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Objective—To determine outcome for dogs and cats with diaphyseal fractures in which a plate-rod construct was used for fracture repair.

Design—Retrospective study.

Animals—35 dogs and 12 cats.

Procedures—Medical records and radiographs were reviewed to obtain information concerning signalment, fracture severity, construct design, time to radiographic union, complications, and outcome. Clients were contacted by telephone to obtain information on complications, limb usage, and overall satisfaction with the procedure.

Results—31 femoral, 9 humeral, and 7 tibial fractures were assessed. Thirteen fractures consisted of 2 fragments, 22 consisted of 3 to 5 fragments, and 12 consisted of >5 fragments. Forty-six of 47 (98%) fractures reached union. Mean ± SD times to radiographic union were 7.5 ± 2.7 weeks for the dogs and 4.8 ± 1.3 weeks for the cats. There were 4 short-term, minor complications and 15 long-term complications (2 major and 13 minor). Owners of 21 of 30 dogs (70%) and 9 of 12 cats reported that their animals had normal limb function. Twenty-six of 28 dog owners (93%) and 12 of 12 cat owners indicated that they were satisfied with results of the procedure. As surgery time increased, time to union also increased. Time to union for fractures with >5 fragments was significantly shorter than time to union for fractures with ≤5 fragments.

Conclusions and Clinical Relevance—Results suggest that plate-rod constructs can successfully be used for repair of diaphyseal fractures of a wide range of severity in dogs and cats. (J Am Vet Med Assoc 2003;223:330–335)

Comminuted long-bone fractures are common in dogs and cats and can successfully be treated with a variety of implant systems, including bone plates, pins and wires, external fixators, and interlocking nails. Mechanical and biological factors should be consid-
able healing times and limb function even if some plate holes were left empty, few or no bicortical screws were used, and intramedullary pins occupied ≤ 50% of the medullary canal.

**Criteria for Selection of Cases**

Medical records of the Gulf Coast Veterinary Specialists of Houston, Texas, and the Texas A&M University College of Veterinary Medicine were searched to identify all dogs and cats with long-bone fractures of any type or severity treated with a plate-rod construct between 1994 and 2001. Animals were included in the study if sufficient follow-up information was available that a final radiographic outcome could be determined. Attempts were made to obtain long-term (> 6 months after surgery) follow-up information via telephone or through reexamination, but long-term follow-up information was not required for inclusion in the study.

**Procedures**

Placement of the plate-rod construct—For all fractures, spatial alignment of the main fragments was initially reestablished by placement of an intramedullary pin following indirect fracture reduction. A skin incision was then made over the fracture site for placement of a bone plate. The incision was no longer than necessary to verify alignment of the most proximal and distal bone fragments and allow for plate placement. Diameter of the intramedullary pin used was approximately 30 to 50% of the diameter of the medullary cavity, as determined from preoperative radiographs and intraoperative observations. Most commonly, the pin was placed in a normograde fashion through the proximal fragment, across the fracture site, and into the cancellous bone of the distal fragment. In selected instances, pins were placed in a retrograde fashion; in such instances, handling of the soft tissues was minimized. Axial realignment (craniocaudal and medial-lateral) and bone length were reestablished as the intramedullary pin was seated in the distal fracture fragment. Preoperative radiographs of the contralateral limb were used to estimate proper length of the fractured limb. Following seating in the cancellous bone, intramedullary pins were cut off flush with the cortical surface of the proximal fracture fragment. During placement of the bone plate, handling of bone fragments was minimized, and efforts were made to preserve soft tissue attachments and the fracture hematoma. Size of the bone plate used was determined on the basis of the patient’s weight, the individual bone size, and the fracture length. In general, a plate equivalent to or slightly smaller than that used for bone plating alone was selected. The plate was contoured to the bone surface and attached to the fracture fragments. Whenever possible, screws were inserted through both the near and far cortices. An attempt was made to place at least 1 bicortical and 2 monocortical screws in each of the main fracture fragments. No cerclage or interfragmentary wires were placed in the zone of comminution; use of cerclage and interfragmentary wires was avoided whenever possible. Large bone fragments that were considered to be too far from the bone column to contribute to healing or to become incorporated in the fracture callus were positioned closer to the main fracture fragments by placing a strand of monofilament suture around the fragment with a wire passer or hemostat and pulling the fragment closer to, but not in apposition with, the bone column.

If a cortical fragment was determined to be void of soft tissue attachment and vascular supply, it was broken up and placed around the fracture hematoma. Autogenous cancellous grafts were collected and placed around the fracture site in selected cases. Soft tissues were apposed over the fracture site, and the skin was closed routinely. Cranio-caudal and lateromedial radiographic projections of the fracture site were obtained immediately after surgery and examined for implant positioning and limb alignment. Follow-up radiographs were obtained every 4 to 8 weeks after surgery until there was radiographic evidence of bridging callus (fracture union) in 2 radiographic planes of projection.

**Data collection**—The following information was recorded for each case: age; weight; sex; affected limb; concurrent injuries; number of fracture fragments; experience of the primary surgeon (surgery resident vs board-certified surgeon); operative time; approximate percentage of the medullary canal filled by the intramedullary pin; bone plate type, size, and length (ie, number of screw holes); total number of screws placed; numbers of bicortical and monocortical screws; number of empty plate holes; time to radiographic union; complications; final outcome; and client opinion of the outcome. Complications were classified as short-term if they resolved within the first 2 weeks after surgery and long-term if they developed or resolved > 2 weeks after surgery. Complications were considered minor if they did not adversely affect the final outcome. For all cases, percentage of the marrow cavity filled by the intramedullary pin was measured on postoperative radiographs by a single individual (MRR); diameter of the marrow cavity was measured at its narrowest point. Final outcome of the fracture (union, delayed union, or nonunion) was also determined by a single individual (MRR) for all cases. Fractures were considered to have reached union when there was radiographic evidence of callus bridging the fracture gap. Fractures were considered to have delayed union if there was radiographic evidence of callus, but callus had not bridged the fracture gap by 3 to 4 months, depending on biological and mechanical factors, after surgery. Limb function at the time of final follow-up was categorized as normal, some stiffness or lameness during or after activity, usually stiff or lame, usually lame and will only toe touch, or non-weight-bearing lame. Client opinion of the outcome was recorded as satisfied, unsatisfied, indifferent, or uncertain.

**Statistical analyses**—Summary statistics (mean, SD, and range) were calculated for all variables. Scatter plots, regression analysis, and multivariate ANOVA were used to determine whether time to radiographic union was associated with any of the following variables: number of empty plate holes, percentage of marrow cavity filled by the intramedullary pin, number of bone fragments (≤ 3 vs > 3), total number of screws,
number of bicortical screws, number of monocortical screws, and operative time. Analyses were performed with standard software.\textsuperscript{a,b} For all analyses, values of $P < 0.05$ were considered significant.

Results

Thirty-five dogs and 12 cats met the criteria for inclusion in the study. Dogs ranged from 4 months to 14 years old (mean, 4.2 years); cats ranged from 6 months to 9 years old (mean, 2.9 years). Eight dogs and 2 cats were < 1 year old. There were 17 female (8 spayed) and 18 male (5 neutered) dogs. There were 7 female (5 spayed) and 5 male (4 neutered) cats. Mean weight of the dogs was 22 kg (48.5 lb; range, 2 to 53 kg [4.4 to 117 lb]); mean weight of the cats was 3.8 kg (8.4 lb; range, 1 to 5.9 kg [2.2 to 13 lb]).

There were 31 femoral (Fig 1), 9 humeral, and 7 tibial (Fig 2) fractures. Thirteen of the fractures consisted of only 2 fragments, 22 consisted of 3, 4, or 5 fragments, and 12 consisted of > 5 fragments. Fractures in 26 of the 35 dogs and 9 of the 12 cats consisted of $\leq$ 5 fragments; fractures in the remaining 9 dogs and 3 cats consisted of $> 5$ fragments.

Cerclage wires were used in 3 cases. Use of monofilament suture material to pull a markedly displaced fracture fragment into position was recorded in only 1 case. Autogenous cancellous bone grafts were used in 8 cases. A frozen allograft was used in combination with an autogenous graft in 1 case.

Forty-six of 47 (98%) fractures reached union, but in 1 of the 46, union was delayed. This was a dog that had a high-energy gunshot wound to the humerus; union was evident 15 weeks after surgery, and there were no complications. The remaining dog had sciatic denervation and severe muscle wasting secondary to trauma to the sciatic nerve by the tip of the intramedullary pin. The dog died 6 months after surgery of an unrelated illness and was still lame at that time. Radiographs taken prior to loss of follow up in this dog showed evidence of bone healing, but the fracture could not be considered to have reached union as defined in this study.

Figure 1—Radiographic projections obtained before (A), immediately after (B), and 12 weeks after (C) repair of a comminuted femoral fracture with a plate-rod construct in a 1-year-old cat.

Figure 2—Radiographic projections obtained before (A), immediately after (B), and 8 weeks after (C) repair of a comminuted tibial fracture with a plate-rod construct in a 2-year-old dog.
Mean ± SD time to radiographic union was 7.5 ± 2.7 weeks (range, 4 to 15 weeks) for the dogs and 4.8 ± 1.3 weeks (range, 3 to 6 weeks) for the cats. Radiographic union was evident on radiographs obtained 8 weeks after surgery for 20 of 26 dogs and 5 of 5 cats.

There were 4 short-term complications, all of which were considered minor, and 15 long-term complications, of which 2 were considered major and 13 were considered minor. Minor complications consisted of pin migration or soft tissue irritation (3 cats and 6 dogs), seroma formation (2 dogs), and loosening of 1 or more screws (1 cat and 5 dogs). Pin migration or irritation of the soft tissues was most frequently resolved with pin removal (n = 5) or reseating of the pin (4). Major complications included formation of a draining tract in 1 dog that did not regain full use of the limb and sciatic denervation because of pin migration in 1 dog. The draining tract resolved with removal of the bone plate and screws. Pin removal 2 weeks after surgery in the dog with sciatic denervation resulted in improvement in sciatic nerve function, but not complete resolution of the abnormality. No bone plates were found to be broken; 1 plate was removed because of formation of a draining tract, and 2 were removed approximately 2 years after surgery because of screw loosening.

Twelve animals had clinically important concurrent injuries, including diaphragmatic hernia (n = 1), metatarsal or metacarpal bone fracture (2), fracture of the scapular spine with trauma to the infraspinatus and supraspinatus muscles (1), pubic and ischial fractures (3), hip joint luxation (3), head trauma (1), radial nerve trauma from a bullet (1), triceps muscle laceration (2), and quadriiceps contracture (1). All injuries, with the exception of hip joint luxation in 1 animal, pubic and ischial fractures in 1 animal, and head trauma in 1 animal, were ipsilateral. The dog with quadriceps contracture required additional surgery for the contracture after the femoral fracture healed.

Long-term (> 6 months) follow-up information was available for 40 of the 45 cases. Twenty-one owners reported that their dogs had normal limb function, 5 reported that their dogs had some stiffness or lameness when active, and 2 reported that their dogs were usually stiff or lame. Nine owners reported that their cats had normal limb function, 2 reported that their cats had some stiffness or lameness when active, and 1 reported that his cat had intermittent or persistent stiffness or lameness. Twenty-six of 28 dog owners (93%) and 12 of 12 cat owners (100%) indicated that they were satisfied with the results of the procedure. Owners of the remaining 2 dogs, which included the dog with a draining tract and the dog with sciatic denervation, were indifferent or uncertain.

Regression analyses and multivariate ANOVA did not reveal any significant relationships between time to radiographic union and the following variables: total number of screws, number of bicortical screws, number of monocortical screws, number of empty screw holes, and percentage of medullary canal filled by the intramedullary pin (Table 1). However, there was a significant linear relationship between surgery time (P = 0.016) and time to union and a significant association between number of fragments (≤ 5 vs > 5; P = 0.017) and time to union. As surgery time increased, time to union also increased. Time to union for fractures with > 5 fragments was significantly shorter than time to union for fractures with ≤ 5 fragments.

Discussion

Results of this study suggest that plate-rod constructs can successfully be used for repair of diaphyseal fractures of a wide range of severity in dogs and cats. Most complications in the present study were minor and related to intramedullary pin migration, irritation of soft tissues by the intramedullary pin, seroma formation, and loosening of bone screws. Results were generally good, with owners of 30 of 42 dogs and cats reporting normal limb function. Healing and total operative times were comparable to published diaphyseal fracture repair studies.

Repairing comminuted diaphyseal fractures in dogs and cats can be challenging. Anatomic reconstruction and rigid stabilization may result in bone healing. However, if complete anatomic reconstruction is not possible, then small fracture gaps will remain. These gaps can potentially be areas of high interfragmentary strain that interfere with bone healing. Biologic osteosynthesis, on the other hand, does not rely on anatomic reconstruction, and the large fracture gaps that remain reduce interfragmentary strain. With biologic osteosynthesis, bone healing is a result of formation of fibrous connective tissue, followed by cartilaginous callus, between fracture fragments. Because the bony column is not anatomically reconstructed, the method of fracture fixation chosen must be capable of supporting the fragments adequately until callus has formed.

With unstable fractures, use of a plate-rod construct has been shown to be mechanically superior to use of a bone plate alone. When a bone plate is used alone, a defect in the cortex opposite the plate will result in large bending moments in the plate, predisposing it to mechanical failure. The addition of an intramedullary pin reduces the strain on a plate by about half, which increases the predicted failure life of the plate by a factor of 10 or more. Thus, use of plate-rod constructs for fixation of highly comminuted fractures that cannot be anatomically reconstructed reduces the risk of catastrophic plate failure during the early postoperative period, as well as the potential risk of fatigue failure during fracture healing.

Results of the present study support the suggestion

Table 1—Details of implants used in 35 dogs and 12 cats with diaphyseal fractures repaired with a bone plate-intramedullary rod construct

<table>
<thead>
<tr>
<th>Factor</th>
<th>Dogs</th>
<th>Cats</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of plate holes</td>
<td>9.8 ± 3.5</td>
<td>9.9 ± 2.4</td>
</tr>
<tr>
<td>Total No. of screws</td>
<td>7.1 ± 2.0</td>
<td>6.8 ± 2.1</td>
</tr>
<tr>
<td>No. of bicortical screws</td>
<td>4.6 ± 2.5</td>
<td>3.7 ± 1.8</td>
</tr>
<tr>
<td>No. of monocortical screws</td>
<td>2.6 ± 2.5</td>
<td>3.3 ± 2.7</td>
</tr>
<tr>
<td>No. of empty plate holes</td>
<td>2.7 ± 3.1</td>
<td>3.0 ± 2.4</td>
</tr>
<tr>
<td>Percentage of medullary canal filled by pin</td>
<td>52.2 ± 17.4</td>
<td>54.1 ± 16.6</td>
</tr>
</tbody>
</table>

Data are given as mean ± SD.
that use of a plate-rod construct is mechanically superior to use of a bone plate alone. In 29 of the cases included in the present study, 1 or more of the plate holes were empty, yet none of the plates broke and 46 of 47 fractures healed. Failure across a plate hole is of great concern when bone plates are used alone, particularly if there are empty holes over fracture defects. The ability to leave plate holes empty, without adversely affecting the potential for fracture healing, when using a plate-rod construct allows for greater versatility in fracture repair.

In the present study, there was a positive linear relationship between operative time and time to union. Longer surgical times were likely associated with greater disruption of the soft tissues, the fracture hematoma, and the cortical fragments, which may have delayed fracture healing. In addition, although not evaluated statistically, most animals for which operative time was >100 minutes were treated at Texas A&M University, rather than at Gulf Coast Veterinary Specialists. It was not possible to determine how many of the surgeries performed at Texas A&M University were performed by surgery residents, rather than a board-certified surgeon; however, it is possible that surgical experience may have been a factor both in operative time and time to union.

Highly comminuted fractures (fractures with >5 fragments) healed faster than fractures with ≤5 fragments in the present study, and other studies have also reported faster healing times for severely comminuted fractures. However, 4 of the 12 highly comminuted fractures received autogenous cancellous bone grafts, whereas only 4 of the 35 fractures with ≤5 fragments did, which may have confounded results. On the other hand, 10 of the 12 highly comminuted fractures had operative times >100 minutes.

The present study was not designed to allow comparisons between plate types and sizes that were used and standard recommendations for plate selection based on animal weight and bone size. In general, however, plates equivalent to or smaller than the recommended plates were used. Our results, therefore, combined with results of biomechanical studies of plate-rod constructs, suggest that with a plate-rod construct, a smaller plate can be used than would be required if the plate were being used alone. In a study of human patients, plate length, plate screw density (ie, No. of screws/No. of plate holes), number of plate holes, and total number of plate screws were significant predictors of success. Longer plates were considered to be mechanically advantageous, because they dissipate forces better and experience less strain and better leverage. Plate length was not evaluated in the present study, because size of the dogs and cats ranged so widely. However, longer plates may be advantageous when using plate-rod constructs for repair of diaphyseal fractures in dogs and cats.

For both dogs and cats in the present study, mean percentage of the medullary canal filled by the intramedullary pin was approximately 50%. In a previous study, plate strain was decreased by approximately 19, 44, and 61% when intramedullary rods filling 30, 40, and 50%, respectively, of the medullary canal were used. Plate stiffness increased by 40 and 78% when the percentage of the medullary canal that was filled increased to 40 and 50%, respectively, and plate fatigue life increased significantly when pins filled ≥30% of the medullary canal. The authors of a previous study recommended using an intramedullary pin that was 35 to 40% of the diameter of the medullary canal, unless a plate smaller than usual was used. Larger-diameter pins may be necessary in animals considered to have a lower healing potential, especially if there is concern about patient or owner compliance. We could not test for any association between pin size and complication rate in the present study; however, we recommend using a pin approximately 35 to 50% of the diameter of the medullary canal. A pin of this size should provide adequate stability, reduce the chance of plate failure, and allow adequate room for placement of bicortical screws.

In our search of the medical records for the study period, we identified 3 dogs with fractures of the radius and ulna that were repaired with a combination of a plate and intramedullary pin. These dogs were not included in the present study, however, because a plate-rod construct was not used. Rather, a bone plate was applied to the radius, and an intramedullary pin was inserted in the ulna. Fractures in all 3 dogs healed.

Cerclage and interfragmentary wires are generally not used in combination with a plate-rod construct when attempting biological osteosynthesis of a diaphyseal fracture, because their placement often requires unnecessary disruption of the fracture hematoma or soft tissue attachments to bone fragments. However, they may be used if needed to reconstruct the main fracture fragments prior to bone plate placement. Cerclage wires were used in 3 cases in the present study. It is suspected that monofilament suture was used to pull outlying fragments closer to the bone column in several cases, although this was reported in the operative report for only 1 case.

One particular advantage of using a plate-rod construct to repair a diaphyseal fracture, compared with use of a plate alone, is that the intramedullary pin can be removed to create intermittent stress across the fracture site and stimulate fracture healing once a callus has started to form, particularly when healing is progressing at a slower rate than expected. Intramedullary pins were removed from 15 of the patients in the present study, but only 3 of these were removed specifically to improve fracture healing. Six pins were removed because of pin migration (n = 4) or soft tissue irritation (2) between 3 and 6 weeks after surgery. The remaining pins were removed by the referring veterinarians at the request of the owner.

The minimum number of screws necessary with a plate-rod construct has not been established. Hulse et al19 have recommended that no fewer than 3 monocortical and 1 bicortical screw be placed in each of the main fracture fragments. Eight cases in the present study had plate-rod constructs with 2 or fewer bicortical screws. Seven of these fractures healed within 8 weeks after surgery, and 1 healed within 12 weeks. Three of these 8 cases had only 2 bicortical screws,
with 1 bicortical screw in the proximal fragment and 1 in the distal fragment (n = 2) or 2 bicortical screws in the distal fragment and none in the proximal fragment (1). Five cases had a single bicortical screw (n = 3) or no bicortical screws (2). All 5 fractures healed without any major complications and only 2 minor complications (screw loosening 2 years after surgery). Thus, fewer screws may be adequate in some instances.

Late radiographic follow-up resulted in an inability to accurately determine time to union in almost 25% of the cases in the present study. These cases were included in the study, but time to union was considered indeterminate for statistical purposes to avoid falsely increasing the mean healing times. Loss of radiographic follow-up prevented a final determination of outcome in the dog with sciatic nerve trauma, although callus formation was evident on the last radiographs obtained.

Decreased operative times have been reported for dogs with comminuted femoral fractures repaired with biological bridging plate fixation (116.5 minutes), compared with anatomic plate reconstruction (191.8 minutes).11 Mean operative time for open reduction, anatomic reconstruction, and bone plate stabilization of tibial fractures in dogs has been reported to be 157 minutes.12 Mean ± SD operative time for fracture repair for dogs in the present study was 105.6 ± 51.4 minutes. This is similar to reported operative times for external fixation in dogs with radial and tibial fractures (96 minutes13 and 86 minutes17) and biological repair of comminuted diaphyseal fractures with interlocking nails in dogs (90.8 minutes8).

Mean ± SD times for fracture union in dogs and cats in the present study were 7.5 ± 2.7 weeks and 4.8 ± 1.3 weeks, respectively. Although direct comparisons with times to union reported in other studies are not possible, these times do compare favorably with those reported following external skeletal fixation of comminuted radial and tibial fractures in dogs (11.4 weeks14), following external skeletal fixation of comminuted tibial fractures in dogs (10 weeks15), and following interlocking nailing of comminuted fractures in dogs (6.8 weeks8). In 1 study,16 mean time to external fixator removal following repair of femoral fractures in cats was 8 weeks.

References

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