Comparison of Two Methods of Long Bone Fracture Repair in Rabbits

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Abstract

Two different methods of rabbit femoral fracture repair were evaluated: (1) stainless-steel surgical plate and bone screws; and (2) placement of an intramedullary pin and an external skeletal fixator device. On average, bones repaired with the bone plate method withstood 35.1 lb/47.6 N (range, 14.4-63.0 lb/19.5-85.4 N) of compressive and bending forces before failure occurred. Bones repaired with intramedullary pin and external skeletal fixator device method withstood an average of 67.7 lb/91.8 N (range, 48.7-94.8 lb/66.0-128.5 N) of compressive and bending forces before failure, but the bone was more likely to shatter during implant application. Normal rabbit femurs placed in the control group were able to withstand an average of 148.4 lb/201.2 N (range, 100.0-192.0 lb/135.6-260.3 N). The fragility of rabbit bones made testing of any implant viability problematic. This study demonstrates advantages and disadvantages to each method of fixation in rabbits and compares important differences in application of fracture repair implants with those of other domestic species. © 2010 Published by Elsevier Inc.

Key words: **bone; ESF device; femur; fracture; plate; rabbit**

Rabbit bones are delicate in comparison with the long bones of other domestic companion animals. The skeleton of a rabbit represents only 7% to 8% of body weight, as opposed to 12% to 13% of a domestic cat's body weight.[1,2] Rabbits have powerful muscular hind limbs, and 70% of their body weight is carried by this part of the body. Therefore, long bone fractures are a relatively common presentation regarding pet rabbits, especially within the hindlimbs.[3] Many veterinarians accus-

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tomed to treating fractures in a small animal practice may attempt to approach rabbit long bone fractures in a manner identical to that used for dogs and cats. Unfortunately, many of the surgical implants made for use in veterinary medicine are too heavy or large for rabbits. Even when standard implants are applied correctly, the brittle bones of the domestic rabbit may fail. The purpose of this study was to test the quality, applicability, durability, and success of 2 different methods of rabbit femoral fracture repair: (1) surgical plate fixation bridging the fracture edges; and (2) placement of a metal pin inside the femur (intramedullary [IM] pin) and an external skeletal fixator (ESF). These methods of fixation are commonly used in other domestic mammals, but the best method of surgical fracture repair has yet to be determined for rabbit patients that present with long bone fractures.

Materials and Methods

Twenty-eight paired femurs harvested from adult male and female New Zealand White rabbits (n = 14) previously euthanized as part of another study at the University of Georgia, College of Veterinary Medicine were used for this study. All rabbits were the same age (1 year), approximately the same size (12-14 lb/5.5-6.4 kg), and were maintained in the same animal care and use facilities approved by the Association for Assessment and Accreditation of Laboratory Animal Care. All rabbits were fed the same diet of commercial laboratory rabbit pellets and timothy hay and provided free choice tap water before being killed. The bones were cleaned of all soft tissue and frozen in physiological saline solution–soaked gauze in a −70°C freezer immediately after euthanasia. Previous studies in rabbits have indicated that freezing does not affect bone integrity.[4] The bones were removed from the freezer after approximately 9 months and allowed to thaw to a temperature of 4°C in the refrigerator for 24 hours. The specimens were then unwrapped from the wet gauze, the fixation device applied, and the bone allowed to air dry for 24 hours before testing. The femurs were divided into 3 groups. Two groups had a transverse fracture of the femur simulated by removing a 1-mm segment of bone at the mid-point of the bone, and repaired by means of 1 of the 2 described methods. The implant devices were all applied by the same veterinary surgeon. One group of intact femurs was used as a control. For group 1, the fixation device was a 6-hole, 2.0-mm stainless-steel bone plate (Dynamic Compression Plate (DCP), Synthes, Paoli, PA USA) that used 2.0-mm bone screws that were 4 mm, 8 mm, or 12 mm in length. The device was applied to an intact rabbit femur. The length of the bone was measured in centimeters from the tip of the greater trochanter to the distal end of the condyles; the midway point of the bone was marked with ink and the bone numbered for identification purposes. The plate was applied to the lateral aspect of the femur and centered over the marked midway point on the bone. Screw holes were predrilled with a 1.5-mm drill bit and air drill (Fig 1). The screw holes were then tapped with a 1.5-mm screw tap. Predrilling and tapping should decrease local stress, thereby lessening the likelihood of iatrogenic bone damage. A 1-mm gap defect (perpendicular cortical bone osteotomy) was then cut into the midway point of the bone from the medial aspect down to the plate with an electric jig saw. For group 2, the fixation device was a 3/32″ IM pin and ESF with 1.57-mm or 0.062-inch mini half pins with positive profile threads tied into a 1/8″ fixation bar with single mini SK clamps (IMEX Veterinary, Inc., Longview, TX USA). The IM pin was placed normograde with a hand chuck. The holes for the ESF pins were predrilled with a 1.5-mm drill bit and then the pins placed with a Makita power drill (Makita Corporation, Anjõ, Japan). Two pins were placed above the fracture site, approximately 1 cm apart, and one was placed below (Fig 2). The fixator bar was placed 2 cm away from the bone

Figure 1. Screw holes were predrilled in all rabbit femurs with a 1.5-mm drill bit and air drill and then tapped before placing 2.0-mm bone screws by hand to hold the 2.0-mm plate to bone. Predrilling and tapping decrease local stress, lessening the likelihood of traumatizing the bone.

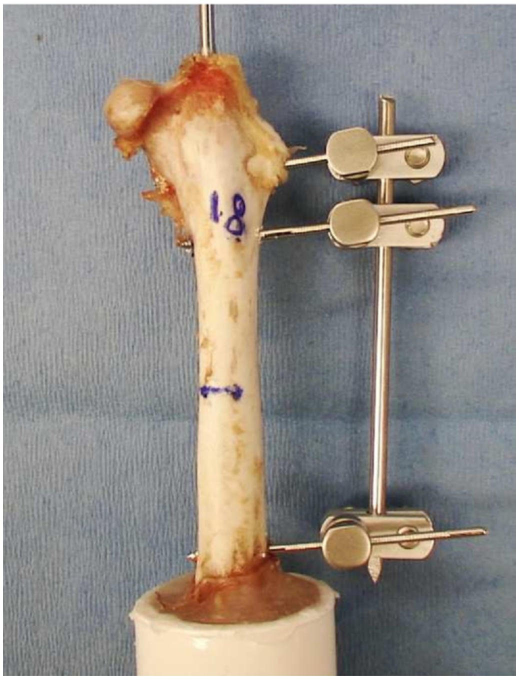

Figure 2. Typical construct placed on rabbit femurs of 3/32″ IM pin and ESF with 1.57-mm or 0.062-inch mini half pins with positive profile threads tied into a 1/8″ fixation bar with single mini SK clamps. Bones repaired with this method withstood an average of 67 lb (91 N) of bending and compressive forces before the bone (not the fixation device) failed.

and tightened down with SK clamps with a 7-mm open-ended wrench. Biomechanical testing of fracture repair methods was performed with a computer-controlled machine (Instron Model 4201 material testing machine; Instron Corporation, Canton, MA USA). This device is designed specifically to simulate the natural stresses that occur on bones. The stress machine tests the specimens to assess the strength and stability of the different fixation systems as well as the maximum amount of pressure that could be applied before failure. Briefly, before testing, the distal end of a model is fixed to the rigid base of an Instron Model 4201 material testing machine and the proximal end fixed to the machine's moveable crosshead. The distal end was fixed in bone cement with a 3/4″ hard plastic cup, which was then attached to the Instron base and a rounded rod connected to the proximal end of the model to the Instron's crosshead, simulating a hip joint (Fig 3). During testing, movement of the crosshead deforms the model in compression. Both the deformation (e.g., crosshead movement) and response force of the model to this deformation were recorded via video and strip-chart recorders at a crosshead speed of 0.02 mm/min. Testing continued until bone rupture occurred, or fixation failure occurred resulting in a decreased load response. After testing, deformation-force graphs were generated and the material properties of the fixation model determined. These properties included stiffness, strength, and toughness. The results of each mode of fixation were plotted on graphs and maximum bending and compressive force load determined. The comparison of these plotted values helped to determine which type of fixation was preferred. Repaired specimens were also radiographed and bone density from each specimen visually estimated to rule out differences in bone density as a factor of failure (Fig 4). All bones appeared of comparable density and size, ranging in length from 9.5 to 10.5 cm.

Results

For group 1, initially an 8-hole, 2.0-mm plate was used. However, this method of fixation resulted in the bone fracturing as the last screw was being applied to the hole second from the distal end. Based on these findings, a smaller 6-hole plate was used. At first, all 3 screws on either side of the fracture were placed through both cortices of the bone. Again, this resulted in the bone fracturing with placement of the last screw in the hole second from the proximal end in 1 more bone. Thus, in the third bone repair attempt, the plate was placed with the 2 end and 2

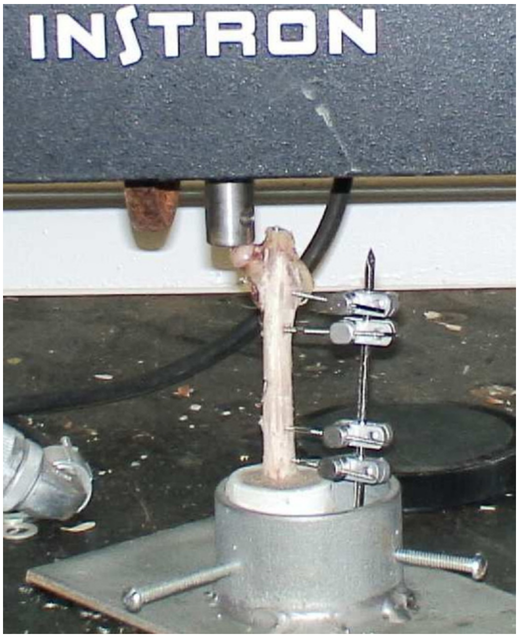

Figure 3. The Instron Model 4201 machine is specifically designed to simulate the natural stresses that occur on bones in live animals. It then records the maximum amount of pressure that can be applied before either the bone or the implant fails.

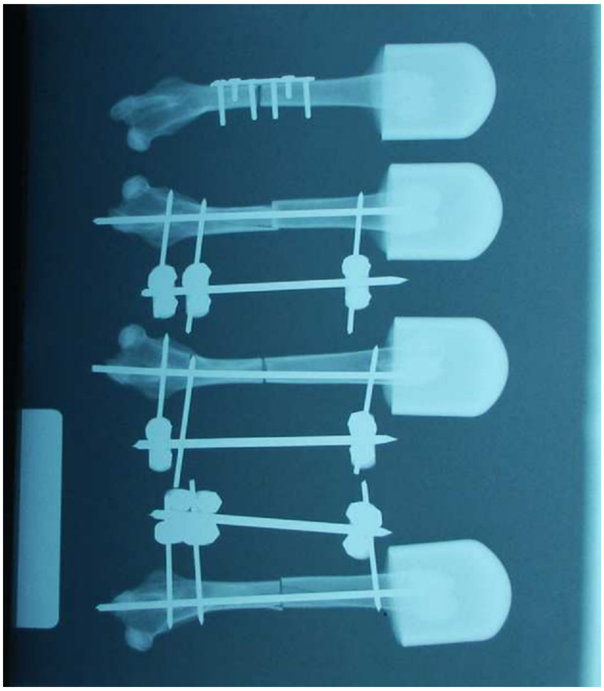

Figure 4. Repaired femurs were radiographed, and bone size and density from each specimen were estimated to be equal. Note the relative size of the IM pin to bone on the constructs in group 2, and placement of screws (only every other screw goes through both cortices) in group 1.

middle screws (closest to the osteotomy sight) being full thickness, but the second screws from the ends being engaged in only 1 cortex. Seven bones from this group had 6-hole, 2.0-mm plates placed with no complications and were used for testing construct load-carrying capacity in the Instron. On average, bones repaired with this method withstood 35.1 lb/ 47.6 N (range, 14.4-63.0 lb/19.5-85.4 N) of compressive and bending forces before failure occurred, usually at the plate and not in the bone (Fig 5). However, it was noted that some bending occurred in the plate near 14 lb/19 N in a few of the bone models. For group 2, 14 bones were placed in this group because of the high failure rate initially experienced when placing IM pins and ESF devices in rabbit bones, thereby necessitating repeated revision of the construct of the fixation device. Based on previous experience and modeling of IM pins used in canine or feline fracture fixation, an IM pin of 2.8-mm or 7/64″ diameter (approximately 75% of the medullary cavity, which is considered appropriate in conventional orthopedic repair in other species) was initially placed with a Makita drill. This resulted in the fracture of 2 normal rabbit bones. A smaller pin of 3/32″ (approximately 50% of the medullary cavity) was then chosen and placed with the same drill. This resulted in the fracture of 2 more bones. A hand chuck was then used to place the 3/32″ pins in all of the remaining 10 bones. Despite extreme care of the surgeon, 3 more bones were fractured during the placement of IM pins. Initially, 2 ESF pins were placed, 1 cm apart above and below the simulated fracture site. However, this resulted in 2 more bones fracturing as the last pin was being placed in the more distal segment of bone. Therefore, an ESF device with 2 pins above the osteotomy and 1 below was used. This allowed for the successful application of an IM pin with an ESF in 5 bones. On average, bones repaired with this method withstood 67.7 lb/ 91.8 N (range, 48.7-94.8 lb/66.0-128.5 N) of compressive and bending forces before failure occurred in the diaphysis of the bone at the sites of implant insertion, but never in the fixation device itself. Control group: Five bones were placed in this group. Normal rabbit femurs were able to withstand an average of 148.4 lb/201.2 N (range, 100.0-192.0 lb/135.6-260.3 N) of compressive and bending forces before failure occurred, usually at the femoral neck.

Discussion

The most profound finding of this initial study was that standard attempts at establishing a competent bone-implant construct for rabbit long bone fractures failed at the bone-implant interface. This primary bone failure made testing of implant viability

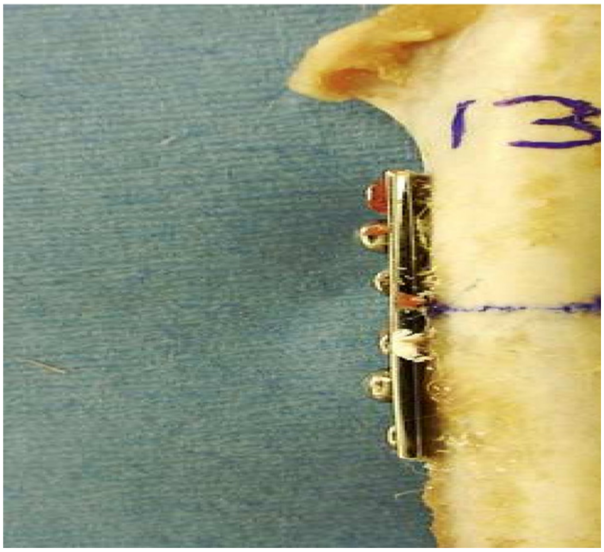

Figure 5. The fixation device pictured here is a 6-hole, 2.0-mm DCP stainless-steel bone plate and 2.0 mm-bone screws either 4 mm, 8 mm, or 12 mm in length. Bones repaired with this method withstood an average of 35 lb (47 N) of compressive and bending forces before failure occurred, usually at the plate and not in the bone.

very difficult. Based on a study investigating bone composition in domestic versus wild rabbits, bone strength in the former appears to be significantly weaker than in the latter (K. Rosenthal, personal communication). It is also the authors' clinical experience that bones of domestic rabbits are extremely brittle and are therefore more difficult to surgically repair than those of other animal species of similar weight and size. Initial data found that at relatively low primary compressive loads (much lower than needed to fail a normal bone) the bone-plate construct placed on rabbit bones in this study had deformation. This was mostly likely due to the short plate and limited number of screws that could be positioned in the bone without cortical fracture. The limitation of only being able to place a 6-hole plate with 5 points of cortical contact on either side of the fracture appears to severely restrict the use of plate fixation on the rabbit femoral diaphysis. The external fixator and IM rod placement revealed a different set of complications. These bone-implant constructs uniformly failed at the sites of implant insertion (both IM pin and external fixator pin). Compressive load application created 1 bone failure before the implant was stressed, which again limited the authors' ability to assess implant performance. The failure of both sets of implant/bone composite fracture fixation devices in this study demonstrates the need for better understanding of rabbit cortical bone and its fundamental structural and mechanical properties. Once the fundamental structure and mechanical properties of rabbit long bones have been determined, surgeons can begin to investigate a successful design for internal or external fixation of long bone fractures in domestic rabbits. Both internal and external fixation devices may have benefits and complications when applied to the live rabbit patient. The data collected here suggest that bone plates are less likely to cause damage when being placed on a normal rabbit bone. However, plates of the size used in this study may not provide the same rigidity as other methods of fixation (i.e., bending was noted in several bones at only 14 lb of compressive force, which approximated body weight in these animals). Advantages of ESF over other methods of long bone fracture repair include versatility in construct assembly, wound management of open fractures, minimal disruption of vascularity at the fracture site, and moderate equipment costs.[5] Several studies have evaluated the biomechanical properties of ESFs alone and in combination with IM pins.[6-10] Although the IM pin was not tied into the ESF for the purposes of this study, because only compressive and not torsional forces were applied, this method has been used clinically by the authors in rabbits and has been shown experimentally to be advantageous in providing greater immobility to the fracture sight in other species.[6,10] Fixator pins were placed as far away as possible from the fracture sight for 2 reasons: (1) in a live animal, the bulk of the muscle lies over the center of the bone and placing pins in this region would cause too much morbidity to the soft tissue; and (2) rabbit bones are very brittle and more likely to shatter when placing pins closer to the narrower center of the bone. In one study, no significant differences were found in the pattern of bone healing with plate fixation versus external fixation in rabbit tibias.[11] If used for repair, it is recommended that bone plates be removed in 4 to 9 weeks after application, necessitating a second surgery.[12] If left longer, bone plates may delay callus formation and bone healing, and may even cause osteoporosis because of the excessive stiffness of the stainless-steel plate shielding the fracture sight from normal stress.[12] One advantage of ESF method is staged reduction of the construct, allowing a gradual return to weight bearing at the callus. Methods of fixation may vary based on the type of fracture, available equipment, and surgeon's experience.

Acknowledgments

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