Biomechanical comparison of a 3.5-mm conical coupling plating system and a 3.5-mm locking compression plate applied as plate-rod constructs to an experimentally created fracture gap in femurs of canine cadavers

Giovanni Tremolada DVM, PhD
Daniel D. Lewis DVM
Ken Luka Paragnani DVM, PhD
Bryan P. Conrad PhD
Stanley E. Kim BVSc, MS
Antonio Pozzi, DVM, MS

Received May 2, 2016.
Accepted September 6, 2016.

From the Comparative Orthopedic and Biomechanics Laboratory (Tremolada, Lewis, Paragnani, Conrad, Kim, Pozzi) and the Department of Small Animal Clinical Sciences (Lewis, Kim, Pozzi), College of Veterinary Medicine, University of Florida, Gainesville, FL 32610; and the Department of Orthopedics and Rehabilitation, College of Medicine, University of Florida, Gainesville, FL 32610 (Conrad). Dr. Tremolada's present address is Department of Clinical Sciences, College of Veterinary Medicine and Biomedical Sciences, Colorado State University, Fort Collins, CO 80523. Dr. Paragnani's present address is Department of Veterinary Clinics, Veterinary Teaching Hospital, University of Pisa, 56122 Pisa, Italy. Dr. Conrad's present address is Nike Sports Research Lab, Nike Inc, One Bowerman Dr, Beaverton, OR 97005. Dr. Pozzi's present address is Clinic for Small Animal Surgery, Vetsuisse Faculty, University of Zurich, 8057 Zurich, Switzerland.

Address correspondence to Dr. Tremolada (giovanni.tremolada@colostate.edu).

OBJECTIVE

To compare stiffness and resistance to cyclic fatigue of two 3.5-mm locking system plate-rod constructs applied to an experimentally created fracture gap in femurs of canine cadavers.

SAMPLE

20 femurs from cadavers of 10 mixed-breed adult dogs.

PROCEDURES

1 femur from each cadaver was stabilized with a conical coupling plating system–rod construct, and the contralateral femur was stabilized with a locking compression plate (LCP)–rod construct. An intramedullary Steinmann pin was inserted in each femur. A 40-mm gap then was created; the gap was centered beneath the central portion of each plate. Cyclic axial loading with increasing loads was performed. Specimens that did not fail during cyclic loading were subjected to an acute load to failure.

RESULTS

During cyclic loading, significantly more LCP constructs failed (6/10), compared with the number of conical coupling plating system constructs that failed (1/10). Mode of failure of the constructs included fracture of the medial or caudal aspect of the cortex of the proximal segment with bending of the plate and pin, bending of the plate and pin without fracture, and screw pullout. Mean stiffness, yield load, and load to failure were not significantly different between the 2 methods of stabilization.

CONCLUSIONS AND CLINICAL RELEVANCE

Both constructs had similar biomechanical properties, but the conical coupling plating system was less likely to fail than was the LCP system when subjected to cyclic loading. These results should be interpreted with caution because testing was limited to a single loading mode. (*Am J Vet Res* 2017;78:712–717)

Bridging plate osteosynthesis is commonly used to manage comminuted diaphyseal long-bone fractures in dogs.[1-5] Locking plates may be particularly advantageous when performing bridging plate osteosynthesis because locking plates do not require precise contouring, allow for the preservation of attached periosseous soft tissue and vasculature, promote rapid fracture healing, and decrease the risk of implant failure and postsurgical infection.[1-3,6-11]

Implant selection plays a critical role in obtaining an optimal outcome when plates are applied in bridging osteosynthesis.[12] The plate must be sufficiently stiff and strong enough to withstand the forces of weight bearing because the implant will not be protected by a reconstructed column of bone.[13,14] Plates used for bridging osteosynthesis are often applied after an intramedullary pin has been placed; use of the intramedullary pin decreases the risk of fatigue failure.[5,12,14,15] A plate-rod construct with an intramedullary pin that is 30% to 40% of the diameter of the medullary canal has been found to increase the fatigue life of a bridging plate by at least 10 times, compared with results for fixation with an isolated plate.[14,16] The addition of an intramedullary pin also reduces the stress concentration at unfilled screw holes in the plate.[14]

Several types of plates, including locking plates, have been used when applying plate-rod constructs to stabilize comminuted diaphyseal long-bone fractures in dogs.[4,5,14,17,18] Multiple locking plate systems are available for use in dogs, and each implant system has unique design features and mechanical properties.[12,19,20] The LCP was one of the first locking plate systems available for use in dogs. The locking mechanism in this system involves the interdigitation of

ABBREVIATIONS

LCP	Locking compression plate

threads located on the base of the heads of specialized locking screws, with corresponding threads in the holes of the locking plates.[21]

Another locking plate system that has been used to perform bridging plate osteosynthesis in dogs is the conical coupling plating system.[22] The conical coupling plating system consists of stainless steel supports with titanium alloy bushings that are screwed into holes in the plate. Recesses in the holes and bushings, which accommodate screws, have a conical shape that match the conical head of the titanium screws, thus creating a conical coupling locking mechanism.[23] The conical coupling plating system also differs from other locking plate systems because screw holes are only positioned at each end of the plate.[23]

Several studies[5,14,15,18,19,24–30] have been conducted to compare the mechanical behavior of LCP-rod constructs with those of various types of plate-rod constructs with locking and nonlocking plates in cadaver bones or synthetic bones. In only a few of these studies[5,18,25–28] have the biomechanical properties of the constructs been tested under cyclic loading, even though cyclic loading is considered to be a more relevant testing method than single load to failure testing.[12]

To address the lack of available data regarding biomechanical properties of the conical coupling plating system applied as a bridging plate, the purpose of the study reported here was to evaluate stiffness and resistance to cyclic fatigue of a 3.5-mm LCP, compared with results for a 3.5-mm conical coupling plating system, in a plate-rod construct applied to experimentally created fracture gaps in femurs of canine cadavers. On the basis of results of previous studies[19,24] conducted to compare the biomechanical properties of the 2 plating systems, we hypothesized that the LCP constructs would be stiffer than the conical coupling plating system constructs and would tolerate more cycles of loading before failing than would the conical coupling plating system constructs.

Materials and Methods

Sample

Twenty femurs were harvested from cadavers of 10 mixed-breed adult dogs (body weight, 25 to 30 kg) donated by a local animal shelter. Dogs were euthanized for reasons unrelated to the study. For euthanasia, dogs were anesthetized and then administered an injection of pentobarbital sodium. All soft tissues were removed from the femurs, and femurs were then radiographed to verify that there were no abnormalities. Specimens were double-wrapped in gauze soaked in saline (0.9% NaCl) solution and frozen at –20°C until used in the study. The study was approved by an institutional animal care and use committee.

Specimen preparation

Each femur was stabilized with a plate-rod construct that involved use of a 3.5-mm LCP[a] (thickness, 3.3 mm; length, 170 mm) or a 3.5-mm conical coupling plating system[b] (thickness, 3 mm; length, 172 mm). One femur from each cadaver was assigned by coin toss to the conical coupling plating system stabilization group, and the contralateral femur was assigned to the LCP stabilization group. Five right and 5 left femurs were allocated to each stabilization group. An intramedullary Steinmann pin was inserted in a normograde direction from the intertrochanteric fossa until the tip was seated in the distal femoral metaphysis. Pin diameter was selected to fill 40% of the mid-diaphyseal medullary canal of each femur. Pins of the same diameter were used for both femurs of a specific cadaver.

Each plate was anatomically contoured over the lateral aspect of the femur. The proximal portion of the plate was contoured over the greater trochanter, and the distal portion of the plate was contoured to conform to the surface of the lateral femoral condyle **(Figure 1)**. Two 1-mm cerclage wires were applied temporarily around the femur at the level of the proximal and distal metaphyses to maintain a constant plate-bone distance. The cerclage wires were removed after application of the plate. A total of 6 locking screws (3 for each major fracture segment) were used in each construct. The most proximal and most distal screws were inserted as bicortical screws, whereas the remaining screws were inserted as monocortical screws. A 40-mm gap was then created by use of an oscillating saw; the gap was centered beneath the central segment of the plate. This segmental gap simulated a nonreconstructed comminuted diaphyseal femoral fracture.

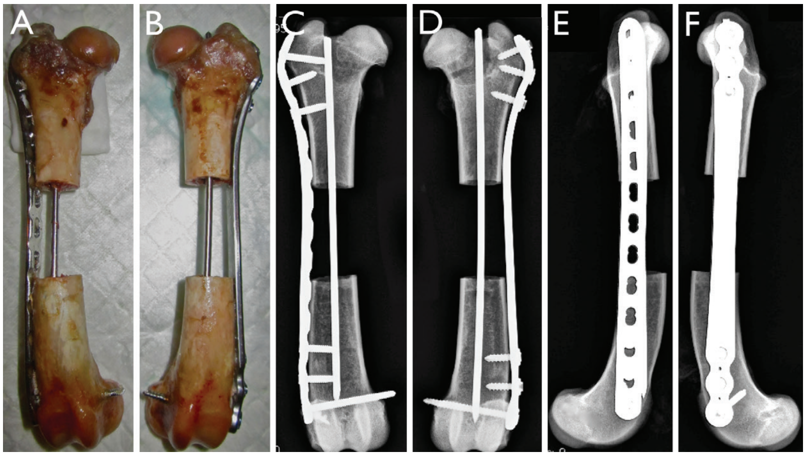

Figure 1—Photographs (A and B), craniocaudal radiographic views (C and D), and mediolateral radiographic views (E and F) of the femurs from a representative canine cadaver after application of a contoured 3.5-mm LCP construct (A, C, and E) and a 3.5-mm conical coupling plating system construct (B, D, and F), insertion of an intramedullary Steinmann pin, and creation of a 40-mm gap that was centered beneath the central portion of each plate.

Orthogonal-view radiographs were obtained after application of the constructs and creation of the 40-mm gap (Figure 1). Radiographs were examined to confirm that the position and length of the fracture gap were appropriate, implants were placed properly, screws did not impinge on the intramedullary pin, and the bones did not have iatrogenic fissures.

After proper plate application was verified, the distal end of each femur was embedded in polymethyl methacrylate. Specimens were oriented and aligned by use of a custom-made jig such that the longitudinal axis of the plate would be maintained parallel to the applied axial load in both the frontal and sagittal planes during mechanical testing. The distal portion of the plate was not embedded in polymethyl methacrylate.

Biomechanical testing

Eccentric axial compressive loading was applied to the femoral head by means of a custom-designed polyethylene cup connected to the load cell of a servo-hydraulic material testing machine.[c] This testing configuration was selected on the basis that it had been used in a similar study.[5] The load cell was adjusted to 0 before testing. A preload of 20 N was applied to each specimen. Each specimen was subjected to a total of 45,000 cycles at 2 Hz, unless failure occurred during cyclic loading. The initial 15,000 cycles were at 200 N, the subsequent 15,000 cycles were at 400 N, and the final 15,000 cycles were at 800 N to simulate progressive increases in postoperative weight bearing. The number of cycles sustained before failure was recorded for each construct. Failure was described as obvious plastic deformation and narrowing of the gap to ≤ 20 mm or catastrophic fracture of the constructs or bone. Loading frequency was set at 2 Hz to mimic the stress to which a plate would be subjected during clinical conditions.

Specimens that had not failed after 45,000 cycles were subsequently subjected to an acute axial load to failure. Constructs were axially loaded to failure by use of a displacement protocol at a rate of 1 mm/min. Stiffness, yield load, and load to failure were recorded. Yield load was determined as the point at which the load displacement curve deviated from the linear region, as determined by use of a 0.2% slope offset criterion. Failure was described as catastrophic fracture of the construct or bone (specifically, when the gap was narrowed to ≤ 20 mm). Construct strength was characterized by the performance under cyclic loading as well as by the maximum load sustained during acute load to failure for those constructs that did not fail during cyclic loading.

Statistical analysis

A χ^2 test[d] was performed to compare the number of plates in both groups that failed during testing. For constructs that did not fail during cyclic testing and that subsequently underwent a single acute load to failure, a Wilcoxon matched-pairs signed rank test[d] was performed to compare stiffness, yield load, and load to failure between groups. Values of $P < 0.05$ were used to determine significance.

Results

During cyclic testing, significantly ($P = 0.019$) more LCP constructs failed (6/10), compared with the number of conical coupling plating system constructs that failed (1/10). Mean ± SD number of cycles at failure was 36,245 ± 4,049 for the LCP constructs. The number of cycles at failure for the single conical coupling plating system construct that failed during cyclic loading was not recorded because the material testing machine continued to cycle; however, we determined that the construct had failed; this determination was made because a fissure was detected in the caudal aspect of the cortex at completion of cyclic loading. Mode of failure of the constructs included fracture of the medial or caudal aspect of the cortex of the proximal segment with bending of the plate and pin (3 LCP constructs and 1 conical coupling plating system construct), bending of the plate and pin without fracture (2 LCP constructs), and screw pullout (1 LCP construct; **Figure 2**). Screw loosening at the screw-bone interface was observed for 2 conical coupling plating system constructs, but overt failure was not evident for either of these constructs. Diameter of the intramedullary pins ranged from 3.2 to 4.0 mm. All of the LCP constructs that failed did so during the final 15,000 loading cycles, when the maximum load applied (800 N) was approximately 3 times the load of the body weight of the subjects.

Constructs that did not fail during cyclic loading were subjected to acute load to failure testing. There were no significant differences in stiffness, yield load, and load to failure between the 2 methods of stabilization **(Table 1)**.

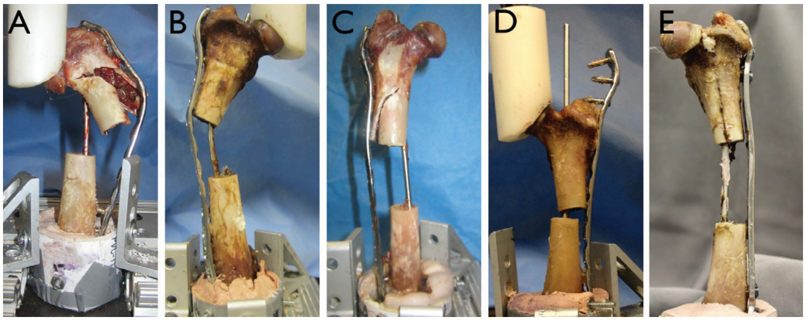

Figure 2—Photographs of 4 LCP constructs (A through D) and 1 conical coupling plating system construct (E) that failed during cyclic testing. A—The construct failed by fracture of the medial aspect of the cortex of the proximal segment and bending of the plate. B—The construct failed by bending of both the plate and intramedullary pin. C—The construct failed by fracture of the medial aspect of the cortex of the proximal segment and bending of the plate. D—The construct failed by pullout of all 3 screws in the proximal segment. E—The construct was considered to have failed because a fissure line in the caudal aspect of the cortex of the proximal segment was detected after the completion of cyclic testing.

Table 1—Mean ± SD values for stiffness, yield load, and load to failure of conical coupling plating system (n = 9) and LCP (4) plate-rod constructs obtained during acute load to failure testing.

Variable	LCP constructs	Conical coupling plating system constructs	*P* value
Stiffness (N/mm)	207.0 ± 56.2	225.3 ± 22.8	0.8
Yield load (N)	993.9 ± 127.4	1,038.7 ± 87.3	0.8
Load to failure (N)	1,067.7 ± 163.1	1,134.3 ± 116.5	0.8

Values were considered significant at $P < 0.05$.

Discussion

For the present study, the hypothesis that LCP constructs would have a greater fatigue life than would conical coupling plating system constructs was rejected because 6 of the LCP constructs failed during cyclic loading but only 1 of the conical coupling plating system constructs failed during cyclic loading. We were uncertain as to the reason or reasons that the LCP group had a higher failure rate. The 2 plating systems did not differ significantly in the area moment of inertia according to the manufacturer, and both were composed of 316L stainless steel.[24] A plausible explanation for the reason that more of the LCP constructs failed during cyclic loading can be based on structural differences between the 2 types of plates. Whereas LCPs have holes positioned along the entire length of the plate, the conical coupling plating system only had holes positioned at the ends of the plate, and the large solid central segment may have made the plate more resistant to cyclic failure. Additionally, all of the holes in the conical coupling plating system were filled with screws, which mitigated the stress effect of unfilled holes in these constructs. The centrally positioned unfilled holes in LCP constructs may have made these constructs more susceptible to fatigue failure.

Results for the present study are in contrast with those of a previous study[24] in which investigators compared 3.5-mm LCP constructs and other 3.5-mm plate constructs in a single cycle to failure test. Authors of that study[24] found that the LCP was significantly stronger and stiffer than the conical coupling plating system constructs, which suggested that the combination of a stainless steel support and titanium inserts lowers the section modulus, thereby affecting mechanical behavior. On the basis of the linear relationship between yield load and fatigue strength,[31] we expected greater fatigue strength of the LCP constructs than that of the conical coupling plating system constructs. These results may have reflected differences in the testing protocol between the 2 studies. In that other study,[24] a 4-point bending test was used, whereas in the study reported here, an eccentric axial load was applied to the femur, which was embedded in polymethyl methacrylate and fixed distally. We suspected that our testing protocol created stress concentration on the plate, which is considered one of the most important factors affecting the fatigue life of any component or structure.[32] The LCP may have been less resistant to stress concentration because of the presence of empty screw holes, which predisposed the LCP to cyclic failure.

In the 4 femurs in which the constructs failed as a result of fracture of the medial aspect of the cortex, the intramedullary pin was positioned in close proximity to the medial aspect of the cortex, and the pin may have impinged on the medial aspect of the endosteal cortex as the femur was loaded, which created high stress in this region of the bone. Impingement would have been more prominent when the femurs were loaded at 800 N because of more pronounced bending at higher loads. Fissures created during preparation of the specimens could also have potentially contributed to osseous failure during cyclic testing. Although fractures were not evident during examination of the radiographs obtained after specimen preparation, the possibility that microscopic fissures may have been present but not detected cannot be excluded. We attempted to avoid fissures and the risk of engaging the intramedullary pin with the screws by placing only 1 bicortical screw in each of the major fracture segments. Having screws engage the intramedullary pin in some, but not all, of the constructs would have created variability in stiffness between constructs, which would have made it difficult to make comparisons between the methods of stabilization.

The cyclic testing protocol for the present study was selected on the basis that it would simulate the progressive increase of weight bearing that normally occurs during the postoperative convalescent period. Modes of failure observed in the present study were similar to those reported for dogs that have undergone plate stabilization of long-bone fractures,[11,22] which suggests that the test protocol mimicked physiologic loading. The total number of cycles was selected on the basis of the mean number of cycles of an individual limb in dogs walked for 5 to 10 minutes 4 times/d for 1 month.[33] The force applied to the constructs was higher than the force reported for dogs while walking, which is 40% to 50% of body weight.[34,35] Loads between 100% and slightly < 400% of body weight were applied to account for loads that would be incurred during trotting or higher-impact activities that may predispose to earlier failure.[35] This may explain the reason that in clinical settings, when postoperative activity is appropriately restricted, both implant systems are effective for achieving bone healing with a low rate of catastrophic failure of fixation.[22,36]

One of the limitations of the study reported here was the use of isolated femurs harvested from canine cadavers. Typical of all ex vivo biomechanical testing of orthopedic constructs, the testing protocol for the present study could not accurately reproduce clinical conditions. The magnitude and direction of applied ex vivo loads cannot simulate the complex in vivo forces that a stabilized fracture is subjected to during the postoperative convalescent period. The method of eccentrically loading a femur is considered a reasonable physiologic means of testing modalities for stabilization of femoral fractures because loading the femur in this manner produces an axial compressive load in addition to a bending moment and weak torque moment.[5,26] A further limitation of the use of cadavers was that osseous remodeling and mechanical support provided by the developing callus were not replicated during the process of cyclic loading. Thus, the influence of fracture healing on implant stability remains unknown. Other limitations included the small number of specimens in both stabilization groups and the relatively short duration of cyclic loading. A more gradual increase in the force applied to the specimens and a longer duration of cyclic loading may help identify optimal amounts of physical activity to be allowed during the postoperative convalescent period that will prevent implant failure but, at the same time, stimulate bone healing.

Although both of these locking plate systems have commonly been used in clinical settings with good results,[11,22] and the 2 constructs had similar biomechanical properties when loaded in eccentric axial compression, results for the present study suggested that the conical coupling plating system plates might be more resistant to cyclic fatigue than LCPs when used as a bridging plate-rod construct to stabilize unreconstructed comminuted diaphyseal femoral fractures. These results should be interpreted with caution because testing was limited to a single loading mode.

Acknowledgments

Supported by SynthesVet and Fixin.

Presented as a poster at the 4th World Veterinary Orthopedic Congress, Breckenridge, Colo, March 2014.

The authors thank Dr. Boero Baroncelli for assistance with development of the mechanical testing protocol.

Footnotes

a. LCP, VP4041.13, provided by Synthes Vet Inc, West Chester, Pa.
b. V3401, provided by Fixin, Traumavet, Rivoli, Italy.
c. MTS 858 Mini Bionix II, Eden Prairie, Minn.
d. Prism, GraphPad Software, La Jolla, Calif.

References

1. Johnson AL, Smith CW, Schaeffer DJ. Fragment reconstruction and bone plate fixation versus bridging plate fixation for treating highly comminuted femoral fractures in dogs: 35 cases (1987–1997). *J Am Vet Med Assoc* 1998;213:1157–1161.
2. Boero Baroncelli A, Peirone B, Winter MD, et al. Retrospective comparison between minimally invasive plate osteosynthesis and open plating for tibial fractures in dogs. *Vet Comp Orthop Traumatol* 2012;25:410–417.
3. Pozzi A, Hudson CC, Gauthier CM, et al. Retrospective comparison of minimally invasive plate osteosynthesis and open reduction and internal fixation of radius-ulna fractures in dogs. *Vet Surg* 2013;42:19–27.
4. Witsberger TH, Hulse DA, Kerwin SC, et al. Minimally invasive application of a radial plate following placement of an ulnar rod in treating antebrachial fractures. Techniqe and case series. *Vet Comp Orthop Traumatol* 2010;23:459–467.
5. Goh CS, Santoni BG, Puttlitz CM, et al. Comparison of the mechanical behaviors of semicontoured, locking plate–rod fixation and anatomically contoured, conventional plate–rod fixation applied to experimentally induced gap fractures in canine femora. *Am J Vet Res* 2009;70:23–29.
6. Perren SM. The concept of biological plating using the limited contact-dynamic compression plate (LC-DCP). Scientific background, design and application. *Injury* 1991;22:1–41.
7. Guiot LP, Dejardin LM. Prospective evaluation of minimally invasive plate osteosynthesis in 36 nonarticular tibial fractures in dogs and cats. *Vet Surg* 2011;40:171–182.
8. Pozzi A, Risselada M, Winter MD. Assessment of fracture healing after minimally invasive plate osteosynthesis or open reduction and internal fixation of coexisting radius and ulna fractures in dogs via ultrasonography and radiography. *J Am Vet Med Assoc* 2012;241:744–753.
9. Miller DL, Goswami T. A review of locking compression plate biomechanics and their advantages as internal fixators in fracture healing. *Clin Biomech (Bristol, Avon)* 2007;22:1049–1062.
10. Gautier E, Sommer C. Guidelines for the clinical application of the LCP. *Injury* 2003;34(suppl 2):B63–B76.
11. Haaland PJ, Jostrom L, Devor M, et al. Appendicular fracture repair in dogs using the locking compression plate system: 47 cases. *Vet Comp Orthop Traumatol* 2009;22:309–315.
12. Chao P, Lewis DD, Kowaleski MP, et al. Biomechanical concepts applicable to minimally invasive fracture repair in small animals. *Vet Clin North Am Small Anim Pract* 2012;42:853–872.
13. Koch D. Implant description and application: screw and plates. In: Johnson A, Houlton JEF, Vannini R, eds. *AO principles of fracture management in the dog and cat*. Davos, Switzerland: AO Publishing, 2005;44.
14. Hulse D, Hyman W, Nori M, et al. Reduction in plate strain by addition of an intramedullary pin. *Vet Surg* 1997;26:451–459.
15. Pearson T, Glyde M, Hosgood G, et al. The effect of intramedullary pin size and monocortical screw configuration on locking compression plate-rod constructs in an in vitro fracture gap model. *Vet Comp Orthop Traumatol* 2015;28:95–103.
16. Hulse D, Ferry K, Fawcett A, et al. Effect of intramedullary pin size on reducing bone plate strain. *Vet Comp Orthop Traumatol* 2000;13:185–190.
17. Reems MR, Beale BS, Hulse DA. Use of a plate-rod construct and principles of biological osteosynthesis for repair of diaphyseal fractures in dogs and cats: 47 cases (1994–2001). *J Am Vet Med Assoc* 2003;223:330–335.
18. Malenfant RC, Sod GA. In vitro biomechanical comparison of 3.5 String of Pearl plate fixation to 3.5 locking compression plate fixation in a canine fracture gap model. *Vet Surg* 2014;43:465–470.
19. Cabassu JB, Kowaleski MP, Skorinko JK, et al. Single cycle to failure in torsion of three standard and five locking plate constructs. *Vet Comp Orthop Traumatol* 2011;24:418–425.
20. Guerrero TG, Kalchofner K, Scherrer N, et al. The Advanced Locking Plate System (ALPS): a retrospective evaluation in 71 small animal patients. *Vet Surg* 2014;43:127–135.
21. Koch D. Implant description and application: screw and plates. In: Johnson A, Houlton JEF, Vannini R, eds. *AO principles of fracture management in the dog and cat*. Davos, Switzerland: AO Publishing, 2005;46–47.
22. Nicetto T, Petazzoni M, Urizzi A, et al. Experiences using the Fixin locking plate system for the stabilization of appendicular fractures in dogs: a clinical and radiographic retrospective assessment. *Vet Comp Orthop Traumatol* 2013;26:61–68.
23. Petazzoni M, Urizzi A, Verdonck B, et al. Fixin internal fixator: concept and technique. *Vet Comp Orthop Traumatol* 2010;23:250–253.
24. Blake CA, Boudrieau RJ, Torrance BS, et al. Single cycle to failure in bending of three standard and five locking plates and plate constructs. *Vet Comp Orthop Traumatol* 2011;24:408–417.

25. Uhl JM, Kapatkin AS, Garcia TC, et al. Ex vivo biomechanical comparison of a 3.5 mm locking compression plate applied cranially and a 2.7 mm locking compression plate applied medially in a gap model of the distal aspect of the canine radius. *Vet Surg* 2013;42:840–846.
26. Irubetagoyena I, Verset M, Palierne S, et al. Ex vivo cyclic mechanical behavior of 2.4 mm locking plates compared with 2.4 mm limited contact plates in a cadaveric diaphyseal gap model. *Vet Comp Orthop Traumatol* 2013;26:479–488.
27. Aguila AZ, Manos JM, Orlansky AS, et al. In vitro biomechanical comparison of limited contact dynamic compression plate and locking compression plate. *Vet Comp Orthop Traumatol* 2005;18:220–226.
28. Filipowicz D, Lanz O, McLaughlin R, et al. A biomechanical comparison of 3.5 locking compression plate fixation to 3.5 limited contact dynamic compression plate fixation in a canine cadaveric distal humeral metaphyseal gap model. *Vet Comp Orthop Traumatol* 2009;22:270–277.
29. Zahn K, Frei R, Wunderle D, et al. Mechanical properties of 18 different AO bone plates and the clamp-rod internal fixation system tested on a gap model construct. *Vet Comp Orthop Traumatol* 2008;21:185–194.
30. Tomlinson AW, Comerford EJ, Birch RS, et al. Mechanical performance in axial compression of a titanium polyaxial locking plate system in a fracture gap model. *Vet Comp Orthop Traumatol* 2015;28:88–94.
31. Pang JC, Li SX, Wang ZG, et al. Relations between fatigue strength and other mechanical properties of metallic materials. *Fatigue Fract Eng Mater Struct* 2014;37:958–976.
32. MacGregor CW, Grossman N. Effects of cyclic loading on mechanical behavior of 24S–T4 and 75S–T6 aluminum alloys and SAE 4130 steel. *National advisory committee for areonautics, technical note 2812*. Washington, DC: NASA Technical Reports Server, 1952;1–53.
33. Aper RL, Litsky AS, Roe SC, et al. Effect of bone diameter and eccentric loading on fatigue life of cortical screws used with interlocking nails. *Am J Vet Res* 2003;64:569–573.
34. Roush JK, McLaughlin RM Jr. Effects of subject stance time and velocity on ground reaction forces in clinically normal Greyhounds at the walk. *Am J Vet Res* 1994;55:1672–1676.
35. Budsberg SC, Verstraete MC, Soutas-Little RW. Force plate analysis of the walking gait in healthy dogs. *Am J Vet Res* 1987;48:915–918.
36. Kowaleski MP. Minimally invasive osteosynthesis techniques of the femur. *Vet Clin North Am Small Anim Pract* 2012;42:997–1022.