Ciência Rural, Santa Maria, v.52:6, e20200892, 2022
http://doi.org/10.1590/0103-8478cr20200892
ISSNe 1678-4596
CLINIC AND SURGERY

Preliminary mechanical evaluation of two novel veterinary angle-stable-threaded interlocking nail systems

Jordana da Costa Nóbrega[1] **Dayvid Vianêis Farias de Lucena**[1] **Bruno Watanabe Minto**[1*] **Luis Gustavo Gosuen Gonçalves Dias**[1]

[1]Departamento de Clínica Cirúrgica de Pequenos Animais, Universidade Estadual Paulista "Júlio de Mesquita Filho" (UNESP), 14884-900, Jaboticabal, SP, Brasil. E-mail: brunominto@fcav.unesp.br. *Corresponding author.

ABSTRACT: *The interlocking nail represents an excellent option as a surgical approach to treat fractures in long bones in veterinary medicine. However, failures were reported mainly due to a slack present in the interface of the rod with the screws. The present study tested and mechanically compare axial compression loads of two novel models of stable angle interlocking nails with threaded holes. Among the two models, one was uniplanar and the other was multiplanar with orthogonally arranged distal holes. Twenty-one specimens made of polylactic acid were used for the implantation of interlocking nail´s rods, divided into three groups: conventional interlocking nail (G1), novel interlocking nail with a stable angle with holes arranged in a single plane (G2), and novel interlocking nail with a stable angle in two planes, with the penultimate hole at 90 degrees from the others (G3). Biomechanical tests were performed using axial, cyclic, and destructive compression load for comparison between them. All the specimens showed plastic deformation in the screws after destructive tests, in both proximal and distal sides, being highly intense in G1. G2 and G3 of the stable angle rods supported higher loads than G1 in all tests performed (P<0.05). The novel stems did not differ statistically from each other (P>0.05). The initial hypothesis that the novel models would provide increased stability was confirmed; however, no differences were demonstrated between them. The screw locking system on the rods allowed high resistance values in the tests performed, proving to be effective and potentially applicable in real clinical situations.*
Key words: *orthopaedics, intramedullary implant, surgery, fracture, osteosynthesis.*

Avaliação mecânica preliminar de dois novos sistemas veterinários de haste intramedular bloqueada em ângulo estável roscada

RESUMO: *A haste intramedular bloqueada representa excelente opção para abordagem cirúrgica de fraturas em ossos longos na medicina veterinária. Todavia, falhas decorrentes principalmente de "folga" presente na interface da haste com os parafusos foram relatadas. O presente estudo teve como objetivo testar e comparar mecanicamente, por cargas de compressão axial, dois novos modelos de haste intramedular bloqueada de ângulo estável com orifícios roscados, sendo uma delas uniplanar e outra multiplanar com orifícios distais dispostos ortogonalmente. Vinte e um corpos de prova confeccionados em ácido polilático (PLA) foram utilizados para implantação das hastes intramedulares bloqueadas, divididos em três grupos: Haste bloqueada convencional (G1); haste bloqueada nova de ângulo estável com orifícios dispostos em único plano (G2); haste bloqueada nova de ângulo estável em dois planos, com o penúltimo orifício em 90 graus dos demais (G3). Utilizou-se ensaios biomecânicos por carga de compressão axial, cíclicos e destrutivos, para comparação entre eles. Todos mostraram deformação plástica nos parafusos após testes destrutivos, tanto proximais como distais, sendo mais intensa no grupo 1. Os grupos 2 e 3 das hastes de ângulo estável suportaram cargas superiores em relação ao G1 em todos os testes realizados (P<0.05). As hastes novas não diferiram estatisticamente entre si (P>0,05). A hipótese inicial de que os novos modelos proporcionariam maior estabilidade foi confirmada, entretanto não foi demonstrada diferenças entre eles. O sistema de bloqueio roscado dos parafusos nas hastes permitiu valores elevados de resistência nos testes realizados, mostrando-se efetivo e, potencialmente aplicável em situações clínicas reais.*
Palavras-chave: *ortopedia, implante intramedular, cirurgia, fratura, osteossíntese.*

A wide range of orthopedic implants is available for fixing long bone fractures in companion animals and many of them showed good results as long as they are correctly applied and follow mechanical and biological principles for decision making and approach (ANDRIANOV et al., 2007). Among them, interlocking nails (INs)stand out for being applied to the neutral axis of the bone and having great resistance to flexion, torsion, and compression loads (DUELAND et al., 1996; WHEELER et al., 2004; GATINEAU et al., 2010). Due to their minimally invasive potential, they also present an advantage from a biological point of view (DÉJARDIN, 2019). However, a certain percentage of implant failures are reported, being especially related to the interface between the locking screws and the nail after implants being subjected to

Received 09.24.20 Approved 09.03.21 Returned by the author 09.29.21
CR-2020-0892.R3
Editors: Rudi Weiblen Daniel Curvello de Mendonça Muller

torsion, compression, and flexion loads (WHEELER, 2004). A significant part of the complications has been attributed to the“gap” existing in the interfaceand; therefore, novel models have been developed and tested. In this study, anIN system with screw threading into the nail body was developed, which can be considered as anangle-stable IN.

This system used two novel types of nails with 8mm diameter and 175mm length, one being uniplanar and the other multiplanar, orthogonal. Synthetic specimens were made of polylactic acid (PLA)to simulate the appendicular bone of a large dog, using the femur, tibia, and humerus as examples. A 25mm gap was used as a standard for all specimens (Figure 1). Each group consisted of 7 specimens and three models of nails were used, all measuring 8 x 175mm, made of 316L steel, and with a total of four holes which allowed the passage of screws of 3.5mm external diameter, with two holes being in the proximal segment and two in the distal segment. In group 1 (G1), a conventional nail model was used, without locking the nail holes. Group 2 (G2) consisted of an angle-stable IN threaded into its holes in only one plane (uniplanar IN). Group 3 (G3), consisted of nails with the same characteristics as G2, but with their penultimate hole placed at 90 degrees to the other holes at a distance of 5.5 mm from the distal hole (Figure 2).

Specific instruments, consisting of a nail guide, a drill ruler, drill guides, a depth gauge, and a tightening wrench were used when assembling the implants. The implantation of the IN followed the same sequence in all specimens, starting with the perforation of the first proximal hole and moving towards the last distal one. In G3, the divergent screw was fixed last, using an adapter that allowed rotation of the ruler by 90 degrees, as well as its fixation.

One specimen from each group was initially subjected to destructive tests and the maximum load was expressed in Newton (N), being identified during plastic deformation, and used individually as a reference for determining a load. The initially stipulated value was 3000 N, equivalent to 300 kg of load, greatly extrapolating the load supported by the implant in a dog. Subsequently, 1000 N of the maximum load was established for the cyclic tests, equivalent to 100 kg of load applied to the implant. If we consider a dog weighing 50 kg, a load equivalent to 15 kg is applied on the thoracic limb and 10 kg is applied on the pelvic limb; therefore, the value used in the cyclic tests was approximately 10 times higher than the supported weight. The cyclic test was performed with a total of 100 samples per specimen to simulate the steps that would be taken by a dog, with the load varying from 100 to 1000 N load and a speed of 1 Hertz, equivalent to 1 second, using the INSTRON 8872 machine. After cycling, another compressive test was performed, using the EMIC DL 10000universal testing machine, until failure to obtain the maximum load values supported individually by the specimens. The test was stopped immediately when the specimen showed any plastic deformity, whether of the PLA material, nail, or screw. The methodology was essentially based on biomechanical tests with IN performed by DEJÁRDIN (2006; 2009; 2014; and 2019); in addition to authors, such as DUELAND (1996), SUBER (2002), APER (2003), REEMS et al. (2006), DALMOLIN (2013), and MACEDO (2017).

All statistical procedures were performed using SPSS software version 20.0 for Windows. The normality of data distribution was assessed by the Shapiro-Wilk test, and a normal distribution was

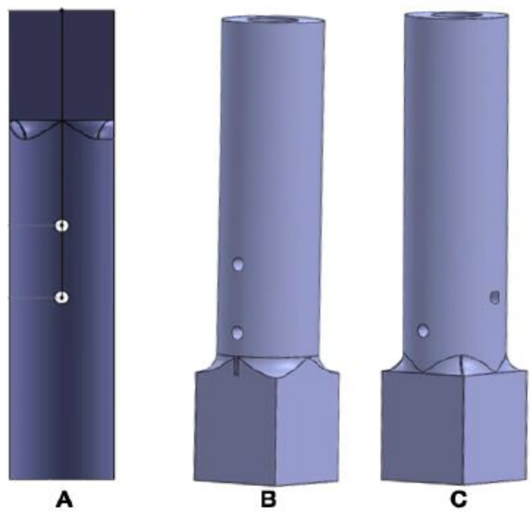

Figure 1 - Illustrative image of three-dimensionally printed bone substitute models with predetermined holes for the passage of screws. (A) illustrates the proximal model that mimicks the proximal bone fragment (groups 1, 2, and 3). (B) represents the distal bone fragment in groups 1 and 2. (C) mimics the distal bone fragment used in group 3. Holes are positioned at 90-degree angles to each other. All models have a square base for easily attaching them to universal testing machines.

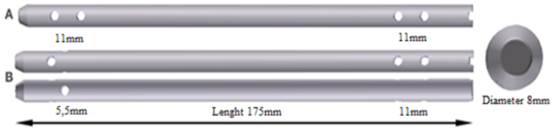

Figure 2 - Illustrative image of the angle-stable nails used in the study, measuring 175 mm in total length and 8 mm in diameter. (A) illustrating the uniplanar nail with proximal and distal holes of 3.5 mm in diameter separated by 11 mm distance. (B) Orthogonal nails developed for the study, with the penultimate hole at 90 degrees to the others and located closer to the distal hole, 5.5 mm away.

reported for the dependent variable. In the descriptive analysis, minimum, maximum, mean, standard deviation, and median values were used as measures of central tendency. In the inferential analysis, associations between quantitative variables were made using the paired t-test.

Axial compression tests revealed higher averages in G2 (250246.1667 ± 157955,74362 N/mm) and G3 (249022.3333 ± 7720.24988 N/mm) than in G1 (183519.5000 ± 13030.42002), with G1 being significantly different from the others (P=0.01). Compression tests after cyclic tests revealed an average of 272628.8333 ± 19362.38220 N/mm in G2, 237383.6667 ± 324229.095551 N/mm in G3 and 220175.8333 ± 23264.27881 N/mm in G1. There were no statistical differences in the models with novel nails (G2, P=0.07; G3, P=0.47), as shown in table 1.

The specimens were radiographed after destructive compressive tests.The radiographs revealed plastic deformation in the screws of all groups;however, it was reportedd to be highly intense in G1. Plastic deformation was also observed in the nails, being highly intense in G2, as well as in G1, as shown in figure 3. All implants resisted the applied cycles in all groups without showing failures of the specimens during the tests.

The nails used in all groups were 8 mm thick and the hole in the specimens measured 10 mm. These measurements were standardized to allow the use of an implant with the correct thickness in the medullary canal, where angle-stable nails occupy at least 70–80% (DÉJARDIN et al., 2019) and Ins occupy at least 80–90% of the intramedullary canal. In this study, all implants occupied 80% of the canal. The space inside the medullary canal that is not occupied by the nail allows it to dislocate when implants are subjected to compression forces (DÉJARDIN et al., 2009). This dislocation is inhibited by the locking screws, and the smaller the space occupied by the nail, the greater the load applied to the screws (APER et al, 2003). The fact that 80% of the canal was occupied in all groups allowed us to homogeneously determine the total load supported by the screws until the screws showed plastic deformation.

It is suggested that the absence of rigid interaction between the nail and the screw reduces the resistance of the IN to plastic deformation (DÉJARDIN et al., 2006). In the present study, the conventional nail group supported a load of less than 6000N, being the lowest among the groups, while both angle-stable nail groups supported high loads before showing signs of plastic deformation in the screws, resisting approximately 7500 N in the uniplanar angle-stable group and 8000 N in the multiplanar angle-stable group. This resistance in both groups may be due to the great rigidity between the screw and the nails, as they feature a threaded interlocking mechanism(REEMS et al, 2006; MACEDO et al., 2017). Furthermore, according to DÉJARDIN et al (2006), angle-stable nails allowed greater mechanical resistance when implants are subjected to axial compression loads. We observed this in the groups with novel nails in addition to an increase in resistance to deformation and great stability in G3, which may be due to the different arrangements of screws. Similar values were obtained in the compression tests after cyclic tests in all groups. Thus, we hypothesized that the cyclic test did not cause significant damage to the screws and that the threaded interlocking system was functionalin groups of angle-stable nails. Therefore, we suggested that the cycles applied to the specimens of both groups were not able to promote deformation in the implants to the point of reducing their resistance.

INs have a “gap” between the screws and the nail, which allows greater dislocation between them (DURALL et al., 2003). When these implants are subjected to compressive loads, deformation in the screw thread pitch occurs more intensely compared to stable-angle models (GOETT et al., 2007; DÉJARDIN et al., 2013). Therefore, it is suggested that the deformation promoted changes in the specimens, allowing them to be better accommodated. It is known that stiffness is characterized by the resistance

Table 1 - Inferential analysis of pre- and post-intervention compression tests on the 3 types of nails tested (N=6).

Variables	Average (SD)		P-value*
	Pre-intervention test	Post-intervention test	
Conventional (G1)	183519.50 (13030.42002)	220175.83 (23264.27881)	0.01
Uniplanar (G2)	250246.17 (15795.74362)	272628.83 (19361.38220)	0.07
Multiplanar (G3)	249022.33 (7720.24988)	237383.67 (32429.09551)	0.47

SD, standard deviation.

ofthe body to deformation after a force is applied (DALMOLIN et al., 2013). We also suggested that the stiffness reported in the novel nail model after the cyclical test was greater due to the more marked deformation of the specimens than in the other groups. This was already expected due to the absence of rigid interaction between the nail and the screw (SUBER et al., 2002; TING et al., 2009).

It is inferred that the use of screws with rigid interaction with the nail improved its mechanical behavior in the compression tests, with the absence of interlocking in the implants reducing its resistance to plastic deformation. Although, the multiplanar nail group showed mechanical resistance slightly superior to the other groups, further studies are needed to confirm the proposed theory.

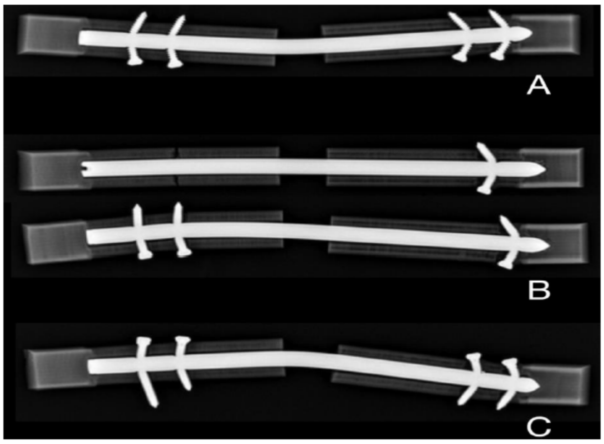

Figure 3 - Image showing models used as specimens after the destructive compressive test. (A) Conventional Interlocking ail Model. (B) Orthogonal nail with a stable angle. (C) Uniplanar angle-stablenail. Plastic deformation due to flexion was observed in all screws being highly intense in screws of the conventional locking nail model. Plastic deformity was also observed in the nails with decreased intensity in the orthogonal nail model.

ACKNOWLEDGMENTS

This study was funded by the Fundação de Amparo á Pequisa do Estado de São Paulo (FAPESP), process number 2018/22293-3 and was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), Brasil.

APPROVAL BY THE BIOETHICS AND BIOSAFETY COMMITTEE

The study was assessed by the Ethics Committee on the Use of Animals (CEUA) of the School of Agrarian and Veterinary Sciences, UNESP, Jaboticabal campus, having a protocol number CEUA 019201/17 and being conducted following the recommendations of the National Council for Control of Animal Experimentation.

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTION

All authors contributed equally to the conception and writing of the article, critically reviewed it, and approved the final version.

REFERENCES

ANDRIANOV, V. et al. Rod-through-plate fixation of canine diaphyseal fractures. **Vet Comp Orthop Traumatol**, v. 20, n. 4, p. 308 – 311, 2007. Available from: <https://www.thieme-connect.com/products/ejournals/abstract/10.1160/VCOT-06-12-0095>. Accessed: Apr. 07, 2020. doi: 10.1160.

APER, R. L. et al. Effect of bone diameter and eccentric loading on fatigue life of cortical screws used with interlocking nails. **American journal of veterinary research**, v. 64, n. 5, p. 569-573, 2003. Available from: <https://pubmed.ncbi.nlm.nih.gov/12755296/>. Accessed: Apr. 08, 2020. doi: 10.2460/ajvr.2003.64.569.

DALMOLIN, F. et al. Bone biomechanics and biomechanics essays - theoretical foundations. **Ciência Rural**, v. 43, n. 9, p. 1675-1682, 2013. Available from: <https://www.scielo.br/scielo.php?pid=S0103-84782013000900022&script=sci_arttext&tlng=pt>. Accessed: Apr. 07, 2020. doi: 10.1590.

DÉJARDIN, L. M. et al. In vitro mechanical evaluation of torsional loading in simulated canine tibiae for a novel hourglass-shaped interlocking nail with a self-tapping tapered locking design. **American journal of veterinary research**, v. 67, n.4, p. 678-685, 2006. Available from: <https://avmajournals.avma.org/doi/abs/10.2460/ajvr.67.4.678>. Accessed: Apr. 07, 2020. doi: 10.2460/ajvr.67.4.678.

DÉJARDIN, L. M. et al. Effect of bending direction on the mechanical behaviour of interlocking nail systems. **Veterinary and Comparative Orthopaedics and Traumatology**, v. 22, n. 04, p. 264-269, 2009. Available from: <https://pdfs.semanticscholar.org/02a7/45d7f0d675678e04a1a1d099729c6ee14e9f.pdf>. Accessed: Apr. 14, 2020. doi: 10.3415.

DÉJARDIN, L. M. et al. Interlocking nails and Minimally Invasive Osteosynthesis. **Veterinary Clinics**: **Small Animal Practice**, v. 50, n. 1, p. 67-100, 2019. Available from: <https://www.vetsmall.theclinics.com/article/S0195-5616(12)00111-8/fulltext>. Accessed: Apr. 13, 2020. doi: 10.1016/j.cvsm.2012.07.004.

DUELAND, R. T.; Structural properties of Interlocking Nails, Canine Femora, and Femur-Interlocking Nail Constructs. **Veterinary Surgery**, v. 25, n. 5, p. 386-396, 1996. Available from: <https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1532-950X.1996.tb01432.x>. Accessed: Apr. 07, 2020. doi: 10.1111/j.1532-950x.1996.tb01432.x.

DURALL, I. et al. Radiographic findings related to interlocking nailing: windshieldwiper effect, and locking screw failure. **Veterinary and Comparative Orthopaedics and Traumatology**, v. 16, n. 04, p. 217-222, 2003. Available from: <https://www.thieme-connect.com/products/ejournals/abstract/10.1055/s-0038-1632783>. Accessed: Apr. 07, 2020. doi: 10.1055/s-0038-1632783.

GATINEAU, M; PLANTÉ, J. Ulnar interlocking intramedullary Nail Stabilization of a Proximal Radio-Ulnar Fracture in a Dog. **Veterinary Surgery**, v. 39, n. 8, p. 1025-1029, 2010. Available from: <https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1532-950X.2010.00731.x>. Accessed: Apr. 08, 2020. doi: 10.1111/j.1532-950X.2010.00731.x.

GOETT, S. D. et al. Mechanical comparison of an interlocking nail locked with conventional bolts to extended bolts connected with a type-Ia external skeletal fixator in a tibial fracture model. **Veterinary surgery**, v. 36, n. 3, p. 279-286, 2007. Available from: <https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1532-950X.2007.00265.x>. Accessed: Apr. 07, 2020. doi: 10.1111/j.1532-950X.2007.00265.x.

JOHNSTON, S.A. et al. Internal Fracture Fixation. In: JOHNSTON, S.A.; TOBIAS, K.M. et al. **Veterinary Surgery**: Small Animal. 1 Ed. Canada: Elsevier, 2017. Cap 41, p. 1892-1968. Accessed: Apr. 12, 2020.

MACEDO, A. S. et al. Ex vivo torsional properties of a 2.5 mm veterinary interlocking nail system in canine femurs. **Veterinary and Comparative Orthopaedics and Traumatology**, v. 30, n. 02, p. 118-124, 2017. Available from: <https://www.thieme-connect.com/products/ejournals/abstract/10.3415/VCOT-16-05-0083>. Accessed: Apr. 07, 2020. doi: 10.3415.

REEMS, M. R.; et al. Ex vivo comparison of one versus two distal screws in 8 mm model 11 interlocking nails used to stabilize canine distal femoral fractures. **Veterinary surgery**, v. 35, n. 2, p. 161-167, 2006. Available from: <https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1532-950X.2006.00127.x>. Accessed: Apr. 07, 2020. doi: 10.1111/j.1532-950X.2006.00127.x.

SUBER, J. T.; et al. Two unreported modes of interlocking nail failure: breakout and screw bending. **Veterinary and Comparative Orthopaedics and Traumatology**, v. 15, n. 04, p. 228-232, 2002. Available from: <https://www.thieme-connect.

com/products/ejournals/abstract/10.1055/s-0038-1632744>. Accessed: Apr. 07, 2020. doi: 10.1055/s-0038-1632744.

SUBER, J.; BASINGER, R. R. Effect of stack pins on the stiffness of interlocking nails in an unstable osteotomy model. **Veterinary and Comparative Orthopaedics and Traumatology,** v. 21, n. 01, p. 15-20, 2008. Available from: <https://www.thieme-connect.com/products/ejournals/abstract/10.3415/VCOT-06-06-0047>. Accessed: Apr. 13, 2020. doi: 10.3415.

TING, D. et al. In vitro evaluation of the effect of fracture configuration on the mechanical properties of standard and novel interlocking nail systems in bending. **Veterinary surgery**, v. 38, n. 7, p. 881-887, 2009. Available from: <https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1532-950X.2009.00584.x>. Accessed: Apr. 13, 2020. doi: 10.1111/j.1532-950X.2009.00584.x.

WHEELER, J. L. et al. Intramedullary interlocking Nail Fixation in Dogs and Cats: Clinical Applications. **Compendium**, p. 519 – 526, 2004. Available from: <http://vetfolio-vetstreet.s3.amazonaws.com/mmah/ed/7e1eca59ac4189914bb36ed54abbeb/filePV_26_07_531.pdf>. Accessed: Apr. 12, 2020.