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Biomechanical comparison of a modified TPLO plate, a locking compression plate, and plate-rod constructs applied medially in a proximal gap model in canine synthetic tibias

[*Comparação biomecânica entre placa de TPLO modificada, placa bloqueada e construção placa-pino intramedular aplicadas medialmente em modelo de fratura proximal em tíbias sintéticas caninas*]

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ABSTRACT

The aim of this study was to develop a modified tibial plateau leveling osteotomy (TPLO) plate and to compare its biomechanical properties with a locking compression plate (LCP) and plate-rod constructs for the stabilization of experimentally induced gap fractures in canine synthetic tibias. The tibial models were assigned to either repair with a modified TPLO plate (Group 1), locking compression plate construct (Group 2), or plate-rod construct (Group 3). The specimens were loaded to failure in axial compression, three-point mediolateral and craniocaudal bending. There was no statistical difference between the three groups regarding stiffness (N/mm) and deformation (mm) in axial compression. The modified TPLO plate achieved load to failure similar to the plate-rod construct in craniocaudal bending. There was no significant difference between groups on mediolateral bending tests regarding load to failure and deformation. Furthermore, there was no significant difference in stiffness between groups 1 and 2. In conclusion, the modified TPLO plate had similar mechanical properties to LCP and plate-rod construct in the axial compression and bending tests. Nonetheless, clinical studies with a large population of dogs are required to determine the value of this new implant in proximal tibial fracture repair.

Keywords: Biomechanical tests, bone plate, fracture fixation, osteosynthesis

RESUMO

Objetivou-se desenvolver uma placa de osteotomia niveladora do platô tibial (TPLO) modificada e compará-la biomecanicamente à placa de compressão bloqueada (LCP) e à construção placa-pino intramedular na estabilização da fratura cominutiva proximal em tíbias sintéticas caninas. Para tal, tíbias caninas sintéticas foram divididas em três grupos, sendo o grupo 1 formado pela placa de TPLO modificada, o grupo 2 por placas LCP e o grupo 3 pela construção placa-pino intramedular. Os espécimes foram submetidos à carga até a falha em compressão axial, flexão mediolateral e craniocaudal em três pontos. Não houve diferença estatística entre os três grupos quanto à rigidez (N/mm) e à deformação (mm) nos testes de compressão axial. A placa de TPLO modificada obteve carga até a falha semelhante à construção placa-pino intramedular em flexão craniocaudal. Não houve diferença significativa entre os grupos nos testes de flexão mediolateral em relação à carga até a falha e a deformação, e a variável rigidez não apresentou diferenças significativas entre os grupos 1 e 2. Em conclusão, a placa de TPLO modificada apresentou similaridade mecânica em comparação com a LCP e a construção placa-pino. No entanto, estudos clínicos são necessários para determinar o valor desse novo implante na fixação de fraturas tibiais proximais.

Palavras-chave: testes biomecânicos, placa óssea, fixação de fratura, osteossíntese

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INTRODUCTION

Tibial fractures account for 15% to 21% of long bone fractures in dogs (Siragusi *et al*., 2015). Bone plates are one of the most common internal fixation implants used for fixation of tibial fractures in dogs. Moreover, plate-rod constructs are described as being stiffer than plates alone, thereby decreasing the risk of fatigue failure of the implants (Vallefuoco *et al*., 2016; Dias *et al*., 2018).

The morphology of the tibia is irregular, with its proximal half being triangular in cross-section and wider than its distal half, which is almost cylindrical (Beierer *et al*., 2014; Vallefuoco *et al*., 2016). Proximal metaphyseal comminuted fractures are technically more challenging to repair than diaphyseal fractures because the proximal bone fragment is smaller in these areas, limiting the use of some implants (Johnson, 2013). Furthermore, in comminuted fractures, it may not be possible to reconstruct the bone anatomically and, in these cases, the bone may be unable to share the loads with the implant in the initial stages of bone healing. Since the implant is required to support all the weight bearing forces its fatigue life is reduced (Demner *et al*., 2014; Pearson *et al*., 2015).

We hypothesized that a modified TPLO plate might offer favorable biomechanical characteristics for repair of proximal tibial fractures with poor bone stock, since the triangular arrangement of screws allows the placement of more screws in the proximal segment than with a conventional locked plate. In addition, the modified TPLO plate could be used in a minimally invasive procedure by allowing insertion of a larger number of screws in the proximal fragment through a small incision. Thus, the aim of this study was to develop a modified tibial plateau leveling osteotomy plate (TPLO) and to compare it biomechanically to a locking compression plate (LCP) and plate-rod constructs for the stabilizations of experimentally induced gap fractures in canine synthetic tibias.

MATERIALS AND METHODS

Synthetic right tibias were fabricated with rigid polyurethane (Nacional Ossos, Sao Paulo, Brazil) using a template from a Siberian Husky tibia. The synthetic tibias had a large proximal and distal block, parallel and aligned, to enable the bone to be coupled to the mechanical test machine, as previously described (Sembenelli *et al*., 2019).

The specimens were divided into three groups of 15, a modified TPLO plate (Group 1), a conventional locked plate (LCP/Group 2), and a plate-rod construct (Group 3). Each group was tested to failure in axial compression, craniocaudal and mediolateral three-point bending (n = 5/ test). In Group 1, the synthetic tibias were stabilized with a custom designed TPLO plate manufactured from 316L stainless steel (Cão Médica, Campinas/SP), measuring 3.5x11x137mm. The modified TPLO plate was designed with its proximal portion similar to a TPLO plate, wider than that of the rest of the plate, with three locking angulated holes, and a specific shape to fit the proximal aspect of the tibia. The distal extension of the plate was longer than conventional locked TPLO plates, allowing for 10 screw holes. All 13 holes were designed to accommodate locked screws of 3.5mm diameter (Fig. 1).

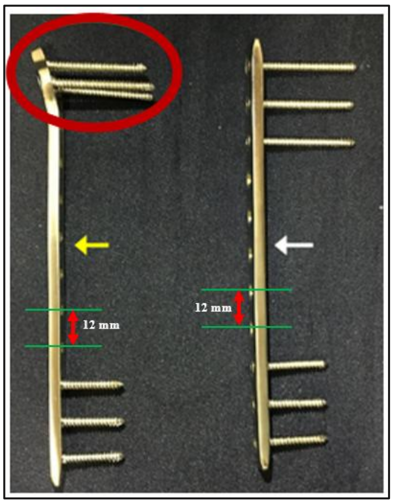

Figure 1. Side view of the modified TPLO plate (yellow arrow) and LCP (white arrow) used in this study. The red circle demonstrates the angulation and direction of the proximal screws in the plate. The distance between the centers of the holes is 12mm.

In Group 2 fractures were stabilized using an eleven-hole 3.5mm LCP (13.7cm length). The distance between the hole centers was 12mm

(Fig. 1). In the plate-rod construct (Group 3), plates with the same dimensions as described in Group 2 were used along with a Steinmann intramedullary pin of 2mm diameter. The plates were fixed on the medial surface of the tibial by a single investigator and the sequence of implantation was standardized in all groups. Three 3.5mm bicortical locking screws were placed in the proximal fragment (42mm length) and 3 in the distal fragment (28mm length). To mimic a proximal comminuted fracture, a standardized 20 mm gap was created with two transverse cuts in the synthetic tibia. The first cut was made 50mm from the tibial plateau and the second at 70mm. The resulting 20mm fracture gap was created after all implants had been correctly applied.

All mechanical testing was performed on a universal testing machine (EMIC model D-10000; EMIC Test Equipment and Systems, São José dos Pinhais, Paraná, Brazil) using a load cell of 200kgf (Fig. 2). Load-displacement curves were generated for each specimen under each testing condition using a commercially available data acquisition system (TESC®; Intermetric, Mogi das Cruzes, São Paulo, Brazil). The three groups were loaded to failure under axial compression, craniocaudal and mediolateral three-point bending at a rate of 5mm/minute and 40mm/minute, respectively. Load to failure (N) was defined as the maximum load recorded immediately prior to a sudden decrease in sustained load. Axial and bending stiffness (N/mm) were calculated by obtaining the slope of the linear elastic portion of the load-displacement curve. Axial and bending deformation data (mm) were obtained at the construct failure.

Data from each test were reported as mean ± standard deviation. Statistical analyzes were performed using commercially available software (SAS 9.1; SAS Institute, Cary, North Caroline, United States). Data were compared using ANOVA and the Tukey post hoc test to identify significant differences between groups. Statistical significance was set at $p < 0.05$.

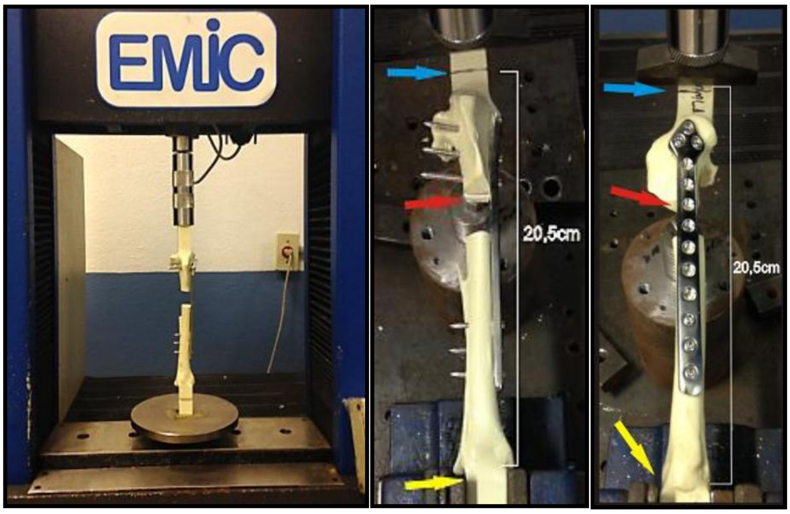

Figure 2. Mechanical configuration used for compression (A) and three-point craniocaudal (B) and mediolateral bending testing (C) of constructs. Yellow arrow: distal block secured in a vice; red arrow: support on the lateral surface of the specimen 45 mm from the tibial plateau; blue arrow: location where the testing machine applied force.

RESULTS

The results of the tests are shown in Table. 1. In the axial compression test, there was no difference between the groups in terms of deformation and stiffness. Otherwise, the load to failure (N) was significantly greater for plate-rod constructs (Group 3).

Values of load to failure in craniocaudal bending tests were similar between the modified TPLO group and plate-rod group and were significantly greater in the LCP group.

Table 1. Mean values and standard deviation (SD) of load to failure, stiffness, and deformation variables in axial compression, craniocaudal and mediolateral bending tests for modified TPLO plate, LCP, and plate-rod construct

Mechanical test	Variables	Modified TPLO plate (Mean±SD)	LCP (Mean±SD)	Plate/rod (Mean±SD)	P value
Axial compression	Load to failure (N)	1562.56b±124.4	1500.55b±81.31	1851.858a±135.7	0.0011
	Stiffness (N/mm)	622.39a±150.4	551.94a±31.49	763.99a±176	0.08
	Deformation (mm)	4.16a±0.69	3.72a±0.45	3.85a±0.36	0.46
Craniocaudal bending	Load to failure (N)	363.25b±44.69	591.74a±66.19	439.79b±36.08	0.0001
	Stiffness (N/mm)	27.36b±7.81	41.72ab±19.17	51.26a±9.21	0.04
	Deformation (mm)	29.63a±5.07	22.99a±4.23	15.67b±3.18	0.0007
Mediolateral bending	Load to failure (N)	351.48a±36.85	339.73a±27.28	384.70a±42.62	0.16
	Stiffness (N/mm)	32.99a±4.38	34.19a±4.85	46.67b±13.19	0.04
	Deformation (mm)	21.70a±4.6	23.54a±3.32	22.60a±3.15	0.74

Means followed by the same letter showed no significant differences.

Plate-rod constructs had the smallest deformation among the evaluated groups, and there was no statistical difference between modified TPLO plate and LCP groups. Craniocaudal bending stiffness was greatest for the plate-rod group, followed by LCP and modified TPLO groups.

Regarding the mediolateral bending tests, stiffness was significantly greater for plate-rod constructs than the other groups. There was no significant difference in the mediolateral bending tests for load to failure and deformation variables.

DISCUSSION

LCP and plate-rod fixation are currently the most widely used osteosynthesis implants in the repair of tibial comminuted fractures. This study compared the biomechanical properties, during compression and bending, of a modified TPLO plate with the LCP and plate-rod fixation methods. The results of our study provide evidence that a modified TPLO plate might be an alternative to minimally invasive plate osteosynthesis. The TPLO plate can be applied with a minimal approach to the fracture gap, in contrast to the exposure necessary during fixation and contouring of conventional plates. In addition, the new plate design allows the insertion of a greater number of screws per fracture fragment, when compared to conventional straight plates. This is a particular advantage in proximal fractures where poor bone stock is available for screw fixation. Another advantage of the modified TPLO plate is the angle of the proximal screws. It is known that appropriate contouring of the locked plate in the proximal region of the tibia can predispose to drilling and screw placement in the intraarticular space (stifle) (Johnson, 2013). However, with the specific angulation of the screws in this new plate, such problems are minimized.

Plate-rod constructs have been shown to be mechanically superior to use of a plate alone (Reems *et al*., 2003). In this study, the plate-rod construct had a higher load to failure in axial compression. These results support findings from other authors stating that the intramedullary pin increases the resistance to axial loads compared to a single plate. However, the addition of the intramedullary pin had little influence on the stiffness of the construction with any of the forces tested. One explanation for this finding is that the intramedullary pin filled less than 30% of the medullary cavity. It has been reported that although a pin of any size increases resistance to axial loads, a pin of at least 30% intramedullary diameter is required to increase bending stiffness (Pearson *et al*., 2015). Furthermore, plate-rod constructs have been used to repair diaphyseal fractures. In this situation, the addition of an intramedullary pin increases the bending and axial stiffness of the construct. Thus, the proximal fracture in our bone model may have influenced the stability of the pin seated in the short proximal metaphysis (Goh *et al*,. 2009). The modified TPLO plate had similar results regarding stiffness and deformation in axial compression compared to the conventional plate or plate-rod construct, with the biological advantages that no contouring was necessary, and the plate could be applied distant from the fracture site. In addition, in previous studies, the modified TPLO plate had greater stiffness than LCP in torsion tests (Sembenelli *et al*., 2019).

Regarding craniocaudal three-point bending, the load to failure was significantly greater in the LCP group than in the modified TPLO plate group. We believe this occurred because of the longer work length in the modified TPLO plate group, which agrees with the findings of Chao *et al*. (2013), who stated that longer working lengths result in lower load to failure. However, increasing working length has been recommended as a strategy to decrease construct stiffness and therefore allow more motion at the fracture gap and callus formation (Craig *et al*., 2018).

Stiffness and deformation were similar in craniocaudal and mediolateral bending tests between the LCP and modified TPLO groups. Thus, based on our results, we suggest that the modified TPLO plate can be considered a viable alternative in proximal tibial fracture repairs as it can be placed with smaller incision and it can accommodate three or more screws. However, a high plate screw density (number of screws inserted/ number of the plates holes) would increase fracture manipulation, plate stress, and could predispose to stress riser fractures. In addition, this bone fracture model may allow flexible fixation which, in turn, has the potential to stimulate osteoblastic activity and bone callus formation (Craig *et al*., 2018). However, since this was an *in vitro* study, further clinical investigation of this plate system is warranted to determine optimal applications when stabilizing tibial fractures in dogs.

This study had several limitations inherent in any mechanical study. Although synthetic tibial models have advantages over cadaveric bones, including ethical considerations, ease of procurement, limited interspecimen variations, and reduced biohazard risks, this fracture bone model repair may not accurately reflect clinical situations of fracture stability because of the lack of interactions with surrounding soft tissues. Furthermore, static loading tests were used, which do not accurately reflect the physiological loading of the tibia *in vivo* (Marturello *et al*., 2019).

Due to the influence of inertia (area moment of inertia is proportional to the third power of the plate thickness), medial plates on the tibia have greater resistance to craniocaudal than to mediolateral bending. This may explain why the plate-rod constructs had approximately 36% increased stiffness in mediolateral flexion in relation to the other groups, but no stiffness benefits in craniocaudal flexion. This may be because the plate alone was sufficiently resistant to craniocaudal bending and therefore the intramedullary pin did not improve the stiffness of the construction (Gautier *et al*., 2000; Beierer *et al*., 2014; Lorenzo *et al*., 2016).

Guthrie *et al.* (2015) observed that constructions with a screw close to the fracture site were more resistant to bending than those with screws far from the site. However, despite the modified TPLO group having a longer work length, there was no difference between this group and the others, and it would be possible to place an additional two screws close to the fracture line. This was not done in this study as screw numbers were standardized in each bone fragment.

We believe that the modified TPLO plate has sufficient biomechanical similarities to the other implants studied to justify its clinical use in repair of comminuted proximal fractures of the tibia, mainly to preserve fracture biology. However, further studies should be carried out to better understand this new implant.

CONCLUSIONS

The modified TPLO plate showed similar mechanical properties to the LCP and plate-rod constructs in the axial compression and bending tests with the potential mechanical and biological advantages of being able to be fixed with a minimal approach to the fracture and achieving better use of the bone stock in proximal fractures of the tibia. Nonetheless, clinical studies with a large population of dogs are required to determine the value of this new implant in proximal tibial fractures.

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