The Intraosseous Blood Supply of the Canine Radius: Implications for Healing of Distal Fractures in Small Dogs

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The intraosseous vascular anatomy of the radius was studied in 12 pairs of canine cadaver limbs. Six pairs of specimens were obtained from small-breed dogs (less than 6 kg) and six pairs were obtained from large-breed dogs (18 to 30 kg). All specimens were studied after arterial injection with India ink. Samples were fixed, frozen, then sectioned and processed using a modified Spalteholz technique. In all specimens, the intraosseous blood supply arose from the nutrient artery with its associated branches and the metaphyseal arteries. In small-breed dogs, there was decreased vascular density at the distal diaphyseal-metaphyseal junction compared with large-breed dogs. The reduced vascularity corresponded to the region associated with a poor prognosis for fracture healing in small-breed dogs. This regional association suggests that a decreased vascular supply in the distal radius may contribute to a higher frequency of delayed union and nonunion in smaller dogs.

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RADIAL FRACTURES in dogs most commonly occur in the distal one-third of the diaphysis. Clinical observations suggest that the prognosis for healing depends, in part, on the size of the dog. Distal radial fractures in young, midsized to large-breed dogs generally progress to healing regardless of the method of stabilization. Fractures occurring in the distal radius of small-breed dogs, however, have a greater risk for the development of delayed union or nonunion.

The method selected for repair of radial fractures influences the course of healing. Closed reduction with a cast or splint is often successful in the larger breeds of dogs, however, a high rate of failure occurs in smaller dogs. Repair of radial diaphyseal fractures using intramedullary pins should be avoided because it has been associated with healing complication rates as high as 80%. Application of an external skeletal fixator (ESF) or plate has been reported to be successful in all size dogs. Plate fixation has been especially useful for treatment of fracture complications, specifically nonunions, in small-breed dogs.

The cause of impaired healing of distal radial fractures in toy and small-breed dogs has not been identified; however, biomechanical or vascular influences, or both, have been implicated. Biomechanical factors which may predispose to con-

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Supported in part by the Tufts University School of Veterinary Medicine Hill’s Research Fund and the Laboratory for Comparative Orthopaedic Research, College of Veterinary Medicine, Michigan State University.

Presented at the Fifth Annual American College of Veterinary Surgeons Poster Session, October 29 to November 1, 1995, Chicago, IL.

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Table 1. Demographic Data of Small-Breed Dog Group

<table>
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<th>Case no.</th>
<th>Breed</th>
<th>Age (yrs)</th>
</tr>
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<tbody>
<tr>
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<tr>
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<td>Jack Russell terrier</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
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<td>4</td>
</tr>
<tr>
<td>4</td>
<td>Yorkshire terrier</td>
<td>13</td>
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<tr>
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</tr>
<tr>
<td>9</td>
<td>Jack Russell terrier</td>
<td>2</td>
</tr>
<tr>
<td>13</td>
<td>Fox terrier</td>
<td>2</td>
</tr>
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continued bone fragment instability after fracture reduction include the local anatomy and fracture configuration. Fractures at this level of the radius can result in minimal bone surface contact after reduction because of the small size of the bones and short oblique or transverse orientation of the fracture. Achieving anatomic alignment of the bone is further impeded by the tendency for the carpal and digital flexor muscles to create caudolateral displacement of the distal bone fragment. A marginal blood supply in the distal radius of toy and small-breed dogs also has been postulated as a cause of nonunions, although no studies examining the intraosseous blood supply of the distal radius have been reported. Because of the suggested diminished vascularity of the distal radius in small-breed dogs, rigid fixation using an ESF or bone plate has been recommended for these fractures.

This study evaluates the intraosseous vascular supply of the radius in dogs, and to determine whether a difference existed between the blood supply of large and small-breed dogs.

MATERIALS AND METHODS

A total of 12 canine cadavers were used in this study, thereby allowing for evaluation of 24 forelimbs. The small-breed group of dogs consisted of six client-owned dogs, representative of the toy or small breeds (less than 6 kg), which were euthanatized for reasons not associated with any abnormality of the forelimbs. All owners had consented to the use of their dogs in this study before euthanasia. The large-breed group of dogs consisted of six mixed-breed dog cadavers (22 to 44 kg) obtained from a student surgical laboratory exercise. The small-breed dogs ranged in age from 2 to 13 years, and the large-breed dogs from 1.5 to 2 years (Table 1). This investigation met all American Association for Accreditation of Laboratory Animal Care guidelines and was approved by the Institutional Animal Care and Use Committee of Tufts University.

After euthanasia, the forelimbs of the dogs were amputated at the level of the scapulohumeral joint, and then either immediately prepared as described later or frozen to −20°C and saved for a later time when they were thawed and identically prepared. The brachial artery and vein of both forelimbs were catheterized with polyethylene tubing that was secured to the vessels with ligatures of 2–0 silk. The catheters were flushed with approximately 20 mL of heparinized saline until the venous effluent was clear. The brachial artery was injected with approximately 20 mL of India ink, and the completion of the injection was determined by the presence of ink in the nail beds and skin. After the India ink infusion, the forelimbs were immersed in 10% buffered formalin for a minimum of 5 days to ensure fixation. The specimens were frozen and 5 mm sections were made, using a bandsaw, in a coronal orientation in one forelimb and in a sagittal orientation in the other forelimb. Finally, the specimens were processed using a modified Spalteholz tissue clearing technique that has been described previously. The intraosseous vascular anatomy, outlined by the India ink perfusion, was visually evaluated. Attention was focused on the distal two-thirds of the radius. Photographic slides were made of all samples, and included the distal two-thirds of the radius as well as close-up views of the distal diaphyseal-metaphyseal junction.

RESULTS

The principal medullary blood supply to the radius was composed of the nutrient artery, with its associated branches, and the metaphyseal arteries. In the specimens examined, the nutrient artery entered the radius through the nutrient foramen located at the junction of the proximal and middle one-third of the diaphysis. As the nutrient artery entered the medullary canal, it consistently divided into an ascending and a descending branch. These branches further divided and entered the endosteum where they appeared to furnish the chief blood supply of the diaphyseal cortex. The proximal and distal regions were supplied by the terminal branches of the nutrient artery and metaphyseal vessels. The metaphyseal vessels emanated from a periarticular plexus and perforated the cortex in a radiate pattern. The branches of the metaphyseal arteries anastomosed with terminal branches of the nutrient artery at the diaphyseal-metaphyseal junction (Fig 1).

Examination of the cleared tissue specimens re-
Fig 1. (A) Sagittal section of the radius of a large-breed dog showing the nutrient artery and metaphyseal arteries. The white arrow points to the nutrient foramen and the black arrow points to the distal diaphyseal-metaphyseal junction where branches from the nutrient artery and metaphyseal arteries anastomose. (B) Schematic sagittal view of the intraosseous blood supply of the radius showing the contribution from the nutrient artery and metaphyseal arteries.

revealed that the distribution of the intraosseous blood supply of the radial diaphysis was similar in both large and small-breed dogs. The greatest density of the metaphyseal arteries was observed in the physeal region of both groups. However, there was a visible qualitative difference in the metaphyseal blood supply of the distal radius between the two groups of dogs. In the tissue sections from five of six small-breed dogs, there was decreased vascular density and arborization of the vessels in the distal metaphysis as compared with the large-breed dog specimens. This paucity of vessels resulted in a zone of reduced vascularity at the distal metaphyseal region of the radius. Conversely, in all the tissue sections from the large-breed dogs an increased density of the medullary vessels was observed in the metaphyseal region compared with the small-breed dog specimens (Figs 2 and 3).

DISCUSSION

This study confirmed the previously described vascular anatomy of the canine radius. It also showed a difference in the intraosseous blood supply of the distal radius between small and large-breed dogs. The decreased vascular density observed in the distal radius of small-breed dogs at the level of the diaphyseal-metaphyseal junction may contribute to the healing complications of fractures occurring in this area. Only one of the small dogs, a 4-year-old Maltese, had a distal radial blood supply similar to that observed in the large dogs, indicating that the area of decreased vascularity probably does not occur in all small-breed dogs.

The intraosseous blood supply is increased in immature bone. Before the onset of skeletal maturity, bone is perfused with a number of active vessels and maintains a high blood flow. There is an extensive periosteal blood supply that atrophies on cessation of growth. None of the samples in this study were derived from immature animals, so differences in vascularity were not attributed to age.

Fig 2. View of the distal two-thirds of a sagittal section of the radius from (A) a 2-year-old Jack Russell terrier and (B) a mixed 1.5-year-old large-breed dog after tissue processing using the Spalteholz technique. Vessels have been injected with India ink. Arrow points to the region of decreased vascular density in the distal metaphyseal region of (A) compared with greater vascular density in the distal metaphyseal region of (B).
the size of the bones limited the number of cut sections that could be generated per sample to one or two. Attempting to quantify the number of blood vessels in so few samples would have yielded imprecise data. Morphometric measurement of blood vessels could quantify vascular density in terms of length of blood vessels per mm² of metaphyseal bone, however, because of the limited number of samples available, this was not performed.

Normally, the metaphyseal arteries provide a minor contribution to the medullary circulation, but when the nutrient artery is damaged, the metaphyseal arteries are capable of dominating the blood supply in this region by the creation of new vascular channels. Fractures of the distal one-third of the radius in small-breed dogs commonly occur at the distal diaphyseal-metaphyseal junction. The regenerative response of the metaphyseal vessels to enhance blood supply to this region after injury may be limited in small-breed dogs because of the decreased vascular density. Therefore, distal radial fractures in small-breed dogs may be more reliant on the nutrient artery as the dominant source for revascularization and subsequent healing.

The regenerative capacity of the vasculature is directly influenced by motion at the site of injury. Delayed union or nonunion of the distal radius in small-breed dogs most often is observed when these fractures are treated by external coaptation. In one study, severe complications were reported in 75% of small-breed dogs whose fractures were treated by cast immobilization, whereas complications occurred in only 12.5% of small-breed dogs whose fractures were plated. The increased stability obtained by plating of long bone fractures promotes regeneration of the medullary blood supply. Restoration of the medullary circulation across a transverse fracture of a canine radius has been reported to occur as early as 1 week postoperatively, if stable internal fixation is provided. Stable internal fixation of distal radial fractures may be particularly important in small-breed dogs to promote revascularization. By providing greater stability, bone plates and ESFs promote a more rapid return of nutrient artery blood flow and subsequent bone healing.

Based on the biomechanical instability inherent in distal radial fractures, as well as the existence of limited soft tissues for provision of an extraosseous circulation, any compromise to the intraosseous...
blood supply would likely impede the healing response. The difference in vascular anatomy that was identified between small and large-breed dogs in this study strongly suggests that a decreased vascular supply to the distal radius contributes to a higher frequency of nonunion in small-breed dogs.

ACKNOWLEDGMENT

The authors thank Dr Steven Arnoczky and Ms Jean Kilfoyle for their assistance.

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