

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

JANET A. WELCH, DVM, RANDY J. BOUDRIEAU, DVM, Diplomate ACVS, LOIC M. DEJARDIN, DVM,  
and GARY J. SPODNICK, DVM, Diplomate ACVS

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.

©Copyright 1997 by The American College of Veterinary Surgeons

**R**ADIAL FRACTURES in dogs most commonly occur in the distal one-third of the diaphysis.<sup>1-4</sup> Clinical observations suggest that the prognosis for healing depends, in part, on the size of the dog.<sup>2,3,5-12</sup> Distal radial fractures in young, midsized to large-breed dogs generally progress to healing regardless of the method of stabilization.<sup>13</sup> Fractures occurring in the distal radius of small-breed dogs, however, have a greater risk for the development of delayed union or nonunion.<sup>2,3,5-12</sup>

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.<sup>2,5-7,11-13</sup> Repair of radial diaphyseal fractures using intramedullary pins should be avoided because it has been associated with healing complication rates as high as 80%.<sup>13</sup> Application of an external skeletal fixator (ESF)<sup>12,13</sup> or plate<sup>12-15</sup> 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.<sup>5,13,14</sup>

The cause of impaired healing of distal radial fractures in toy and small-breed dogs has not been identified; however, biomechanical<sup>2,5,16,17</sup> or vascular<sup>3,11,14,17</sup> influences, or both, have been implicated. Biomechanical factors which may predispose to con-

---

From the Department of Surgery, Tufts University School of Veterinary Medicine, North Grafton, MA; and the Laboratory for Comparative Orthopaedic Research, Michigan State University, College of Veterinary Medicine, East Lansing, MI.

Dr Welch's current address is Department of Small Animal Surgery and Medicine, Auburn University, College of Veterinary Medicine, Auburn, AL 36849-5523.

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.

Address reprint requests to Randy J. Boudrieau, DVM, Department of Small Animal Surgery, Tufts University School of Veterinary Medicine, 200 Westboro Rd, North Grafton, MA 01536.

©Copyright 1997 by The American College of Veterinary Surgeons  
0161-3499/97/2601-0009\$3.00/0

Table 1. Demographic Data of Small-Breed Dog Group

Case no.	Breed	Age (yrs)
1	Poodle	6
2	Jack Russell terrier	3
3	Maltese	4
4	Yorkshire terrier	13
7	Maltese	4
9	Jack Russell terrier	2
13	Fox terrier	2

tinued 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.<sup>2,5,11</sup> 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.<sup>11,13</sup> A marginal blood supply in the distal radius of toy and small-breed dogs also has been postulated as a cause of non-unions, 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.<sup>12-15</sup>

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 Institu-

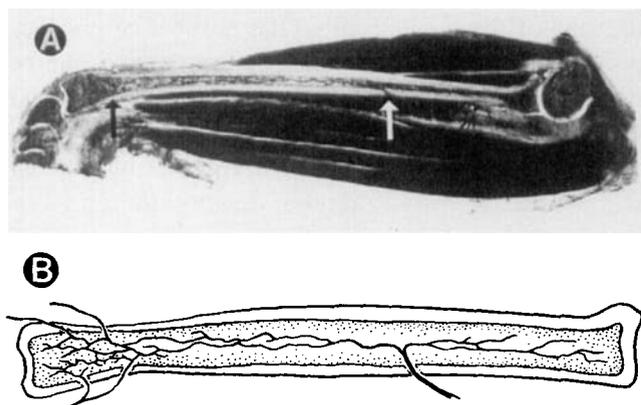
tional Animal Care and Use Committee of Tufts University.

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  $-20^{\circ}\text{C}$  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 band-saw, 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.<sup>18-22</sup> 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.

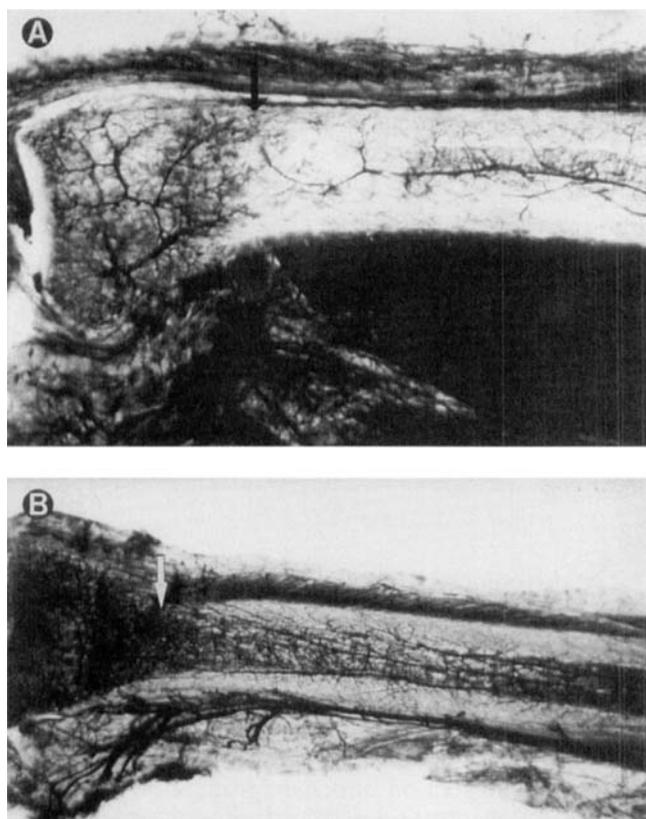
vealed that the distribution of the intraosseous blood supply of the radial diaphysis was similar in both large and small-breed dogs. The greatest density of the metaphyseal arteries was observed in the physal region of both groups. However, there was a visible qualitative difference in the metaphyseal 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

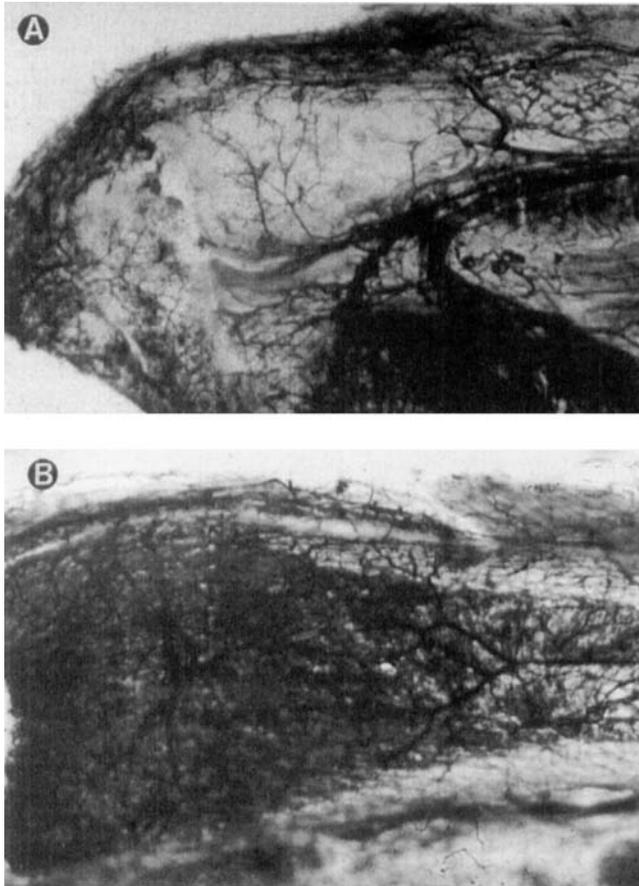
This study confirmed the previously described vascular anatomy of the canine radius.<sup>9</sup> It also showed a difference in the intraosseous blood supply of the distal radius between small and large-breed dogs. The decreased vascular density observed in the

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.<sup>23,24</sup> Before the onset of skeletal maturity, bone is perfused with a number of active vessels and maintains a high blood flow.<sup>24</sup> There is an extensive periosteal blood supply that atrophies on cessation of growth.<sup>24</sup> 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).



**Fig 3.** Close-up views of sagittal sections of the distal radius of (A) a 4-year-old Maltese 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. Decreased vascular density is evident in the distal metaphyseal region of the small-breed dog compared with the large-breed dog.

The differences in vascular density of the samples in this study were assessed by direct visualization. This type of descriptive analysis has been used in other vascular studies of bone and soft tissue.<sup>18-22</sup> Quantitative techniques for analyzing the vascular density of tissue samples include counting blood vessels per tissue section under magnification<sup>25</sup> or tracing the length of blood vessels with a cursor and a digitizing tablet (morphometry).<sup>26</sup> Examining the samples under magnification through a grid would allow an estimation of the number of intersections of grid lines with blood vessels. The accuracy of this technique is improved by examining multiple cut sections of bone to obtain an average vascular density per sample. In the small-breed group of dogs,

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  $\text{mm}^2$  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.<sup>24</sup> Fractures of the distal one-third of the radius in small-breed dogs commonly occur at the distal diaphyseal-metaphyseal junction.<sup>3,5,12</sup> 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.<sup>25</sup> Delayed union or nonunion of the distal radius in small-breed dogs most often is observed when these fractures are treated by external coaptation.<sup>2,13</sup> 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.<sup>13</sup> The increased stability obtained by plating of long bone fractures promotes regeneration of the medullary blood supply.<sup>27</sup> 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.<sup>27</sup> 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.

### REFERENCES

1. Wallace MK, Boudrieau RJ, Hyodo K, et al: Mechanical evaluation of three methods of plating radial osteotomies. *Vet Surg* 21:99-106, 1992
2. Denny HR: Fracture of the radius and ulna, in Denny HR (ed): *A Guide to Canine Orthopaedic Surgery* (ed 2). Boston, MA, Blackwell Scientific, 1985, pp 179-196
3. Leonard EP: Fracture of the radius and ulna, in Leonard EP (ed): *Orthopedic Surgery of the Dog and Cat* (ed 2). Philadelphia, PA, Saunders, 1971, pp 163-172
4. Phillips IR: A survey of fractures in the dog and cat. *J Small Anim Pract* 20:661-674, 1979
5. Vaughan LC: A clinical study of non-union fractures in the dog. *J Small Anim Pract* 5:173-177, 1964
6. Sumner-Smith G, Cawley AJ: Nonunion fractures in the dog. *J Small Anim Pract* 11:311-325, 1970
7. Sumner-Smith G: A comparative investigation into the healing of fractures in miniature poodles and mongrel dogs. *J Small Anim Pract* 15:323-328, 1974
8. Sumner-Smith G: A histological study of fracture nonunion in small dogs. *J Small Anim Pract* 15:571-578, 1974
9. Nunamaker DM: Fractures of the radius and ulna, in Newton CD, Nunamaker DM (eds): *Textbook of Small Animal Orthopedics*. Philadelphia, PA, Lippincott, 1985, pp 374-379
10. Hunt JM, Aitken ML, Denny HR, et al: The complications of diaphyseal fractures in dogs: A review of 100 cases. *J Small Anim Pract* 21:103-119, 1980
11. Herron MR: Repair of distal radio-ulnar fractures in toy breeds of dogs. *Canine Pract* 1:12-17, 1974
12. Waters DJ, Breur GJ, Toombs JP: Treatment of common forelimb fractures in miniature- and toy-breed dogs. *J Am Anim Hosp Assoc* 19:643-650, 1983
13. Lappin MR, Aron DN, Herron HL: Fractures of the radius and ulna in the dog. *J Am Anim Hosp Assoc* 19:643-650, 1983
14. DeAngelis MP, Olds RB, Stoll SG, et al: Repair of fractures of the radius and ulna in small dogs. *J Am Anim Hosp Assoc* 9:436-441, 1973
15. Sumner-Smith G: Bone plating for radial fractures in small dogs. *Mod Vet Pract* 51:278-282, 1970
16. Atilola MAO, Sumner-Smith G: Nonunion fractures in dogs. *J Vet Orthop* 3:21-24, 1984
17. DeAngelis MP: Causes of delayed union and nonunion of fractures. *Vet Clin North Am* 2:251-258, 1975
18. Arnoczky SP, Rubin RM, Marshall JL: Microvasculature of the cruciate ligaments in response to injury. *J Bone Joint Surg Am* 61:1221-1229, 1979
19. Arnoczky SP, Tarvin GB, Marshall JL: Anterior cruciate ligament replacement using patellar tendon. *J Bone Joint Surg Am* 64:217-221, 1982
20. Boudrieau RJ, Kaderly RE, Arnoczky SP, et al: Vascularized patellar tendon graft: Technique for cranial cruciate ligament substitution in the dog-vascular evaluation. *Vet Surg* 14:196-203, 1985
21. Mikic ZD: Blood supply of the articular disc of the antebrachio-carpal joint in dogs. *J Anat* 181:447-453, 1992
22. Smith JW, Arnoczky SP, Hersh A: The intraosseous blood supply of the fifth metatarsal: Implications for proximal fracture healing. *Foot Ankle* 13:143-152, 1992
23. Kelly PJ: Anatomy, physiology, and pathology of the blood supply of bones. *J Bone Joint Surg Am* 50:766-778, 1968
24. Wilson JW: Vascular supply to normal bone and healing fractures. *Semin Vet Med Surg* 6:26-38, 1991
25. Bray R, Rangayyan R, Eng K: A study of the vascular behavior in normal and healing medial collateral ligaments. *Trans Orthop Res Soc* 18:57, 1993 (abstr)
26. Steven CR, Blake DR, Merry P, et al: A comparative study by morphometry of the microvasculature in normal and rheumatoid synovium. *Arthritis Rheum* 34:1508-1513, 1991
27. Rhinelander FW: The normal microcirculation of diaphyseal cortex and its response to fracture. *J Bone Joint Surg Am* 50:784-800, 1968