor sites in several of the horses. However, the two cases involving violent recovery periods did provide some indication of the ability of the donor sites to hold up under adverse conditions.

In horses 1 and 8 the etiology of the renal failure was never fully established. The tubular nephrosis and marked crystalluria could have been attributed to poor renal perfusion during prolonged anesthesia. However, the horses were maintained on fluids throughout the surgical procedure. Also, several other horses which underwent surgery in the hospital during the same time period were affected and some of these horses had anesthesia periods of under 1 1/2 hours. Only one other horse died but several horses showed clinical signs of uremia and had marked elevations in BUN and creatinine. The osmolality of the fluid was one of the possibilities investigated but a definitive answer was not concluded.

Retrospectively, in view of subsequent clinical experience and studies done by other investigators it is probable that 2 of the horses in this experiment developed acute phenylbutazone toxicity.[74] Horse #7 had a total protein of 7.1 gm/dl 11 days prior to the onset of diarrhea and endotoxic shock 4 weeks postsurgery. At the onset of acute signs the horse had a serum protein of 3.6 gm/dl and a PCV of 39%. At the time of death 48 hrs later the serum protein was less then 2 gm/dl. The horse died on a weekend and was not necropsied until Monday at which time there was significant autolysis present. The necropsy diagnosis was a rupture of a branch of the cranial mesenteric artery. No mention was made of the condition of the gastrointestinal tract, presumably due to the state of autolysis. It is conceivable that this vessel was involved in an ulcerative lesion of the gut wall due to phenylbutazone toxicity. Horse #11 developed signs of acute peritonitis 4 weeks postoperative. At that time the serum protein was 3.3 gm/dl. The nucleated cell count in the peritoneal fluid was 200,000 $/mm^3$. One month previously his serum protein had been 6.8 gm/dl. This horse responded to therapy and completed the experiment. At the time of necropsy there were multiple peritoneal adhesions, a small abscess in the intestinal wall, and suppurative inflammation in the intestinal mucosa. It is probable that this horse had a perforating ulcer secondary to acute phenylbutazone toxicity at the time of acute peritonitis.

The earliest and most consistent laboratory change in acute phenylbutazone toxicity is a decrease in serum protein; which was seen in both these horses[74]. Other signs that may be seen in severe cases are diarrhea, endotoxic shock, and ulcers of the gastrointestinal tract. Both of these horses had shown pain postoperatively due to the arthrodesis procedure. Both horses had been maintained on 1 1/2 to 2 gm of phenylbutazone orally b.i.d. postoperatively and both horses had been given an increased dose of 3 gm of phenylbutazone orally b.i.d. for 9 days prior to the onset of acute signs.

It has been shown that a defect in the cortex of long bones can decrease its energy absorbing capacity by 40 to 70%, due to a stress concentration effect[16,22]. Yet, none of the bones in the in vitro or in vivo parts of this study showed a significant reduction in strength. Other factors besides the stress concentration effect may be more significant within the confines of this study and the clinical situations it represents, to explain why significant reduction in load required to fracture the tibias in torsion was not observed.[22,36,66,68]

There are several factors which are probably of significance. In other experiments which have looked at the effects of stress concentration, the location of the stress concentration has been determined by experimental design to be placed in the area of maximum tensile or torsional stress.[16,55] In this experiment the placement of the hole was determined by clinical usage. Most fractures of the tibia occur in the distal third of the diaphysis or near the junction of the distal and middle thirds. This is the narrowest region of the diaphysis. The cortex in this area is much thicker than the cortex in the metaphyseal regions and the total cross-sectional area of bone material at this sight may be equal to or greater than the cross-sectional area of cortical bone in the metaphysis. However, because the bone material in the proximal third of the tibia is distributed further from the torsional axis than the bone material in the distal third, the bone in the proximal third of the diaphysis has over twice the polar moment of inertia that the distal third has.[35] The polar moment of inertia is a major determinant of the strength of the tibia in torsion.[4,35,66]

Another factor is that other experiments testing the affects of stress concentrations in tubular bone have made their holes in the diaphysis and communicated with the marrow cavity.[16] The holes created in this experiment were created in the metaphysis where the architecture of the cancellous bone may be acting to redistribute forces similar to stress distribution in a geodesic dome. Factors such as the heterogeneous and anisotropic nature of bone also may serve to dampen the affect of stress concentration.[16,22,68] The sum total of these factors is that even with a hole in the cortex of the metaphysis and removal of cancellous bone the weakest area of the tibia is the distal tibial diaphysis.

After making a hole in bone, the bone begins to remodel rapidly. Studies in rabbits have shown that the stress concentration effect of a hole drilled in the cortex was almost gone by 8 weeks.[22] When boney defects were created in the distal femur of dogs, the bone regained 80% of its strength by 16 weeks and 93% by 48 weeks.[55]

Most surgical conditions in the horse which would benefit from autogenous cancellous bone, such as arthrodesis, bone cysts, and fresh fractures do not require large amounts of cancellous bone. Up to 55 ml of cancellous bone was removed from tibias in this experiment without a significant decrease in load to fracture in the bone. This amount would fulfill the requirements of the majority of orthopedic procedures in the horse with the exception of those cases where large defects are present.

Other investigators have found that when the defect created in the cortex was less than 30% of the diameter of the bone the size of the hole was not significant.[16,22,36] At some point the amount of bone removed becomes significant. The present study does not explore that limit.

The results of this experiment indicate that the tibia can be used as a source of cancellous bone in the horse without significantly altering the torsional load capacity of the tibia or increasing the chance of pathologic fracture in adult horses using the technique described. The tibia was found to be a convenient, and practical site to harvest cancellous bone in a minimum amount of time. The incidence of complications associated with the graft site was low and preventable. The results of this study justifies increased use of the tibia as a convenient source of cancellous bone in the adult horse. It cannot be recommended in horses with open tibial physes or for cases where the need for more than 50 mls of graft is anticipated.

SUMMARY

The safety and practicality of the use of the proximal tibia as a source of autogenous cancellous bone in the adult horse were studied from 2 aspects. Nine adult horses underwent surgery for bilateral arthrodesis of the tarso-metatarsal and distal intertarsal joints. The proximal medial tibia was used to harvest autogenous cancellous bone for grafting the arthrodesis sites in each case. The convenience of the procedure and the accessibility of the site were noted. The healing of the soft tissue wound was monitored clinically and the healing of the osseous defect was monitored radiographically at regular intervals up to 6 months in 2 cases. The healing of the donor site was observed histologically at varying stages of healing in 5 cases.

Complications were noted in only 3 of the 16 incisions followed for more than 10 days. It was concluded that these complications were secondary to other problems or attributable to errors in surgical technique. The site was found to provide convenient access to cancellous bone in either lateral or dorsal recumbency. The anatomical landmarks were reliable and the surgical procedure for harvesting the graft was simple and short.

To further evaluate the safety of this procedure in terms of increased risk of pathological fracture through the donor site the load required to fracture 12 pairs of equine adult tibias in torsion was determined. A 1 cm defect was created in the proximal medial tibial cortex of the tibia in each pair, a volume of cancellous bone was removed through this defect, and the volume recorded. The tibia's were then fractured in torsion. Load to fracture was recorded as well as the general pattern of fracture and whether the fracture entered the graft donor site. It was found that there was no significant difference in load to fracture or in fracture pattern between the treated and control tibia in each pair.

The results indicate that the technique used for harvesting cancellous bone from the proximal tibia did not increase the risk of fracture since the weakest area was the distal third of the tibial diaphysis.

The decreased surgery time, simplicity, and accessibility of this technique regardless of surgical position made the tibia an attractive alternative to the ilium for most procedures requiring cancellous bone in the adult horse.

TABLE I

Subject Identification

Number	Weight	Age	Sex	Description
1	800	12 yr	Fe	Appaloosa X
2	850	8 yr	Fe	QH--Red Dun
3	920	8 yr	M/C	QHX Bay
6	880	10 yr	M/C	QH--Red Dun
7	950	14 yr	M/C	QH Sorrel
8	900	9 yr	Fe	Paint
9	1200	8 yr	M/C	Buckskin
11	1000	11 yr	M/C	QH Sorrel
12	1100	12 yr	M/C	QH Sorrel

TABLE II

Clinical Observations

Group	Horse	Right Leg	Left Leg	Observation Period	Clinical Course of Donor Site	Complication
II	1	Elect. Stim.	Drill and graft	10 days	Wounds healing without complication at the time of euthanasia	Renal failure--unknown etiology
I	2	T plate	Drill and graft	6 months	Wounds healed without complication	None
II	3	Elect. Stim.	Drill and graft	7 weeks	Ibid	Euthanatized due to unstable arthrodesis site
III	6	Elect. Stim.	T plate	7 weeks	Ibid	Euthanatized due to ascending infection from electrode wires and instability at the arthrodesis site
I	7	Drill and graft	T plate	4 weeks	Left rear healed first intention, right rear dehiscenced due to urine scald and ascending infection	Died--endotoxic and hemorrhagic shock
I	8	T plate	Drill and graft	12 days	Wounds healing without complication at the time of euthanasia	Renal failure--unknown
III	9	T plate	Elect. Stim.	Euthanitized in recovery	N.A.	Fractured MT-III along line of screws during recovery
II	11	Drill and graft	Elect. Stim.	6 months	Bilateral seroma formation healed following drainage	Peritonitis and hypoproteinemia 4 weeks postoperatively responded to therapy (see Discussion)
III	12	T plate	Elect. Stim.	Euthanatized in recovery	N.A.	Pulmonary edema, myositis, cerebral edema or trauma

TABLE III

Group I
Cancellous Bone Harvested From The Left Leg Tibial Crest Rotated Laterally

Specimen	Volume (ml) of Cancellous Bone Removed	Load at Failure (in lb.)	Type of fracture
1L	25	4530	Comminuted spiral oblique fracture of the tibial diaphysis
1R		4650	Ibid
2L	30	4500	Same, but one fracture line extended up through hole in the cortex
2R		4250	Comminuted spiral oblique fracture of the tibial diaphysis
3L	25	5190	Ibid
3R		4830	Ibid
4L	35	4380	Ibid
4R		4550	Ibid
5L	25	4550	Ibid
5R		4820	Ibid
6L	20	4360	Ibid
6R		3990	Ibid

TABLE IV

Group II
Cancellous Bone Harvest From The Right Leg Tibial Crest Rotated Medially

Group II	Volume (ml) of Cancellous Bone Removed	Load at Failure (in lb.)	Type of fracture
7R	25	3270	Comminuted spiral oblique of the diaphysis*
7L		3650	Ibid
8R	55	6720	Ibid
8L		6520	Ibid
9R	25	3300	Ibid
9L		4410	Ibid
10R	25	3710	Ibid
10L		3800	Ibid
11R	40	4190	Ibid
11L		3860	Ibid
12R	45	3500	Fractured more distal than the others and with less comminution
12L		4480	Comminuted spiral oblique of the diaphysis
			*Group 2--as a whole showed more comminution than group one

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SAFETY AND PRACTICALITY OF USING THE PROXIMAL TIBIA AS A SOURCE OF AUTOGENOUS CANCELLOUS BONE IN THE HORSE

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AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Surgery and Medicine

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1982

ABSTRACT

Autologous cancellous bone grafts are indicated in the following clinical situations: delayed and nonunion, arthrodesis, osseous defects following sequestrectomy in osteomyelitis or curettage of bone cysts, missing fracture fragments, and fracture gap.[49,61] They may also be indicated in certain fresh fractures treated with internal fixation in which stimulation of early callus formation is deemed essential.

The ilium has been the most common site for harvesting cancellous bone in the horse.[73,76] The use of the proximal medial tibia has been reported but questions of the safety of its use were raised.[82] The ilium is inaccessible in dorsal recumbency. The tibia would be an attractive alternative to the ilium in many situations if it could be safely used. To test the safety of using the tibia as a source of autologous cancellous bone for grafting in the horse, the tibia was used as the donor site for cancellous bone for use in a study of 3 techniques for arthrodesis of the tarsometatarsal and distal intertarsal bones.

The convenience and accessibility of the site and technique were noted. Wound healing of the soft tissue was monitored clinically and the bone healing was monitored radiographically and histologically. Complications with the bone graft procedure included seromas in 2 incisions and one dehiscence. These were attributed to errors in surgical technique or secondary to other problems. The technique was considered simple and practical.

The safety of the technique in relation to the possibility of increased risk of pathologic fracture through the donor site was investigated by testing the load to fracture in 12 treated and control pairs of equine tibias. The

treated tibias had cancellous bone removed through a one centimeter defect. Both tibias in each pair were then fractured in torsion and the load to fracture and fracture configuration in each pair recorded.

No significant difference between load to fracture in treated and control tibias or fracture pattern was found.

In conclusion the tibia was felt to be a safe and attractive alternative to the ilium as a source of cancellous bone in adult horses.