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Biomechanical Comparison of Plate-Nail Vs. Plate-Rod for Experimentally-Induced Gap Fractures in *ex vivo* Canine Femora

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ABSTRACT

The purpose this original article is to compare the mechanical properties of an interlocking nail-plate combination (plate-nail) vs. an intramedullary pin-plate combination (plate-rod) applied to experimentally induced gap fractures in canine femora. Twenty four paired canine femora were assigned to either plate-nail or plate-rod with 2.7 mm or 3.5 mm system constructs. In each femur, a mid-diaphyseal ostectomy was performed and the selected system was applied. Paired system constructs were subjected to compression and bending tests. The maximum load differed significantly between fixation systems. The plate-nail system had greater maximum load than plate-rod system. The strength, stiffness and maximum deformation was similar between plate-rod and plate-nail. The plate-nail system proved to be a good option for diaphyseal long bone fracture fixation in dogs.

Key words: Interlocking nail, bone plate, intramedullary pin, femur, loading profile

INTRODUCTION

Treatment of unstable shaft fractures, that are deemed unsuitable for reconstruction, is a difficult challenge in orthopaedic veterinary medicine (Hulse *et al*., 1997; Bernarde *et al*., 2001; Goh *et al*., 2009). The repair of these injuries requires implants that can maintain the alignment of the bone during consolidation (Bernarde *et al*., 2001; Stiffler, 2004).

Successful internal fixation of the fracture requires an understanding of the loading forces acting upon the fracture fragments and the resistance due to the mechanical stiffness of the implant (Bernarde *et al*., 2001; Gordon *et al*., 2010).

Comminuted fractures require a fixation system that provides adequate stability to the bone-implant construct during the initial phase and which can act for a long period enough to allow bone healing (Bernarde *et al*., 2001; Muzzi *et al*., 2009). In comminuted diaphyseal fractures, comprised of a large number of small fracture fragments, it may not be possible to reconstruct the bone anatomically and in these cases, the loads acting on the implant and bone must be considered (Bernarde *et al*., 2001; Reems *et al*., 2006). Thus, in extremely comminuted diaphyseal fractures, the bone may not be able to share the load with the implant in the initial stages of bone healing. This situation decreases the fatigue life of the implant as it requires the implant to support all the weight bearing forces (Reems *et al*., 2006).

The intramedullary pin-plate combination (plate-rod system) is primarily indicated for comminuted fractures, when it is not possible to achieve anatomical reduction of bone fragments (Beale, 2004; Von Pfeil *et al.*, 2005; Goh *et al.*, 2009; Konning *et al.*, 2013). The presence of the intramedullary pin reduces the forces acting on the bone plate, which increases the fatigue life of the plate and prevents breakage. The intramedullary pin also facilitates the alignment of the bone shaft (Hulse *et al.*, 1997; Goh *et al.*, 2009; Niederhauser *et al.*, 2015). The rate of bone union described for the plate-rod system is around 98% and major complication is the migration of the intramedullary pin, requiring subsequent removal (Hulse *et al.*, 1997; Beale, 2004).

Recently, an interlocking nail-plate combination (plate-nail system) has been developed with the objective of achieving, in a single system, the advantages of each implant alone. Therefore, this system can neutralize more effectively the main forces acting on the fracture. The implant seems to promote high stiffness and stability for comminuted diaphyseal fractures, allowing adequate bone repair (Muzzi *et al.*, 2009).

The aim of this study was to compare the mechanical properties of the plate-nail vs. plate-rod systems in compression and bending tests. These mechanical properties included the maximum load supported by the implants, bending and compressive strength of the implants and the structural modulus of each system. Besides the mechanical values, the maximum deformation of bone defects and the types of failure which occurred with each system were also evaluated.

MATERIALS AND METHODS

Study design: The study was approved by the Bioethics Committee in Utilization of Animals of the Federal University of Lavras, under protocol number 016/2009. Forty eight femora, without evidence of orthopaedic disease, were harvested from twenty four middle to large sized adult dogs, which had been euthanatized for reasons unrelated to this study. Specimens were wrapped in towels soaked with isotonic saline (0.9% NaCl) solution and frozen in a conventional freezer until plate-nail or plate-rod biomechanical testing. Twenty four hours prior to specimen reconstruction and testing, they are removed from the freezer and thawed at room temperature (Von Pfeil *et al.*, 2005; Gordon *et al.*, 2010).

In order to minimize differences among the animals with regards to age, bone porosity, bone mineralization and anatomic conformation, which can alter the biomechanical results, comparison between the two systems was performed using the pair of femora from the same animal. Thus, the plate-nail system was applied to a femur and the plate-rod was applied to the contralateral femur from the same dog. The selected bones were divided in 24 femora for the compression tests and 24 femora for bending tests. For the compression test, the bones were divided into two groups of 12 femora each, which the plate-nail system was implanted in one group and the plate-rod system in the other group. In both plate-nail system and plate-rod system groups there were also two subgroups of 2.7 and 3.5 mm implant constructs (six femora each). For the bending test the same distribution of groups was performed.

Preparation of bone-implants constructs: An ostectomy was performed in each femoral mid-diaphysis using a bone saw. The length of the bone defect corresponded to the diameter of the femoral mid-diaphysis (Fig. 1). One femur received an interlocking nail-plate combination (Brasmed Veterinária, Paulínia-São Paulo, Brazil) (plate-nail system) (Fig. 2). The plate-nail system subgroups were composed of a either an 6 mm interlocking nail in combination with a 2.7 mm bone plate or an 8 mm interlocking nail with a 3.5 mm bone plate. The bone plate was

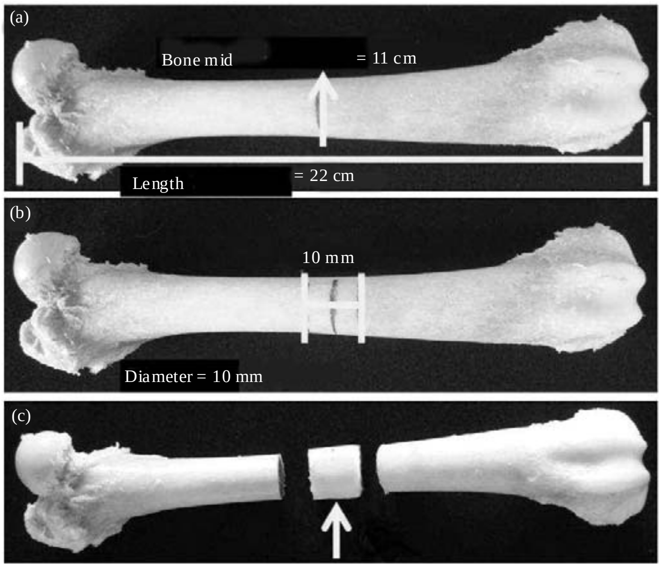

Fig. 1(a-c): (a) Bone length determination and identification using the same, (b) Marking the places where the bone is sawed and (c) Upon completion of the ostectomies to mimic bone defect

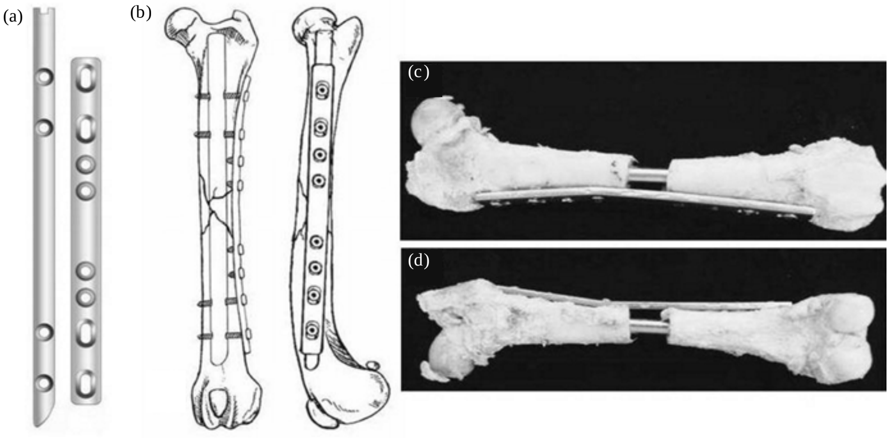

Fig. 2(a-d): (a) Interlocking nail (left) and bone plate (right), (b) Drawing demonstrating the correct positioning of plate-nail system in femur. Cranial view (left) and lateral view (right), (c) Cranial view and (d) Caudal view of specimens with plate-nail system. Right canine femur with mid-diaphyseal gap and internal fixation with interlocking nail-plate combination (plate-nail)

designed to accommodate the interlocking nail screws in its proximal and distal holes as a bridging plate. The contralateral femur then received a intramedullary pin-plate combination (Brasmed Veterinária, Paulínia-São Paulo, Brazil) (plate-rod system) (Fig. 3). The plate-rod system consisted of an intramedullary pin which filled approximately 40% of the diameter of the medullary cavity in the bone isthmus. For plate-rod system, the bridging plate used was the same plate designed for the plate-nail system with 2.7 and 3.5 mm plate constructs.

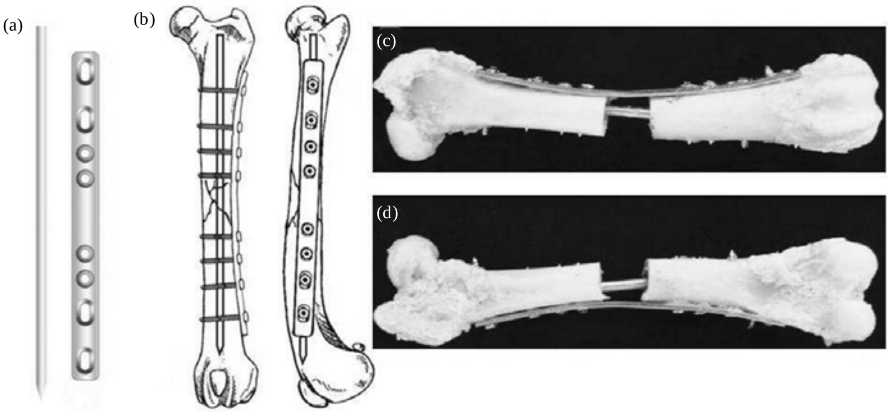

Fig. 3(a-d): (a) Intramedullary pin (left) and bone plate (right), (b) Drawing demonstrating the correct positioning of plate-rod system in femur. Cranial view (left) and lateral view (right), (c) Cranial view and (d) caudal view of specimens with plate-rod system. Left canine femur with mid-diaphyseal gap and internal fixation with intramedullary pin-plate combination (plate-rod)

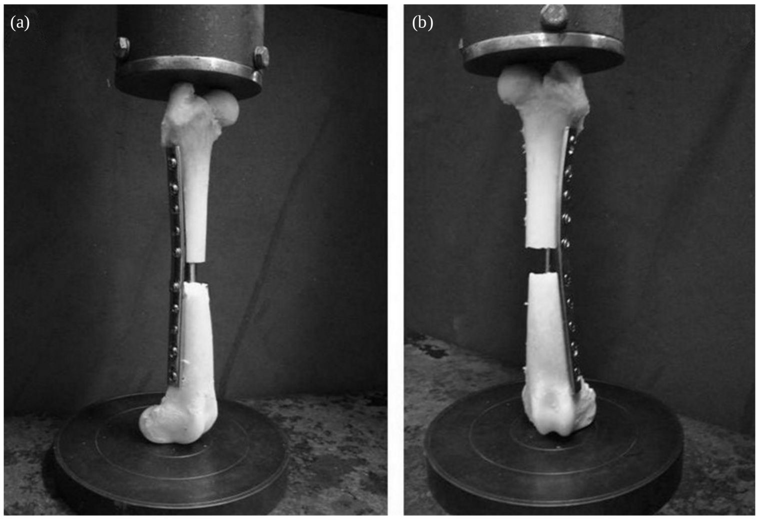

Fig. 4(a-b): Compression mechanical testing using femoral specimen, (a) Interlocking nail-plate combination (plate-nail system) and (b) Intramedullary pin-plate combination (plate-rod system)

All specimens were radiographed before biomechanical testing to assure correct alignment of the implants. After testing, radiographs of each femur were taken to determine the maximum deformation of the bone gap.

Mechanical testing: The compression test (Fig. 4) was performed in a universal testing machine EMIC DL 30000 model (EMIC DL 30000, EMIC equipamentos e sistemas de ensaios Ltda., São José dos Pinhais, Paraná, Brazil) using two plates for compression. The load cell used was 19600 Newton (N) and displacement speed was 10 mm sec^{-1}. Proximal and distal epiphyseal ostectomies

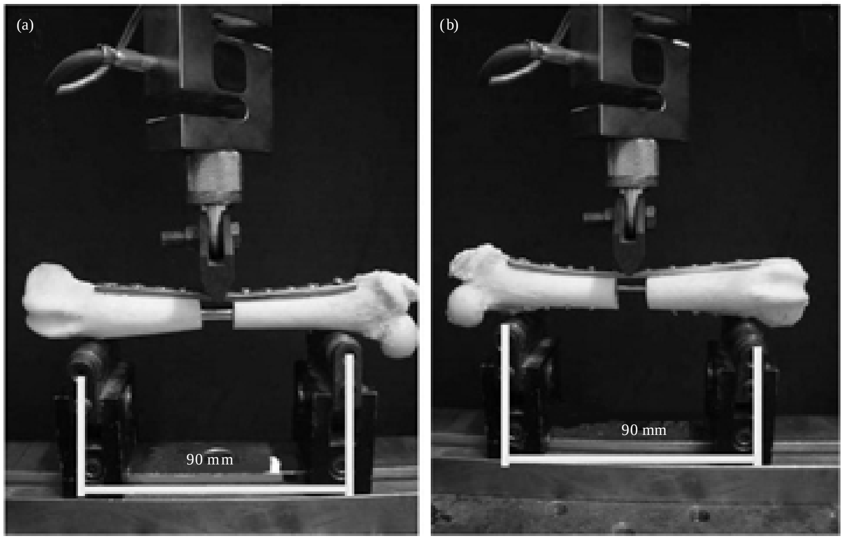

Fig. 5(a-b): Bending mechanical testing using femoral specimen, (a) Interlocking nail-plate combination (plate-nail system) and (b) Intramedullary pin-plate combination (plate-rod system)

were performed to allow placement of the specimens in the testing frame. Failure in compression testing was determined when the specimens fractured (Alves *et al*., 2010).

The bending test (Fig. 5) was performed in a universal testing machine EMIC DL 30000 model (EMIC DL 30000, EMIC equipamentos e sistemas de ensaios Ltda., São José dos Pinhais, Paraná, Brazil), with a load cell of 19600 N and displacement speed of 10 mm sec^{-1}. Failure in bending was considered complete when the specimens ruptured (Alves *et al*., 2010). The force was applied to the lateral aspect of the femur bone on the plate.

The software provided by the universal testing machine gave the maximum load and stiffness and strength of specimens in the compression and bending tests.

Statistical analysis: A Shapiro Wilk test was used to determine, if the data met the assumptions of the ANOVA. If the overall F-test was significant, pairwise comparisons were based on one-sided Tukey tests. The non-parametric data were evaluated using the Mann-Whitney test. Statistical significance was set at 0.05 for all tests.

RESULTS AND DISCUSSION

The mean and standard deviation were presented in Table 1-4. The maximum load in compression test was significantly different between the plate-nail and plate-rod systems in the 2.7 and 3.5 mm constructs ($p = 0.03$ in both). The maximum load in bending test was significantly different between the plate-nail and plate-rod systems in the 2.7 mm constructs ($p = 0.01$) but it was not significantly different between the systems in the 3.5 mm constructs ($p = 0.73$).

The stiffness in compression test was not significantly different between the systems in both constructs sizes ($p = 0.64$ in 2.7 mm constructs and $p = 0.17$ in 3.5 mm constructs). The stiffness in bending test was significantly different between the plate-nail and plate-rod systems in the 2.7 mm constructs ($p = 0.02$), but it was not significantly different between the systems in the 3.5 mm constructs ($p = 0.86$).

Table 1: Summary of compression test data comparing plate-nail (interlocking nail-plate combination) vs. plate-rod (intramedullary pin-plate combination) with 2.7 mm system constructs

System	Maximum load (N)	Compression strength (MPa)	System stiffness (MPa)	Maximum deformation (mm)
Plate-nail	1098.00±301^{a}	11.0±4^{c}	1362±875^{d}	1.6±1.5^{e}
Plate-rod	581.00±508^{b}	7.0±5^{c}	1207±342^{d}	1.3±0.8^{e}
p-value	0.03	0.1	0.64	0.76

Data with different superscripted letters are significant differences between constructs. N: Newton, MPa: Megapascal, mm: Millimeter

Table 2: Summary of compression test data comparing plate-nail (interlocking nail-plate combination) vs. plate-rod (intramedullary pin-plate combination) with 3.5 mm system constructs

System	Maximum load (N)	Compression strength (MPa)	System stiffness (MPa)	Maximum deformation (mm)
Plate-nail	1493±420^{a}	10.00±4^{c}	786.00±416^{d}	1.50±0.8^{e}
Plate-rod	1001±310^{b}	9.00±5^{c}	1055.00±541^{d}	2.00±1.7^{e}
p-value	0.31	0.03	0.17	0.92

Data with different superscripted letters are significant differences between constructs, N: Newton, MPa: Megapascal, mm: Millimeter

Table 3: Summary bending test data comparing plate-nail (interlocking nail-plate combination) vs. plate-rod (intramedullary pin-plate combination) with 2.7 mm system constructs

System	Maximum load (N)	Bending strength (MPa)	System stiffness (MPa)	Maximum deformation (mm)
Plate-nail	791±525^{a}	86.5±71^{c}	2502±1055^{d}	1.5±1.3^{f}
Plate-rod	160±91^{b}	20.0±12^{c}	1301±1119^{e}	3.8±2.7^{g}
p-value	0.01	0.06	0.02	0.02

Data with different superscripted letters are significant differences between constructs, N: Newton, MPa: Megapascal, mm: Millimeter

Table 4: Summary bending test data comparing plate-nail (interlocking nail-plate combination) vs. plate-rod (intramedullary pin-plate combination) with 3.5 mm system constructs

System	Maximum load (N)	Bending strength (MPa)	System stiffness (MPa)	Maximum deformation (mm)
Plate-nail	819±790^{a}	58.5±45.8^{b}	1838±1288^{c}	1.2±0.8^{d}
Plate-rod	979±926^{a}	41.6±32.6^{b}	2086±1922^{c}	5.0±4.7^{d}
p-value	0.73	0.4	0.86	0.19

Data with different superscripted letters are significant differences between constructs. N: Newton, MPa: Megapascal, mm: Millimeter

The compressive resistance was statistically similar for both systems in the 2.7 mm constructs ($p = 0.1$) and 3.5 mm constructs ($p = 0.31$). The bending resistance was similar in the plate-nail compared to the plate-rod system in both 2.7 and 3.5 mm constructs ($p = 0.06$ and $p = 0.4$, respectively).

The result of the maximum deformation was not significantly different between the two systems in both 2.7 and 3.5 mm constructs ($p = 0.76$ and $p = 0.92$, respectively).

The mean of maximum deformation in bending test for the plate-nail system was 1.5 mm and for the plate-rod system was 3.8 mm in 2.7 mm constructs. The result was statistically different between the two systems ($p = 0.02$) in compression test and it was also observed in bending test in the two systems ($p = 0.19$).

Plate-rod and plate-nail systems allow maintenance of bone alignment without precise anatomical reconstruction of the bone fragments. They present similar configurations and reduce the chance of bone plate failure due to overloading forces (Bernarde *et al.*, 2001; Stiffler, 2004; Muzzi *et al.*, 2009). Mechanical properties comparison between these two fracture fixation systems was performed in this study aiming the subsequent clinical use of the implants. The use of canine femora was felt to closely mimic clinical reality as other materials would not have the same bone biomechanical properties (Gordon *et al.*, 2010). The paired femora used for comparison between systems minimized variations like bone porosity and mineralization. However, some researchers recommend experimental models using other materials such as polymethyl methacrylate and polyvinyl chloride (Hammel *et al.*, 2006; Alves *et al.*, 2010).

The maximum load supported by plate-nail and plate-rod systems was higher than the peak vertical force sustained by a healthy dog. A large breed dog supports most of its weight on forelimbs and runs and jogs at a peak vertical force of approximately 76-107%, equivalent to a force of 223 and 315 N, respectively (Goh *et al.*, 2009). Both constructs were able to appropriately neutralize the forces acting during the normal locomotion of the dog but excessive activities like jumping from great heights should be avoided.

The ordinary bone plate, when used alone, usually supports a mean load of 352.33 N in bending and 547.7 N in compressive loads (Alves *et al.*, 2010). Compared to current biomechanical data, the plate-nail and plate-rod constructs use the combination of orthopaedic implants and they were superior to neutralize both compression and bending loads.

A study compared the plate-rod system constructed with conventional bone plate and locking plate in compression tests. The maximum load supported by the locking plate-rod was 1493.83±200.12 N and by the conventional plate-rod was 1276±156.11 N and this difference was not statistically significant (Goh *et al.*, 2009). These published values are different from those described in our study for the plate-rod system, but they are similar to those obtained with plate-nail system. However, it is difficult to compare the studies, because the aforementioned researchers (Goh *et al.*, 2009) applied the load on the greater trochanter, while in the current study the load was applied along the axial length of the femur. Other study showed that plate-rod is more effective with a more number of monocortical screws (Delisser *et al.*, 2013).

According to published results, the intramedullary pin-plate construct is 10 times stronger than bone plate used alone (Burton and Owen, 2007). It was also expected that the plate-nail system construct was stiffer and stronger than bone plate alone when used for diaphyseal fixation. However, the plate-nail system proved to be superior to the plate-rod system in maximum load and similar in stiffness and strength in this report. The results of the current study revealed that interlocking nail-plate combination is an effective fixation system in resisting both compression and bending loads.

The bone plate is inferior to the interlocking nail when supporting bending loads, because the interlocking nail has the larger inertial area (Von Pfeil *et al.*, 2005; Kurum, 2012). Some researchers (Radcliffe *et al.*, 2001; Piorek *et al.*, 2012) relate this fact to the eccentric location of the plate in the bone, while interlocking nail occupies the central axial bone. As an interlocking nail is more effective in neutralizing bending forces whereas the plate is fragile to neutralize this load, great biomechanical synergism is expected with the combination of these orthopedic implants, as observed with the plate-nail system.

The interlocking nail must occupy, as much of the medullary canal as possible to contain the bending and torsion loads but in many cases there is slack between the interlocking nail and the medullary canal, which increases the instability of the fracture fixation (Bruckner *et al.*, 2014; Dejardin *et al.*, 2012, 2014). An external skeletal fixator combined with an interlocking nail is an attempt to decrease bending and torsional instabilities (Klein *et al.*, 2004; Goett *et al.*, 2007; Lansdowne *et al.*, 2007). The plate-nail system acts decreasing the bending and torsion instabilities and the postoperative management of the device is easier for the owner when compared to the external fixator. The interlocking nail associated with external skeletal fixator replacing the bone screws decreases instabilities (Goett *et al.*, 2007). In this study, the plate-nail system allowed the use of the interlocking nail juxtaposed to the medullary canal and the associated bone plate and bicortical screws, optimizing the advantages of these orthopaedic implants.

Slightly flexible and elastic internal fixation is somewhat desirable for bone indirect healing (Stiffler, 2004; Goh *et al.*, 2009). The stiffness was similar between evaluated systems, except for bending test in 2.7 mm system constructs. However, the great stiffness of both systems is desirable in the initial phases of bone healing, because excessive movement at the fracture site can prevent bone healing especially in highly comminuted fractures.

The maximum deformation was similar statistically between plate-nail and plate-rod systems in most tests conducted. In a mechanical study (Goh *et al.*, 2009), the maximum deformation during compression testing was not significantly different between plate-rod with conventional bone plate and plate-rod with locking plate. The values obtained by researchers (Goh *et al.*, 2009) were 5.02±0.87 mm using the plate-rod system with a conventional plate and 5.46±0.47 mm with the locking plate. These results demonstrate that orthopaedic implant combinations, such as the plate-nail construct used in this study, are able to decrease strain on the bone defect. Other studies have reported axial deformations less than 0.2 mm when comparing plate-rod to interlocking nail. In addition, implants with reduced deformation values favor bone healing (Von Pfeil *et al.*, 2005). Furthermore, micromovements within the fracture site, as can be deduced from the results in the present study, appear advantageous to bone healing.

CONCLUSION

In conclusion, the plate-nail system is biomechanically similar in stiffness and strength to the plate-rod system but the maximum load supported by plate-nail is superior to the plate-rod system and this new orthopedic implants combination are a good option for diaphyseal long bone fracture fixation in dogs.

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