http://dx.doi.org/10.1590/1678-4162-12611

***Arq. Bras. Med. Vet. Zootec.*, v.75, n.1, p.27-34, 2023**

Biomechanical study of partial lateral corpectomy with or without an association with pediculectomy and hemilaminectomy in canine specimens

[Estudo biomecânico de corpectomia lateral parcial com ou sem associação com pediculectomia e hemilaminectomia em espécimes caninos]

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ABSTRACT

The present objective was to increase the number of biomechanical cycles performed using non-chondrodystrophic dog specimens, based on the study by Araújo (2017), comparing partial lateral corpectomy (PLC) alone, corpectomy and pediculectomy, and PLC associated with pediculectomy and hemilaminectomy to determine if there are significant differences between them regarding deformation versus applied force. Groups were divided as: control (G1), corpectomy (G2), corpectomy + pediculectomy (G3), and corpectomy + pediculectomy + hemilaminectomy (G4). The level of displacement versus force was observed during axial compression, flexion, extension, right and left lateral bending, and right and left axial rotation. Significant differences were observed between groups for flexion, extension, right and left axial rotation, and left lateral bending, whereas there was no difference for axial compression and right lateral bending. PLC and PLC with pediculectomy had significant differences in flexion and in extension, similar to PLC associated with pediculectomy and with hemilaminectomy in right and left axial rotation, flexion, extension, and right lateral bending.

Keywords: Vertebral column, intervertebral disc disease, spinal cord, decompression techniques

RESUMO

O presente objetivo foi, a partir de grupos de espécimes caninas não condrodistróficas, aumentar o número de ciclos biomecânicos realizados, com base no estudo de Araújo (2017), comparando-se corpectomia parcial lateral (CPL) isolada, corpectomia e pediculectomia, à CPL associada à pediculectomia e à hemilaminectomia, no intuito de determinar se há diferenças significativas entre eles quanto à deformação versus *à força aplicada. Os grupos foram divididos em: controle (G1), corpectomia (G2), corpectomia + pediculectomia (G3) e corpectomia + pediculectomia + hemilaminectomia (G4). O nível de deslocamento* versus *a força foi observado durante a compressão axial, a flexão, a extensão, a flexão lateral direita e esquerda e a rotação axial direita e esquerda. Observaram-se diferenças significativas entre os grupos para flexão, extensão, rotação axial direita e esquerda e flexão lateral esquerda, ao passo que, na compressão axial e na flexão lateral direita, não houve diferença. CPL e CPL com pediculectomia tiveram diferenças significativas na flexão e na extensão, semelhantemente à CPL associada à pediculectomia e à hemilaminectomia nos movimentos de rotação axial direita e esquerda, flexão, extensão e flexão lateral direita.*

Palavras-chave: coluna vertebral, doença do disco intervertebral, medula espinhal, técnicas de descompressão

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Submitted: November 15, 2021. Accepted: November 9, 2022

INTRODUCTION

Intervertebral disc disease (IVDD) is one of the diseases that most affects the spinal cord in dogs (Dewey and Costa, 2017). Surgical removal of the compressive material from the vertebral canal is the primary goal for treatment of thoracolumbar IVDD (Forterre *et al*., 2015; Kervin *et al*., 2018).

Hemilaminectomy (HL) is considered a technique which allows good visualization of the spinal cord and nerve roots in the lateral aspect, allowing removal of material located within the vertebral canal (Shores, 2017). Pediculectomy aims to allow decompression of the spinal cord via a less invasive approach which preserves the zygapophyseal joint and removes less vertebral bone (Brisson, 2017).

The use of partial lateral corpectomy (PLC) in patients with chronic IVDD has been shown to be an excellent alternative because the material is often located on the ventral aspect of the vertebral canal, encapsulated and adhered to the dura mater or venous sinus. PLC is indicated for the surgical treatment of protrusion, chronic extrusion, and the association of both forms, however, the location of the material in some cases can make removal of the material using PLC challenging, and an association of PLC with HL and pediculectomy has been suggested (Moissonnier *et al*., 2004).

Biomechanical studies associating PLC with HL (Revés *et al*., 2011), PLC with mini-hemilaminectomy (MHL) and with HL (Vicente *et al*., 2013), and PLC with pediculectomy and with HL (Araújo, 2017) have been performed, showing some degree of vertebral instability when all techniques are used in association. In their study, Araújo (2017) concluded that PLC associated with pediculectomy did not lead to differences in compression, right and left axial rotation, flexion, extension, and left and right lateral bending evaluated in Dachshund cadavers; however, PLC associated with pediculectomy and with HL led to a significant increase in range of motion, which may lead to vertebral instability. Because the study performed by Araújo (2017) used a single cycle during testing, there was a question of whether those results would be duplicated under a greater number of cycles.

The objective of this study was to compare the intact segment group with the PLC technique on its own, PLC in association with pediculectomy, PLC in association with pediculectomy and HL in the lumbar region in non-chondrodystrophic breeds to determine whether there is a difference between them regarding the level of deformation versus force applied, with the aim of eliminating limitations from prior studies.

MATERIAL AND METHODS

Spinal columns were collected from 20 mixed-breed dog cadavers, weighing between 15 and 25 kilos, regardless of gender and age. The cadaveric vertebral segments were distributed into four groups composed of 5 specimens each for the biomechanical analyses: control (intact) (G1), PLC (G2), PLC and pediculectomy (G3), PLC and pediculectomy and HL (G4).

Thoracic T12 to lumbar 7 segments were removed en block with the surrounding paravertebral musculature intact to preserve the joint capsules and vertebral ligaments. They were kept wrapped in lap sponges moistened with saline solution at 0.9%, preserved in a plastic bag, identified, and stored in a freezer at -20°C until testing.

Prior to biomechanical analyses, specimens were evaluated and selected via computed tomography (CT) (Toshiba 64-channel computed tomography scanner, using 120 Kv and 160 mA, bone window and 2-mm thick slices). Computed tomography scans of each segment of the vertebral column were performed to rule out vertebral malformations, vertebral diseases, degenerative changes, or bone density changes that could compromise stability of the vertebral column during the biomechanical tests.

Vertebral density measurements were analyzed at the cancellous bone of the vertebral bodies of L2 and L3 (Costa *et al*., 2010). Images were processed using Clearcanvas® software and evaluated by a professional with experience in veterinary radiology.

One day prior to the biomechanical tests, the specimens were transferred to a refrigerator at 0 to 4°C to thaw. Twelve hours before the tests, the specimens were prepared for fixation onto the biomechanical testing device. To prepare the specimens, the vertebrae were disarticulated to isolate the intact segment L1-L4. Bone surfaces were cleaned, and paravertebral musculature was removed, leaving the articular joint capsules and spinal ligaments intact.

When the bone surfaces were cleaned, the following techniques were performed in each group: PLC in G2, PLC and pediculectomy in G3, and PLC with pediculectomy and HL in G4, all between the L2-L3 vertebrae on the left side.

Kirschner wires (1.5 mm in diameter) were applied to the articular processes of all L1-L2 and L3-L4 vertebrae, including those in G1, to obtain a partial fixation of the vertebrae. Subsequently, 2.5-mm Steinmann pins were inserted in a crisscross manner from the cranial vertebral endplate of L2 into the caudal vertebral endplate of L1 and from the caudal endplate of L3 into the cranial endplate of L4 to fixate those vertebrae and thus only allow movement of the L2-L3 segment.

All vertebrae were centered in a PVC tube with 75 mm width by 50 mm length, and fixed in place using 2.5-mm Steinmann pins inserted perpendicularly in a ventrodorsal direction into the cranial endplate of L2 and caudal endplate of L3 and into the center of the vertebral body of L1 and L4. Then, another pin of the same size was inserted from the right lateral side of the endplate, at the cranial and caudal limit of L2-L3, respectively. Additionally, 304 steel screws (3.5 x 20 mm) were inserted into the base of the spinous processes of the L1 and L4 vertebrae to improve fixation to the acrylic resin (Fig. 1).

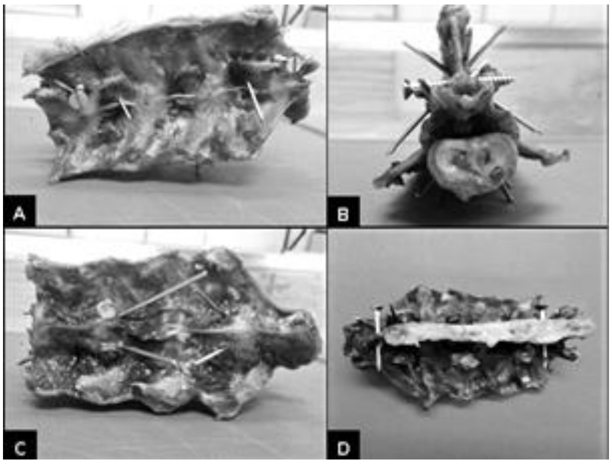

Figure 1. Final appearance of the L1-L4 vertebral segment after placement of 1.5-mm Kirschner wires into the cranial and caudal articular processes at L1-L2 and L3-L4, and insertion of 2.5-mm *Steinmann* pins in a crisscross manner into the cranial vertebral endplate of L2 toward the caudal endplate of L1 and from the caudal endplate of L3 toward the cranial endplate of L4, and of 3.5 x 20 mm 304 steel screws at the base of the spinous processes of L1 and L4, left lateral (A), cranial (B), ventral (C), and dorsal (D).

Next, the pipes were filled with polymethylmethacrylate acrylic resin in its working phase until final polymerization. During polymerization, the assembly was immersed in a container with water at room temperature to reduce the damage to the specimen caused by the exothermal reaction. Next, the cranial and caudal, dorsal and ventral, and right and left lateral aspects of the specimens were identified. During preparation, the vertebrae were constantly immersed in saline solution (NaCl 0.9%) and refrigerated between 0 and 4°C to avoid dehydration of the structures. After preparation, the assembly was kept immersed in saline solution (NaCl 0.9%) and refrigerated between 0 and 4°C until fixed to the biomechanical testing apparatus for the biomechanical tests.

This technique was performed as described by Moissonnier *et al*. (2004). The window was centered on the intervertebral disc space. Initially, fenestration of the disc was performed on the left side, removing all the annulus fibrosus within the limits of the PLC. Then, the nucleus pulposus was removed with a curette. The dimensions of the opening were 1/4 of the length of the body of the cranial vertebra caudocranially, 1/4 of the length of the body of the caudal vertebra craniocaudally, 2/3 of the width of the vertebral body and ½ the height. The PLC was performed with a high-speed drill and n. 117 dental bur.

Pediculectomy was performed according to Brisson (2017). The intervertebral foramen was widened at L2-L3 via removal of the external cortical and cancellous bone of part of the pedicle of the two adjacent vertebrae and of the accessory process using a double-hinged Beyer rongeur, preserving the articular processes. The window was completed with the same high-speed drill and dental bur used for the PLC. The internal cortical bone was then removed with a 2-mm Kerrison rongeur.

HL was performed according to Shores (2017): the vertebral pedicle, from the ventral aspect of the accessory process to the base of the spinous process, and the base of the cranial and caudal articular processes of the L2-L3 vertebrae on the left side were removed with a double-hinged Beyer rongeur. As with the pediculectomy, a high-speed drill and dental bur were used to complete this procedure. The internal cortical bone was removed with a 2-mm Kerrison rongeur. To standardize the decompressive procedures and avoid variations in technique, all were performed by the same person.

Biomechanical analyses were performed on the L2-L3 vertebral segments of the specimens at the Laboratory for Mechanical Testing in the College of Mechanical Engineering (LME) of the Universidade Federal do Vale do São Francisco.

The biomechanical tests were performed using a universal testing machine (UTM) EMIC®. The UTM interfaces with the Tesc® software which allows collection and analysis of data regarding velocity, load, and material deformation (Fig. 2).

Figure 2. Universal Testing Machine (UTM) with the coupled component of the torsion apparatus (A) and the specimen coupled to the apparatus during the test for left lateral bending (B).

Tests performed were axial compression, right and left lateral bending, flexion/extension and right and left axial rotation. The order of the tests was random, with five movement cycles for each test. These were performed within the limits of the elastic phase values for the segments, with force and velocity values controlled based on results obtained from a pilot test. During the tests, the curves for force versus displacement were observed to detect any signs of damage to the sample, that is, a sudden decrease in force or motion. Mean values for compression, flexion, extension, and lateral bending were obtained in millimeters, while those for axial rotation were in degrees.

During the tests, the samples were maintained immersed in and constantly sprayed with refrigerated saline solution (NaCl 0.9%) to avoid dehydration of the intervertebral disc and adjacent structures.

For compression tests, maximum load forces were 200 Newtons (N) and maximum velocity 0.1 mm/s, with a preload of 30 N. In right and left lateral bending, flexion, and extension, maximum load forces were 50 N and maximum velocity 0.1 mm/s, with a preload of 1 N. For right and left axial rotation, maximum load forces were 2 Nm and maximum velocity 1º/s, with a preload of 1 N.

Limits for force and velocity were based on the protocols described by Revés *et al*. (2011), Vicente *et al*. (2013) and Araújo (2017) and from a pilot biomechanical test performed to confirm that these values did not exceed the elastic phase of the bone. These data were not included as analysis results.

For axial rotation tests, an apparatus constructed at the LME at Universidade Federal do Vale do São Francisco. (Cardoso, 2018) was used. The apparatus was designed to be coupled to the UTM DL 10000 EMIC (Fig. 3).

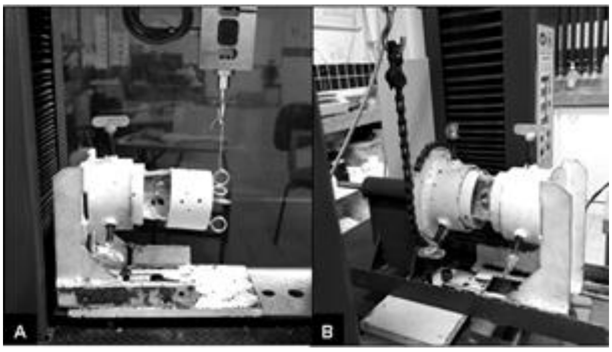

Figure 3. A torsion device used for the biomechanical tests in this experiment. In (A) and (B), the apparatus is fixed to the UTM with a specimen coupled to it during extension (A) and right axial rotation (B).

Values for maximum force and for pre-load, as well as values for force and deformation for each biomechanical test were controlled and collected by a member of the laboratory of material testing from the mechanical testing device which regulates data regarding time, load, and material deformation, using the Tesc® software, which permitted instantaneous computerized collection and analysis of the aforementioned data.

Upon biomechanical analysis, vertebral deformation values were compared between control, PLC, PLC with pediculectomy, PLC with pediculectomy and HL groups for L2-L3 segments of the vertebral column, in millimeters (mm).

Data collected from the analyses were stored in individual charts and registered automatically into the operating system. After completion of the study, the variables were analyzed. The Kolmogorov Smirnov test was used to verify the normality of the data. All variable showed normal distribution and were analyzed via ANOVA and the means compared using Tukey's test, with the level of significance set at 10%. Analyses were performed using the software Graphpad Instat.

RESULTS AND DISCUSSION

Results showed that the addition of decompression procedures in a single intervertebral space increased displacement during right axial rotation, left axial rotation, flexion, extension, and left lateral bending, leading to deformation in the caudal segment of the vertebral column (Tab. 1). However, significant differences were not observed regarding axial compression and right lateral bending, contrary to what was reported by Vicente *et al*. (2013) and Araújo (2017). According to those authors, the differences observed under compression were justified due to the progressive collapse of the intervertebral disc after undergoing all decompression procedures when compared to the intact specimens. Some aspects that may justify the absence of these differences in the present study are the use of groups with different specimens, since previous studies used the same specimens throughout the experiment, stressing the ligamentous structures.

Table 1. Statistical values for mean lumbar displacement in control, corpectomy, corpectomy with pediculectomy, corpectomy with pediculectomy and hemilaminectomy groups, as well as SD (standard deviation) and p values

Variables	Groups Control (G1) n = 5 Mean ± SD	Corpectomy (G2) n = 5 Mean ± SD	Corpectomy + Pediculectomy (G3) n = 5 Mean ± SD	Corpectomy + Pediculectomy + Hemilaminectomy (G4) n = 5 Mean ± SD	p values
Compression	0.77±0.43	0.70±0.15	0.61±0.15	0.64±0.25	0.8038
Right axial rotation	1.47±0.35^{B}	1.61±0.32^{B}	1.70±0.46^{B}	5.26±1.49^{A}	< 0.0001
Left axial rotation	1.24±0.29^{B}	1.42±0.16^{B}	1.56±0.24^{B}	2.50±0.36^{A}	< 0.0001
Flexion	11.86±1.20^{B}	14.56±1.45^{A}	14.44±0.47^{A}	15.32±1.40^{A}	0.0027
Extension	9.74±1.64^{B}	9.94±1.85^{AB}	10.76±1.68^{AB}	12.96±1.90^{A}	0.0411
Right lateral bending	20.64±3.39	17.65±0.73	22.02±5.10	19.92±2.86	0.2672
Left lateral bending	18.90±2.80^{B}	22.35±1.08^{A}	23.23±3.01^{A}	24.55±5.25^{A}	0.0917

Different letters in the same row indicate significant differences between groups. Mean values expressed in millimeters.

Group G4, which associated HL with the other techniques, showed a significant increase in range of motion in right and left axial rotation when compared to the other groups. In a study performed by Revés *et al*. (2011), a significant increase in range of motion was observed during right and left axial rotation after the addition of HL to PLC, supporting the results of the present study. Araújo (2017) noted that removal of articular processes when adding a HL to the association of PLC and pediculectomy led to an increase in neutral zone curves, which had not occurred prior to addition of the HL. This may be explained due to removal of the articular processes from the left lateral aspect when using the abovementioned technique. One of the functions of the articular processes is to limit the excess axial rotation along the longitudinal axis of the vertebral column (Evans and De Lahunta, 2013; Konig and Liebich, 2016).

As observed by Araújo (2017), mean values between procedures during right axial rotation were greater than for left axial rotation. Knowing that the articular facets present in the articular processes restrict axial rotation, as explained by (Panjabi *et al*., 1976; Miele *et al*., 2012), it can be supposed that the absence of these structures on the left side favors the increase in vertebral displacement on the contralateral side.

In flexion, G1 had a significant difference when compared with G2, G3, and G4, where mean values were greater and without statistical difference between the three. Revés *et al*. (2011) also observed that mean displacement in flexion behaved in an increasing manner with the addition of PLC and HL. Vicente *et al*. (2013) observed that adding a PLC and HL led to an increase in range of motion when compared to the intact specimen in flexion, with an increase in vertebral instability. In the present study, where there were various groups and each specimen was not its own control, there were no differences observed when compared to previous studies.

The fact that the groups with decompressive procedures had greater mean values and were significantly different from the control in flexion may be explained by the partial loss of the vertebral body when performing the PLC. The vertebral body actively participates in providing resistance during flexion of the vertebral column. This structure, together with the dorsal longitudinal ligament, which is removed during a PLC, are structures that limit flexion, thus preventing that flexion exceed normal limits (Patterson and Smith, 1992; Sharp and Wheeler, 2005).

The increase in mean flexion values was similar with the addition of procedures in each group; however, statistically, there was only a difference between the control and other groups, which was not observed in the study by Araújo (2017). In that study, mean values were statistically significant with the addition of PLC, followed by the addition of pediculectomy and HL, when compared to the control specimen. Perhaps this difference between the present study and the one by Araújo (2017) can be justified by the number of cycles each specimen underwent and/or by the population of dogs in each study, since this research used groups with specimens undergoing five cycles for each biomechanical test while

Araújo (2017) submitted the same specimen to a single cycle for each test.

When testing extension, G4 had a significant difference when compared to G1. Araújo (2017) also found higher mean values during extension for PLC with pediculectomy and HL, similar to the present study. However, when compared to the other groups, Araújo (2017) found significant differences between PLC and PLC with pediculectomy and HL, whereas in this study, comparing those same groups, there were no statistical differences. Group G1 did not statistically differ from G2 and G3 whereas in the study by Araújo, (2017) the authors found differences between the intact specimens and those with a PLC or PLC associated with pediculectomy. Revés *et al*. (2011) found statistical differences between the three evaluated groups (control, PLC, and PLC associated with HL). Absence of articular processes in the PLC with pediculectomy and HL in the present study may have contributed to greater mean values for displacement and subsequent difference compared to G1, since the articular processes also inhibit excessive extension in the vertebral column (Evans and De Lahunta, 2013; Konig and Liebich, 2016).

On left lateral bending, G1 behaved statistically differently from G2, G3, and G4. Vicente *et al*. (2013) and Araújo (2017) observed that the addition of each technique led to significant differences in left lateral bending. According to Miele *et al*. (2012), a partial loss of the vertebral body and/or intervertebral disc combined with a loss of dorsal elements results in loss of integrity of the vertebral column. Based on this premise, it is presumed that the statistical difference observed in left lateral bending between G1 and the other groups may be explained by the partial loss of structures on the left side.

The neutral zone is a state of intervertebral movement around a neutral posture, where little resistence is offered by the passive vertebral column. Various biomechanical studies, in vivo and with mathematical simulations, showed that the neutral zone is a parameter that relates well to other parameters that are indicative of vertebral column instability (Panjabi, 1992).

This parameter was evaluated by Panjabi (1992) and Réves *et al*. (2011), who verified that there was a direct correlation with range of motion when the neutral zone suffered any changes when decompressive techniques were added. The authors noted that as the neutral zone increased, range of motion also increased, resulting in increased vertebral instability (Revés *et al*., 2011; Panjabi, 1992).

In the present study, the significant increase of vertebral displacement observed in group G4 when compared to groups G1, G2, and G3 under right and left axial rotation led to significant vertebral displacement, which requires caution due to the lack of clinical data. Araújo (2017), working with Dachshund breed dogs, also found similar results to the present study for right and left axial rotation and recommended caution due to the lack of parameters regarding the influence of this increase in range of motion and long-term vertebral instability in clinical patients.

A limitation of the present study was the absence of CT of the specimens after the biomechanical tests to investigate injury to the vertebral column that would not be visible macroscopically, such as those described by Revés *et al.* (2011).

It is important to note that, similarly to what was mentioned by Araújo (2017), the results demonstrated in this study should be considered with care, since it is a biomechanical study that did not take into consideration other stabilizing structures surrounding the vertebral column, such as the musculature, and did not evaluate all the complex vertebral movements that may occur during locomotion.

Considering these findings, clinical trials are important, since some anatomical structures must be removed for biomechanical tests. It has been shown that lumbar PLC on its own and lumbar PLC with pediculectomy did not lead to significant destabilization in right and left axial rotation and extension, and may be used with minimal clinical consequences in non-condrodystrophic dogs with IVDD, as stated by Revés *et al*. (2011) and Araújo (2017).

CONCLUSION

PLC and PLC associated with pediculectomy can be used in dogs with lumbar IVDD without clinical consequences, since a significant difference was observed only in two tests compared to the control group, whereas the association of all three techniques in this type of patient is not recommended due to a significant difference in five of the seven tests performed when compared to the control group.

ACKNOWLEDGEMENTS

The authors would like to thank the team at the Petrolina-PE Zoonosis Control Center for the disposal of the corpses. We would also like to thank Ricardo Santana de Lima, professor at the Medical College of UNIVASF, for his help in acquiring tomographic images. The authors would also like to thank Ana Catarina Luscher Albinati, professor at the College of Veterinary Medicine at UNIVASF for assigning the freezer for specimen conservation. The authors would also like to thank Alexandre Coutinho Antonelli, professor at the College of Veterinary Medicine at UNIVASF for his support in the statistical analysis of the data.

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