Distraction Osteogenesis Using Modified External Fixation Devices in Five Dogs

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Distraction osteogenesis was used to treat five dogs with limb deformities or limb shortening. The affected bones underwent osteotomy, and modified external fixators were attached. Complications included pin loosening, implant breakage, and soft-tissue contracture. Adequate limb length was attained in all cases, but clinical results varied from poor to excellent. Two dogs were not lame after the procedure, two dogs had improved function but were still lame, and one dog had complications necessitating amputation.

DISTRACTION OSTEOGENESIS (CALLUS distraction, callotasis) is a bone-lengthening technique that involves slow, controlled distraction of callus formed after subperiosteal osteotomy. The technique was introduced for use in humans in 1951 by Ilizarov, a Russian physician who developed it to salvage limbs with severe congenital or acquired deformities. Since that time, callus distraction has been used in humans for many purposes, including lengthening limbs of achondroplastic dwarfs; reconstructing hand deformities; lengthening limbs shortened by congenital deformities, trauma, osteomyelitis, and tumor resection; and correcting deformities from partial growth plate arrest. In dogs, premature closure of the distal radial and ulnar growth plates can result in angular limb deformities, shortened limbs, and subluxation of the elbow and carpus. Surgical treatment of premature physeal closure in young dogs must maintain normal elbow and carpal joints, prevent angular limb deformities, and preserve limb length. During the stage of rapid long-bone growth, these objectives are best achieved with a dynamic treatment process. Treatment of premature physeal closure in dogs by dynamic methods has been reported, but callus distraction was not used.

The original distraction device was constructed with stiff through-and-through transfixation wires attached under tension to circular rings. Callus distraction with a ring fixator (modified Ilizarov apparatus) and daily distractions of 1 or 2 mm was reported in two dogs. A dynamic axial fixation system with a unilateral external fixator was developed for distraction osteogenesis in humans. The purpose of this report is to describe the clinical results after distraction osteogenesis with modified external fixators in five dogs. The intent of the procedure was to restore limb length in three dogs and to prevent limb shortening in two dogs.

Case Descriptions

Dog 1

An 8-month-old, 24-kg female Doberman pinscher was referred to the Texas Veterinary Medical Center for evaluation of right forelimb lameness present since the dog was 6 weeks old. When examined, the dog did not bear weight on the right forelimb. The limb had a cranial bow and valgus deviation of the carpus. Curvature of the distal third of the radius, with caudal angulation, was noted on radiographs. Measurements made from radiographs showed the right radius was 16 mm shorter than the left (Table 1).

Osteotomies at the level of the midshaft of the right radius and ulna were performed. A 6-pin bilateral external fixator was applied to the radius (Fig. 1A). Threaded rods were used in place of standard connecting bars, and the radial osteotomy was distracted 5.0 mm. Daily distractions...
TABLE 1. Signalment and Summary of Lengthening Data in Five Dogs Treated with Distraction Osteogenesis

<table>
<thead>
<tr>
<th>Case Number</th>
<th>Breed</th>
<th>Age (months)</th>
<th>Sex</th>
<th>Bone</th>
<th>Affected Bone</th>
<th>Contralateral Bone</th>
<th>Total Length Gained (mm)</th>
<th>Total Distraction (mm)</th>
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<td>F</td>
<td>Radius</td>
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<td>176</td>
<td>175</td>
<td>175</td>
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<tr>
<td>2</td>
<td>Greyhound</td>
<td>4</td>
<td>F</td>
<td>Tibia</td>
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<td>172</td>
<td>210</td>
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<tr>
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<td>9</td>
<td>M</td>
<td>Tibia</td>
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<td>Terrier cross</td>
<td>5</td>
<td>F</td>
<td>Radius</td>
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<td>111</td>
<td>127</td>
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<tr>
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<td>Terrier cross</td>
<td>3</td>
<td>F</td>
<td>Radius</td>
<td>84</td>
<td>101</td>
<td>94</td>
<td>106</td>
</tr>
</tbody>
</table>

* Measured from radiographs.
† Distraction at time of surgery (mm) + [rate of distraction owner was instructed to perform (mm/day) × duration of distraction (days)].
‡ Length after osteotomy and straightening of bone.

Fig. 1. (A) Cranio-caudal radiograph (dog 1) after osteotomy of the radius and ulna. There are threaded connecting bars and locknuts on the external fixator. (B) Cranio-caudal radiograph (dog 1) 22 days after osteotomy of the radius and ulna and daily distraction (1 mm/day). Callus within the osteotomy gap and deformation of the proximal Ellis pin at the thread-shaft junction are visible. (C) Cranio-caudal radiograph (dog 1) at the time of fixator removal 77 days after surgery. The tip of the Ellis pin is broken, and there is lucency around the remaining pins.
of 1.0 mm (0.5 mm q 12 hours) were begun on day 10. Radiographs made on day 22 showed callus formation within the osteotomy gap (Fig. 1B). Progressive callus formation and breakage of the tip of the most proximal half-pin were noted on radiographs made on day 29. The non-threaded portion of the pin was removed. Distraction was discontinued because adequate limb length had been attained. The dog was active but usually lame on the leg. Bridging callus at the osteotomy site was evident in radiographs made on day 50. The lateral connecting bar and pins were removed to destabilize the fixator. Bony union and lucency around the proximal and distal pins were evident in radiographs made on day 77 (Fig. 1C). The remaining parts of the external fixator were removed. The dog was active and used the leg but would usually limp; the cause of the lameness could not be determined. Twenty-one months after surgery, the owner reported no further change in the dog’s clinical condition but was satisfied with the improvement over the dog’s preoperative condition.

Dog 2

A 4-month-old, 14-kg female greyhound was referred for evaluation of malunion of left tibial and fibular diaphyseal fractures caused by a dog bite injury that occurred when the dog was 4 weeks old. The dog did not bear weight on the left hind limb. There was marked caudal angulation of the tibia and fibula and shortening of the limb. (Fig. 2).

Osteotomies of the tibia and fibula were performed at the level of maximal angulation. The proximal and distal segments of the tibia were aligned and stabilized with a 6-pin unilateral external fixator. A threaded rod was used in place of a standard connecting bar. After surgery, the straightened left tibia was 52 mm shorter than the right tibia (Table 1). Distraction of the tibial osteotomy was begun on day 10 at a rate of 1.0 mm daily (0.5 mm q 12 hours). The dog used the leg intermittently until day 28, when the connecting bar broke and she became non-weight-bearing. The external fixator was converted to a bilateral configuration, and distraction was continued until day 91. Although the left tibia was still shorter than the right tibia, total limb length when the dog was standing was equivalent between the right and left hind limbs. Normal healing of the osteotomy, lysis around the four proximal pins, and breakage of the tip of the most proximal half-pin were evident on radiographs made on day 120. Bony union was evident on radiographs made on day 151, and the fixator was removed. The owner reported the dog would bear weight on the limb but limped at a walk and held the leg up when running. The owner reported no change in clinical results 22 months after surgery.

Dog 3

A 9-month-old, 13.6-kg male greyhound was referred for evaluation of a right hind limb deformity present since 8 days of age. Two previous surgical procedures to correct the deformity had been unsuccessful. The dog was non-weight-bearing on the right hind limb. There was marked muscle atrophy. The tarsal joint was held in extension and had limited range of motion. There was a slightly decreased range of motion in the stifle joint. Radiographs revealed malarticulation of the femorotibial joint. The right tibia was 51 mm shorter than the left (Table 1).

A proximal osteotomy of the tibia was performed, and the bone was stabilized with a 4-pin unilateral external fixator. A specially designed distraction rod (Fig. 3A) was used in place of a standard connecting bar. On day 7, daily distractions of 2.0 mm (1.0 mm q 12 hours) were begun. Callus formation within the osteotomy gap was evident on radiographs made on day 26. However, the stifle was fixed in flexion, and degenerative changes of the stifle were seen on radiographs. Continued callus formation within the osteotomy gap was seen on radiographs made on day 47 (Fig. 3B). The right tibia was 2 mm longer than the left. Distraction was stopped because adequate length had been attained. On day 67, the osteotomy was healed and the fixator was removed. The dog was non-weight-bearing on the affected limb. Muscle atrophy was severe; the stifle was fixed in flexion and the tarsus was fixed in extension. The limb was considered unsalvageable and was amputated.

Dog 4

A 5-month-old, 8-kg female mixed breed dog was referred for evaluation of progressive right forelimb lameness of 3 weeks’ duration. There was no history of trauma. The dog had a weight-bearing lameness and slight valgus
which was thought to be preventing further lengthening. There was lucency around the proximal and distal pins. Distraction was stopped because the osteotomy was healing. The right radius measured 18 mm shorter than the left, but the dog was asymptomatic. On day 72, the osteotomy was healed and the fixator was removed (Figs. 4D and 4E). Elbow joint congruency was normal. There was mild subluxation of the antebrachiocarpal joint. The contralateral distal radial physis was open, and both proximal radial physes were closed. Three months after surgery, the owner reported the dog would occasionally hold the leg up after heavy exercise, but the dog otherwise behaved normally. Six months after surgery, the limb occasionally appeared "stiff" after the dog got up in the morning, but the dog otherwise behaved normally.

Dog 5

A 3-month-old, 4.7-kg female mixed-breed dog was referred for evaluation of progressive right forelimb lameness. The dog fell off a third-story balcony 6 weeks earlier. The dog had a weight-bearing lameness of the right forelimb and valgus deformity of the right carpus and showed mild pain when the elbow was extended. Closure of the deformity of the carpus and showed mild pain when the elbow was extended. Closure of the distal radial physis, mild carpal valgus, slight subluxation of the radial head, and proximal subluxation of the humeroulnar joint were evident on radiographs (Figs. 4A and 4B). On measurements taken from radiographs, the right radius was 19 mm shorter than the left (Table 1), and the right ulna was 13 mm shorter than the left.

A radial osteotomy was performed; the ulna was not cut. The radius was straightened and stabilized with a 4-pin bilateral external fixator. Threaded rods were used in place of standard connecting bars. Daily distractions of 0.5 mm (0.25 mm q 12 hours) were begun on day 7. Callus formation within the osteotomy gap and improved elbow joint congruency were evident on radiographs made on day 19. At this time, the dog was using the leg well with minimal lameness. Continued callus formation was evident on radiographs made on day 33 (Fig. 4C). Distraction was reduced to 0.25 mm q 24 hours, based on comparison with the growth rate of the normal limb. On day 55, the owner reported that for the past 7 days, the dog had been exhibiting pain after distraction. Radiographs revealed bridging callus across the osteotomy, which was thought to be preventing further lengthening. There was lucency around the proximal and distal pins. Distraction was stopped because the osteotomy was healing. The right radius measured 18 mm shorter than the left, but the dog was asymptomatic. On day 72, the osteotomy was healed and the fixator was removed (Figs. 4D and 4E). Elbow joint congruency was normal. There was mild subluxation of the antebrachiocarpal joint. The contralateral distal radial physis was open, and both proximal radial physes were closed. Three months after surgery, the owner reported the dog would occasionally hold the leg up after heavy exercise, but the dog otherwise behaved normally. Six months after surgery, the limb occasionally appeared "stiff" after the dog got up in the morning, but the dog otherwise behaved normally.
lateral aspect of the distal radial physis, valgus deformity of the carpus, a healing fracture of the styloid process of the ulna, subluxation of the radial head, and proximal subluxation of the humeroulnar joint was seen on radiographs of the right antebrachium (Figs. 5A and 5B). Based on measurements made from radiographs, the right radius was 10 mm shorter than the left (Table 1), and the right ulna was 10 mm shorter than the left.

Osteotomies of the right radius and ulna were performed. The radius was straightened and stabilized with a 4-pin bilateral external fixator. Threaded rods were used in place of standard connecting bars. Postoperatively, the radius was distracted 5.0 mm. Daily distractions of 1.0 mm (0.5 mm q 12 hours) were begun 7 days after surgery. On day 12, distractions were changed to 0.5 mm daily (0.25 mm q 12 hours), based on comparison with the growth rate of the normal limb. On day 16, callus formation within the osteotomy gap was evident on radiographs (Fig. 5C). The dog had a mild weight-bearing lameness and hyperextension, mild valgus deviation, and laxity of the carpus. On day 31, the owner reported that the proximal fixator pin was loose. Bridging callus, evident on radiographs, was thought to be preventing further lengthening. There was lucency around the proximal and distal pins. Elbow joint congruency was normal. Distraction was stopped because the osteotomy was healing. The fixator was removed on day 37 when the osteotomy was fully healed (Fig. 5D). The right radius was 5 mm shorter than the left radius. The left proximal and distal radial physes and the left distal ulnar physis were open. The right proximal radial and distal ulnar physes were open. The dog bore weight but had a slight limp. Carpal hyperextension, valgus deviation, and laxity were still present in the right forelimb. Three months after surgery, the owner reported that the dog behaved normally. The carpal laxity and hyperextension had resolved, although a slight valgus deformity remained. Six months after surgery, the owner reported that the dog behaved normally and did not limp.

Discussion

When bone is subjected to controlled tension after subperiosteal osteotomy, regenerate bone forms in the osteotomy gap, a process known as distraction osteogenesis. When the osteotomy is lengthened by gradual, controlled distraction, the process is called callus distraction, or callotasis. Soft tissues also undergo lengthening during the distraction process; they are not simply stretched. In a study of callus distraction in rabbits, callus formation was seriously hindered when the periosteum was removed. The importance of preserving medullary circulation is controversial. One author contended that the medullary
Figs. 5A, 5B. Craniocaudal (A) and lateral (B) preoperative radiographs (dog 5). Lesions include proximal subluxation of the humeroulnar joint, lateral subluxation of the radial head, valgus deformity of the carpus, closure of the lateral aspect of the distal radial physis, and fracture of the styloid process of the ulna.

canal should not be transected because maintenance of the medullary blood supply and marrow elements resulted in more rapid new bone formation. He recommended that only the cortex be cut, a technique called a corticotomy (diaphysis) or compactotomy (metaphysis). Others found no difference in the periosteal or endosteal blood supply between dogs undergoing distraction osteogenesis after corticotomy or osteotomy. In the dogs described in this report, osteotomies were performed with an oscillating saw after periosteal elevation. The periosteum was preserved, which was relatively simple because the dogs were young. Preservation of the periosteum is more difficult in older dogs. More studies are needed to determine if this will be a problem clinically. No attempt was made to save the bone marrow or endosteum at the site of the osteotomy. Regenerate bone formed in all dogs, indicating that preservation of bone marrow and endosteum may not be essential for callus formation.

A delay of 5 to 15 days before distraction is recommended to allow time for healing of soft tissue, periosteum, and marrow, and to allow some early callus to form. Distraction can be started sooner in younger dogs. A delay of 10 days is recommended for humans younger than 15 years of age and 15 days for older patients. Others commence distraction when callus is seen radiographically, usually between 10 and 15 days. In our cases, initiation of distraction was 7 to 10 days after osteotomy.

In experiments with dogs, the optimal distraction rate was 1.0 mm per day. A rate of 0.5 mm per day often led to premature consolidation of the bone, whereas a rate of 2.0 mm per day often resulted in local ischemia and decreased osteogenesis. The greater the frequency of distraction, the better was the rate of formation and quality of the regenerate bone. The author recommended a rate and frequency of 0.25 mm every 6 hours. We considered a frequency of 4 times daily impractical for clients and recommended a distraction frequency of every 12 hours. This was convenient for the client and resulted in good callus formation.

In dogs 4 and 5, distraction rates varied from the recommended rate of 1.0 mm per day. Because they were rapidly growing dogs with little length discrepancy, the distraction rate was decreased in an attempt to equal the growth rate of the contralateral limb. Consequently, the osteotomies healed prematurely. Although not a clinically significant problem in these cases, premature healing can result in inadequate length. To prevent this complication, the distraction rate should probably be 1.0 mm per day.

Fig. 5C. Craniocaudal radiograph (dog 5) 16 days after radial and ulnar osteotomies and daily distractions (1 mm/day for 5 days, 0.5 mm/day for 4 days) with threaded connecting bars and locknuts. There is callus within the osteotomy gap.
even if the affected limb is distracted to a length longer than the normal limb. The normal limb will “catch up” when distraction is stopped. Slight adjustments in the distraction rate may be needed and should be monitored carefully.

In dog 4, the distraction rate was also influenced by the fact that only the radius had been cut. The ulna was not cut because the proximal and distal physes were still open; thus, the ulna would grow as the radius was lengthened. Retrospectively, we realized that iatrogenic distal subluxation of the humeroulnar joint might occur if radial distraction exceeded ulnar growth. The distraction rate was decreased to prevent this potential complication. This problem was avoided in dog 5 by cutting both the radius and the ulna, and this is our recommendation for future cases involving the radius or ulna.

Neither dog 4 nor dog 5 had marked limb length discrepancies. The intent of the procedure was to prevent limb shortening and further joint subluxation. This was accomplished. In addition, humeroulnar joint subluxation was resolved in both dogs, and antebrachio-carpal joint subluxation was improved in both dogs. This procedure appears to be a good method to prevent limb deformities in young dogs with premature growth plate closure.

Distraction in dog 3 occurred at twice the intended rate (2.0 mm per day instead of 1.0 mm per day). There was adequate osteogenesis, but severe soft-tissue and joint complications ensued. Joint deformity, degeneration of articular cartilage, and impairment of articular function are reported complications of limb lengthening in humans. Other complications include muscle contracture, joint luxation, neurologic and vascular injury, and permanent joint stiffness. In a study of soft-tissue effects of tibial lengthening in sheep, there was histologic evidence of degeneration in the articular cartilage and extensor muscles of the hock; the authors concluded that the changes probably resulted from tension in the muscles and compression of the articular cartilage.

The original device was a circular external skeletal fixation system attached to the bone with tensioned transfixation wires. Since then, various external skeletal fixation systems have been used for distraction osteogenesis in humans. In three dogs, we used a bilateral external skeletal fixator because of its availability, ease of application, rigid fixation, and ability to be destabilized as healing progressed. This configuration was easily modified for use as a distraction device by using threaded rods in place of standard connecting bars. Locknuts were placed below the clamps proximal to the osteotomy and above the clamps distal to the osteotomy. The locknuts were used to prevent collapse of the osteotomy and to achieve distraction. The pitch of the threaded connecting rods was such that one complete revolution of the locknut caused a distraction of 1 mm. This could be done by the owner with an appropriate-sized wrench. In dog 3, we used a specially designed distractor in place of a standard connecting bar. This distraction rod used a turnbuckle design in which one revolution of the turnbuckle distracted 2.0 mm.

Implant complications occurred in all cases. In dog 2, the connecting bar on the first (unilateral) fixator broke. In dogs 1 and 2, the tip of the proximal bone threaded pin broke. Loosening of some pins occurred in four dogs. With unilateral or bilateral external fixator distractors, stability depends on the pins transmitting stress from the bone to the fixator. With external fixator rings, pins of small diameter are placed under tension. Stability depends on the tension in the wire. Because pin stability does not rely on tightness in the bone, pin loosening is not a problem. The bulkiness of a ring fixator may not be as well tolerated as a unilateral fixator in dogs, and use on the femur and humerus would be difficult. Currently, unilateral fixators are more available and easier to use. Until the clinical use of ring fixators in dogs is proven, steps can be taken to maximize stability.

* Ellis pin, Kirschner Medical Corporation, Timonium, Maryland.
in unilateral fixators. Using positive profile pins\(^\ddagger\) and the largest connecting rod possible while restricting the patient’s activity may minimize the incidence of premature pin loosening and fatigue failure.

Discrepancies between the total length gained (measured from radiographs) and the total calculated distraction (calculated from rate, frequency, and duration of distraction) could be due to several factors. Magnification may vary from radiograph to radiograph, causing inaccuracies in length measurements. Slightly different views of the same limb may also affect measurements. Owner error in distraction magnitude, frequency, or direction may occur. Distracting against a healing osteotomy may result in less actual length than calculated. Slippage of the locknuts may occur, decreasing the total length. Finally, growth from the normal growth plate on the affected limb can generate length more than that accounted for by distraction.

Based on experimental work in dogs and our preliminary experience with distraction osteogenesis using external skeletal fixators, we have found that distraction should begin 7 to 10 days after osteotomy; the distraction rate should be 1.0 mm per day; the distraction frequency should be every 12 hours; slight adjustments in the distraction rate may be needed in rapidly growing dogs; careful and frequent evaluation of the procedure is critical; limb length should be evaluated by comparing the affected limb with the normal limb clinically and radiographically; and periodically counting the threads showing on the connecting bar between the two middle clamps if the pitch is known (1 thread = 1 mm) may be a good way to compare calculated distraction with actual distraction.

**References**