

COMPARISON OF CERVICAL LAMINOPLASTY TECHNIQUES IN 3D MODELS

COMPARAÇÃO DE TÉCNICAS DE LAMINOPLASTIA CERVICAL EM MODELOS 3D

COMPARACIÓN DE TÉCNICAS DE LAMINOPLASTIA CERVICAL EN MODELOS 3D

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ABSTRACT

Objective: To define which laminoplasty technique provides the greatest increase in spinal canal dimensions. **Methods:** This was an experimental clinical trial. A patient diagnosed with multilevel degenerative cervical spinal canal stenosis causing myelopathy was initially identified. Magnetic resonance imaging and computed tomography of the patient's cervical spine were imported to a software program to print the anatomical model. A total of 20 identical cervical spine biomodels were printed, equally distributed into four groups: control, Open-door (OD), French-door (FD), and Two-open-doors (TOD) laminoplasty. The biomodels of the experimental groups underwent the laminoplasty surgical procedure, from C3 to C6, according to each technique. All specimens underwent computed tomography, and the cross-sectional area and anteroposterior diameter of the spinal canal were measured. The data were subjected to statistical analyses, and p-values < 0.05 were considered statistically significant. **Results:** All techniques increased the dimensions of the spinal canal. OD laminoplasty was superior to FD in the area evaluation (OD: 2.17 cm²; FD: 1.92 cm²), and there was no statistically significant difference in the increase in anteroposterior diameter (OD: 10.97 mm; FD: 10.42 mm). TOD laminoplasty (area: 2.30 cm²; diameter: 11.94 mm) was superior to FD in both variables. There was no statistical difference between OD and TOD laminoplasty. **Conclusions:** The OD technique expands the cross-sectional area of the spinal canal more than FD laminoplasty, with no significant difference in diameter. TOD laminoplasty increases the dimensions of the spinal canal more than FD, and it tends to be superior to OD laminoplasty. **Level of Evidence I, Therapeutic Studies.**

Keywords: Laminoplasty; Cervical Vertebrae; Spinal Cord Diseases; Models, Anatomic.

RESUMO

Objetivo: Definir qual técnica de laminoplastia proporciona o maior aumento nas dimensões do canal vertebral. **Métodos:** Trata-se de um estudo experimental, tipo ensaio clínico. Inicialmente foi identificado um paciente com diagnóstico de estenose degenerativa do canal vertebral cervical em múltiplos níveis, causando mielopatia. A ressonância magnética e a tomografia computadorizada da coluna cervical do paciente foram importadas para um programa de software para impressão do modelo anatômico. Um total de 20 biomodelos idênticos da coluna cervical foram impressos, igualmente distribuídos em quatro grupos: controle, laminoplastia open-door (OD), French-door (FD) e two-open-doors (TOD). Os biomodelos dos grupos experimentais foram submetidos ao procedimento cirúrgico de laminoplastia, de C3 a C6, de acordo com cada técnica. Todos os espécimes foram submetidos à tomografia pós-operatória, e a área de secção transversa e o diâmetro ântero-posterior do canal vertebral foram medidos. Os dados foram submetidos à análise estatística e os resultados do valor de p < 0,05 foram considerados estatisticamente significativos. **Resultados:** Todas as técnicas aumentaram as dimensões do canal vertebral. A laminoplastia OD foi superior à FD na avaliação da área (OD: 2,17cm²; FD: 1,92cm²) e não houve diferença estatística no aumento do diâmetro ântero-posterior (OD: 10,97mm; FD: 10,42 mm). Laminoplastia TOD (área: 2,30cm²; diâmetro: 11,94mm) que foi superior ao FD em ambas as variáveis. Não houve diferença estatística entre a laminoplastia OD e TOD. **Conclusões:** A técnica OD expande mais a área de secção transversa do canal vertebral do que a laminoplastia FD, sem diferença significativa no diâmetro. A laminoplastia de TOD aumenta as dimensões do canal espinhal mais do que a FD e tende a ser superior à laminoplastia de TOD. **Nível de Evidência I; Estudo terapêutico.**

Descritores: Laminoplastia; Vértabras Cervicais; Doenças da Medula Espinal; Modelos Anatômicos.

RESUMEN

Objetivo: Definir qué técnica de laminoplastia proporciona el mayor aumento de las dimensiones del canal espinal. **Métodos:** Este es un estudio de ensayo clínico experimental. Inicialmente, se identificó un paciente con diagnóstico de estenosis degenerativa del canal espinal cervical a múltiples niveles, causante de mielopatía. La resonancia magnética y la tomografía computarizada de la columna cervical del paciente se importaron a un programa de software para imprimir el modelo anatómico. Se imprimieron un total de 20 biomodelos

Study conducted by the Faculdade Evangélica Mackenzie do Paraná, Curitiba, Paraná, Brazil.

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idénticos de la columna cervical, distribuidos equitativamente en cuatro grupos: control, laminoplastia open-door (OD), French-door (FD) e two-open-doors (TOD). Los biomodelos de los grupos experimentales fueron sometidos al procedimiento quirúrgico de laminoplastia, de C3 a C6, de acuerdo con cada técnica. Todas las muestras se sometieron a tomografía postoperatoria y se midió el área de la sección transversal y el diámetro anteroposterior del canal vertebral. Los datos se sometieron a análisis estadístico y los resultados del valor de $p < 0,05$ se consideraron estadísticamente significativos. Resultados: Todas las técnicas aumentaron las dimensiones del canal espinal. La laminoplastia OD fue superior a la FD en la evaluación del área (OD: 2,17 cm²; FD: 1,92 cm²) y no hubo diferencia estadística en el aumento del diámetro anteroposterior (OD: 10,97 mm; FD: 10,42 mm). La laminoplastia TOD (área: 2,30 cm²; diámetro: 11,94 mm) fue mayor que la FD en ambas variables. No hubo diferencia estadística entre la laminoplastia OD y TOD. Conclusiones: La técnica OD expande el área de la sección transversal del canal espinal más que la laminoplastia FD, sin diferencia significativa de diámetro. La laminoplastia TOD aumenta las dimensiones del canal espinal más que la de FD y tiende a ser superior a la laminoplastia TOD. Nivel de Evidencia I; Estudios terapéuticos.

Descriptor: Laminoplastia; Vértebras Cervicales; Enfermedades de la Médula Espinal; Modelos Anatómicos.

INTRODUCTION

Cervical laminoplasty consists of opening the arch of the vertebrae to increase the diameter of the spinal canal. This technique was designed to be an alternative to laminectomy to avoid its complications, such as instability¹⁻³.

The first laminoplasty techniques were developed by Japanese orthopedists. In 1973, Oyama described the Z-shaped expansive laminoplasty^{4,5}. In 1977, Hirabayashi developed the open-door laminoplasty, whereby the laminotomy is performed on one side and the osteotomy is constrained on the other side to the cortical portion of the laminae^{5,6}. This forms a hinge, or “greenstick” fracture, enabling the opening of the spinal canal. Most patients obtained good results, with a 66% improvement in the Japanese Orthopaedic Association (JOA) score, and the diameter of the spinal canal increased by an average of 5 mm⁵. In 1982, Kurokawa described French-door laminoplasty, whereby the laminae are only submitted to partial osteotomy on both sides, and the spinous processes are sectioned in the midline^{4,7}. The technique is effective, but the surgical procedure requires more time and, because it involves more osteotomy sites, it promotes increased bleeding^{3,7}. Meta-analysis studies show some differences in these two techniques, yet without demonstrating any superiority^{3,8,9}.

In 2014, Brazilian neurosurgeons developed a modification of the Hirabayashi technique, whereby two openings are made on opposite sides¹⁰. This technique performs laminotomy on one side in C3 and C4 and on the other side in C5 and C6. Then on the contralateral sides of each level, partial osteotomy of the laminae is performed, forming a hinge and allowing the opening of the spinal canal. This open-door variation does not seem to generate instability and its great advantage is that it enables bilateral C4-C5 foraminotomy, preventing C5 root neuropraxia. In that study, the diameter of the spinal canal increased by 6 mm, there were no cases of instability, and an 88% functional improvement was reported.

There are nuances in the development of all techniques, and they have achieved satisfactory postoperative results. Nonetheless, the studies comparing these techniques are restricted to postoperative follow-up, and none have evaluated which technique actually leads to a greater increase in spinal canal dimensions^{3,8,9,11-14}.

Therefore, the objective of this study was to evaluate which of these three cervical laminoplasty techniques provides the greatest increase in spinal canal dimensions.

MATERIALS AND METHODS

The study was approved by the Research Ethics Committee of the Faculdade Evangélica Mackenzie do Paraná – opinion number: 4,023,742. The identity of the participant was protected, and confidentiality was guaranteed.

This experimental study was conducted at the Laboratory of Surgical Techniques of the Faculdade Evangélica Mackenzie do Paraná, Curitiba, PR, Brazil. The first step was to identify a patient diagnosed with spinal canal stenosis of degenerative etiology causing spondylotic cervical myelopathy. A search was performed in the patient database to select a patient who was being treated

at the Outpatient Clinic of the Department of Neurosurgery of the Hospital Universitário Evangélico Mackenzie, Curitiba, PR, Brazil, and who was scheduled to undergo surgery. The selected patient signed the Informed Consent Form and underwent a new CT and MRI examination of the cervical spine.

Initially, the CT and MRI images of the patient's cervical spine, in DICOM file format, were imported into the 3D Slicer software (BSD-style, The Slicer Community) to prepare the biomodel. The CT and MRI (T2-weighted sequence) images were superimposed on the sagittal axis. Then, the images were imported into the Cura software (UltiMaker Cura, New York, New York, USA) and the prototype was printed.

The additive manufacturing method used for fused deposition modeling (FDM) utilized polylactic acid as the primary raw material. It was printed on the Creality® Ender 5 printer (Creality 3D Technology Co., Shenzhen, China). Twenty identical biomodels were printed and divided into 4 groups: a control group – CTL (n = 05) with specimens not submitted to any surgical procedure, only computed tomography; Open-door laminoplasty group – OD (n = 05) with specimens submitted to cervical laminoplasty using the open-door technique; French-door laminoplasty group – FD (n = 05) with specimens submitted to cervical laminoplasty using the French-door technique; and two-open-door laminoplasty group – TOD (n = 05) with specimens submitted to cervical laminoplasty using the two-open-door technique.

Description of procedures

The biomodel was placed in a rigid compartment and fastened by 3 metal pins (Figure 1).

The procedures were performed using 3.0× medical loupes (Surgitel, Ann Arbor, Michigan, USA) with an attached 75,000-lux photophore and an electric drill (Bien-Air, OsseoDuo model, Biene, Switzerland) set at 20,000 revolutions per minute (rpm) with continuous irrigation. Drill bits of 2 mm and 3 mm were used. One experienced neurosurgeon performed all procedures.

Open-door Laminoplasty

The procedure was initiated by resecting the ligament between C2-C3 and C6-C7, using 2-mm drill bits. Subsequently, laminotomy was performed with 3-mm C3, C4, C5 and C6 drill bits on the right side, and partial osteotomy of the laminae on the contralateral side to form the hinge. The canal was opened, and titanium plates were fastened between the laminae and the lateral masses with screws (Figure 2a).

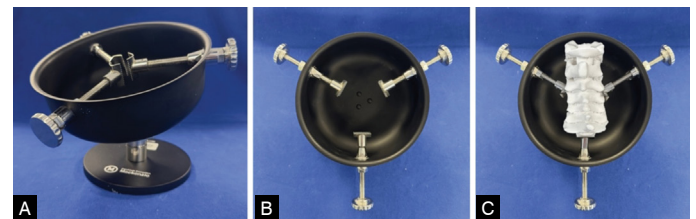


Figure 1. The rigid compartment. A) lateral view; B) superior view; C) biomodel fastened in the compartment.

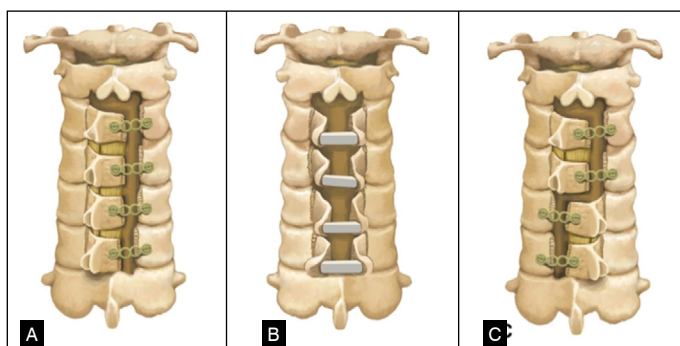


Figure 2. Illustration of the laminoplasty techniques performed in the study. A) Open-door laminoplasty. B) French-door Laminoplasty. C) Two-open-doors laminoplasty.

French-door Laminoplasty

The procedure was initiated by resecting the ligament between C2-C3 and C6-C7. Next, partial bilateral osteotomy of the laminae was performed, followed by sectioning the spinous processes in the midline. The opening of the canal was carried out and the removal of the spinous processes was maintained by applying a piece of latex next to the spinous processes (Figure 2b).

Two-open-door Laminoplasty

The procedure was initiated by resecting the ligament between C2-C3, C4-C5 and C6-C7, using 2-mm drill bits. Subsequently, laminotomy was performed with a 3-mm drill bit in C3 and C4 on the right side, and partial osteotomy of the laminae on the contralateral side to form the hinge. In C5 and C6 the reverse was done. The canal was opened, and titanium plates were fastened between the laminae and the lateral masses with screws (Figure 2c).

Postoperative CT

CT scans were performed on all biomodels individually. The specimens were placed on a polyethylene foam base – Ethafoam (Figure 3), prepared by the authors, and placed in the CT scanner.

A single protocol was used for all studies. Contiguous 1.25 mm scans of the 3D models were acquired on the axial plane with a multi-slice helical system (GE Medical Systems, Waukesha, WI). The images were acquired with a 10-cm field of view (FOV) and a high-resolution soft tissue and bone algorithm. The examination was performed in spiral acquisition and evaluated utilizing multisurface and three-dimensional reconstructions.

The studies were reviewed on the Aurora DICOM Arya/Picture Archiving and Communication System (PACS) software terminals (Pixon, São Caetano do Sul, SP, Brazil, 2024) version 23.7.1. These workstations provide magnification capabilities and an electronic caliper, allowing for accurate and reproducible measurements.

All measurements were performed only once, by three different radiologists.

The vertebral canal was measured at the anteroposterior

diameter and the transversal area, on the axial axis, at the levels of the C3, C4, C5, and C6 pedicles and at the disc levels of C3-4, C4-5, C5-6, and C6-7.

Statistical analysis

The minimum sample size was calculated based on a pilot study developed by the authors, with the aid of G*Power software. The minimum sample size was three biomodels in each group.

The increase in canal diameter and area was evaluated as the difference between the mean measurements of each experimental group and those of the control group, and was expressed as a percentage.

Analysis of variance (ANOVA) followed by the Games-Howell post-hoc test was applied to verify statistical significance between the groups. P-values < 0.05 were considered statistically significant for all tests. Equivalence tests were performed between the groups where there was no statistically significant difference in the post-hoc test. The pair-by-pair TOST test was applied to verify the equivalence between the techniques of interest. The upper and lower limits were set at 1 mm for diameter and 0.5 cm² for area. All statistical analyses, construction of graphs and tables were performed using the JAMOVI version 2.5.0 statistical software, which is based on the R language.

RESULTS

All techniques increased the area (Table 1) and the anteroposterior diameter (Table 2) of the spinal canal.

Figures 4, 5, and 6 show the biomodels from each experimental group, and Figures 7 and 8 show the tomographic images at the pedicle level and at the disc level, respectively, with demarcation of the cross-sectional area, the anteroposterior diameter, and the expansion of the spinal canal.

Table 1. Mean cross-sectional area of the spinal canal (cm²).

Groups	Mean (SD)	Canal expansion	P (ANOVA)
cTL	1.52 (± 0.0134)	-	
OD	2.17 (± 0.1145)	0.65	<0.001
FD	1.92 (± 0.0387)	0.40	<0.001
TOD	2.30 (± 0.1507)	0.78	<0.001

Table 2. Mean anteroposterior diameter of the spinal canal (mm).

Groups	Mean (SD)	Canal expansion	P (ANOVA)
CTL	7.78 (± 0.0898)	-	
OD	10.97 (± 0.2968)	3.19	<0.001
FD	10.42 (± 0.4011)	2.64	<0.001
TOD	11.94 (± 0.6970)	4.16	<0.001

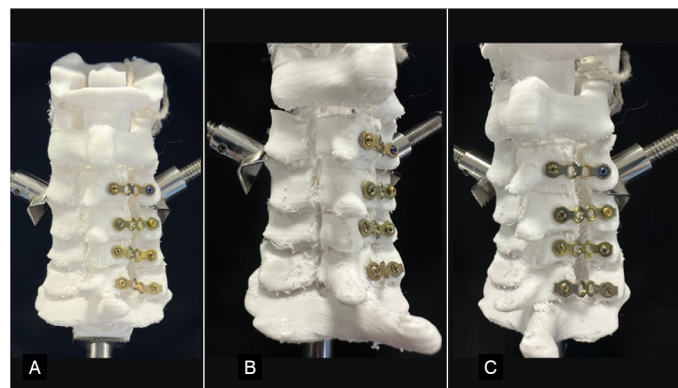


Figure 4. Biomodel subjected to open-door laminoplasty. A) Posterior view. B) Part of the lamina where the hinge was formed. C) Opening of the spinal canal and fastening the laminae with titanium plates and screws.

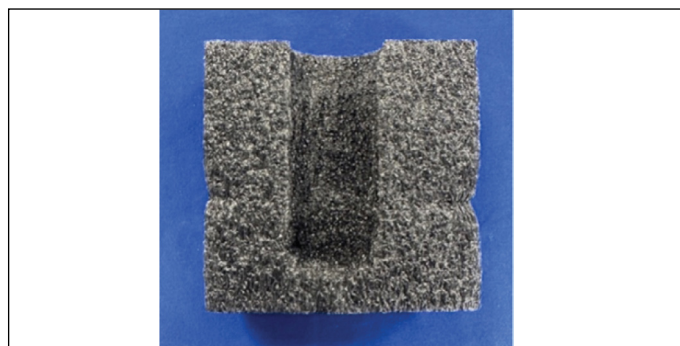


Figure 3. The polyethylene foam base.

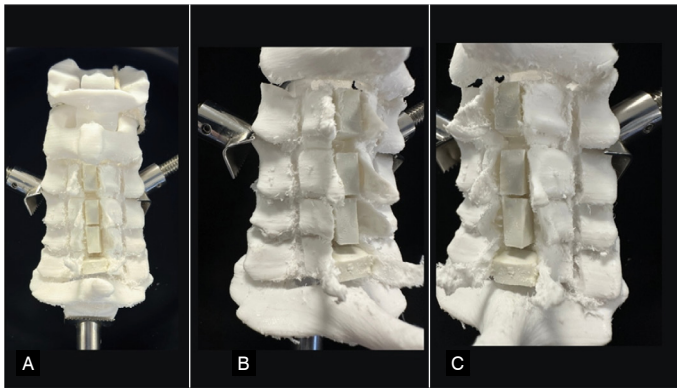


Figure 5. Biomodel subjected to French-door laminoplasty. A) Posterior view. B) Hinge on the left lamina. C) Hinge on the right lamina.

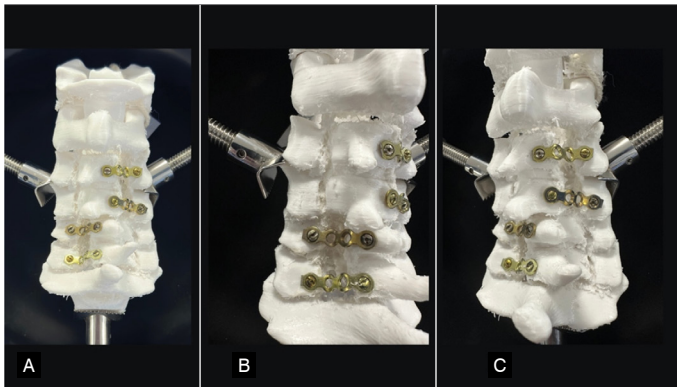


Figure 6. Biomodel subjected to two-open-door laminoplasty. A) Posterior view. B) Left side – hinge on the C3 and C4 laminae and canal opening on the C5 and C6 laminae. C) Right side – canal opening in C3 and C4 and hinge in the C5 and C6 laminae.

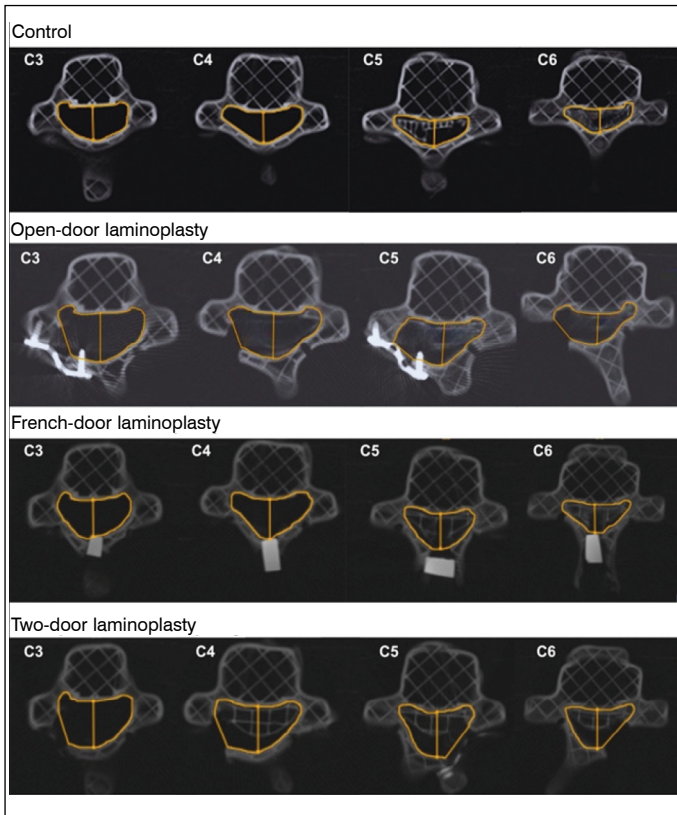


Figure 7. CT images of the biomodels, at the pedicle level.

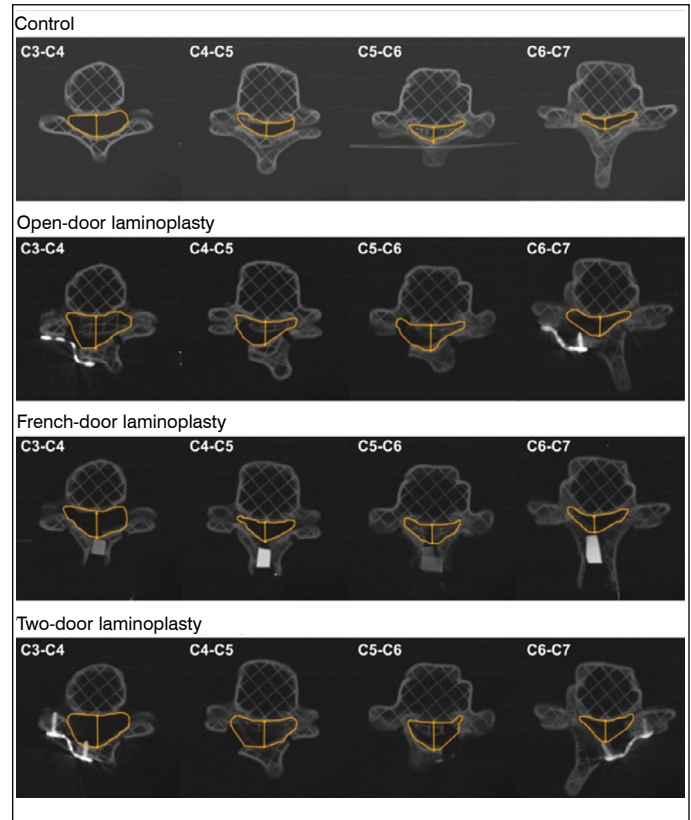


Figure 8. CT images of the biomodels, at the disc level.

Comparison between groups – spinal canal area

OD laminoplasty increased the spinal canal area by 43%, FD by 28%, and TOD by 51%.

Both OD and TOD laminoplasty produced a significant increase in the spinal canal cross-sectional area when compared with the French-door technique. There was no statistically significant difference between the OD and TOD groups, although the canal area was larger with the latter technique (Figure 9).

In the equivalence test between the OD and TOD groups, the techniques were found not to be equivalent, as shown in Figure 10: the black bar on the X-axis (the difference between the means of the OD and TOD groups) is not fully within the defined equivalence limits.

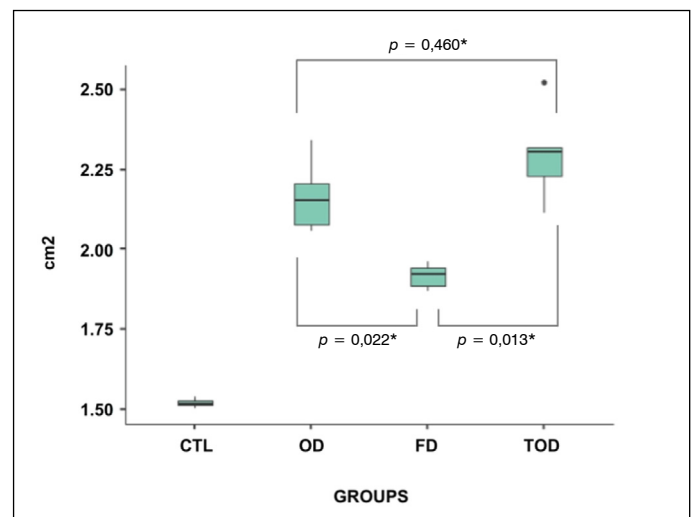


Figure 9. Comparison of the cross-sectional area of the spinal canal between the groups. * Post-hoc Games-Howell Test.

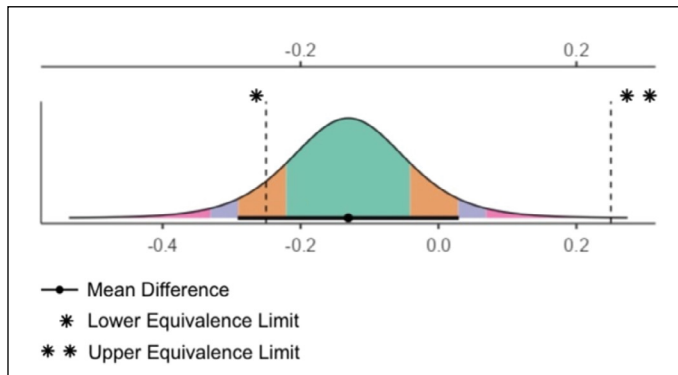


Figure 10. Equivalence test of the cross-sectional area of the spinal canal between the OD and TOD groups.

Comparison between groups – spinal canal diameter

OD laminoplasty increased the diameter of the spinal canal by 41%, FD by 34%, and TOD by 54%.

The TOD technique produced a statistically significant increase in the spinal canal diameter compared with FD. When compared with OD laminoplasty, the increase was almost 1 mm, but without a statistically significant difference. There was no statistically significant difference between OD and FD laminoplasty (Figure 11).

In the equivalence test between the OD and FD groups, the techniques were found not to be equivalent, since the difference between the means of the groups exceeded the upper equivalence limit (Figure 12).

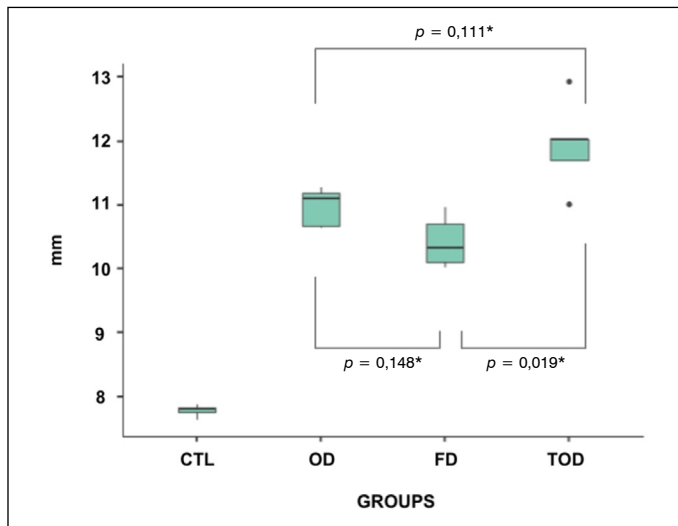


Figure 11. Comparison of the anteroposterior diameter of the spinal canal between the groups. * Post-hoc Games-Howell Test.

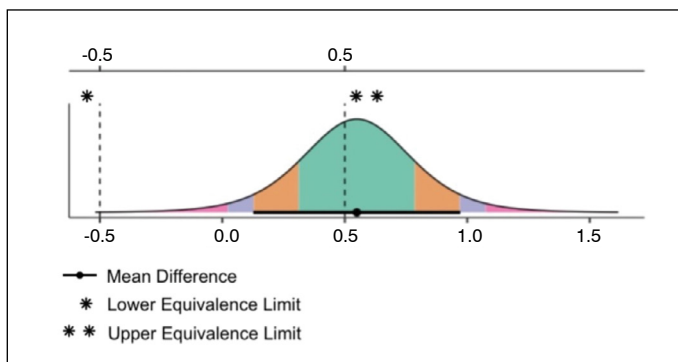


Figure 12. Spinal canal diameter equivalence test between the OD and FD groups.

In the equivalence test between the OD and TOD groups, the difference was found to be relevant, indicating that the techniques are not equivalent in increasing the spinal canal diameter. The difference between the group means was below the lower equivalence limit, suggesting that two-open-door laminoplasty tends to produce a greater increase in spinal canal diameter (Figure 13).

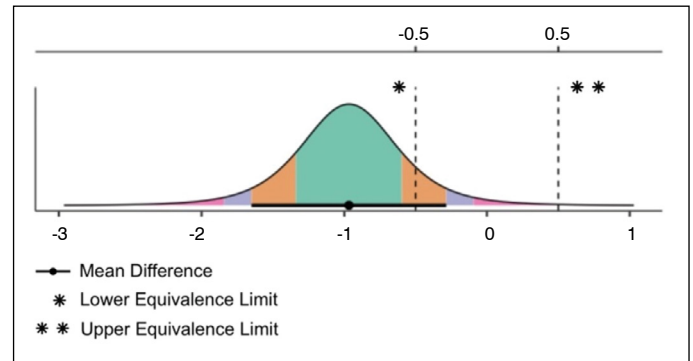


Figure 13. Spinal canal diameter equivalence.

DISCUSSION

3D printing is considered an industrial revolution and has been widely used in medicine, including spine surgery¹⁵⁻²¹. It is possible to print personalized models based on CT and/or MRI scans of the patient's spine by employing this technology²². It is already evident that these personalized models are beneficial for surgical planning, teaching, and the improvement of surgical techniques, as well as for clarifying the disease and proposing treatments to patients²³⁻²⁷. Cervical laminoplasty in biomodels is feasible and has become an alternative for improving techniques and comparing existing techniques.

The literature is still limited regarding the impact of preoperative and postoperative morphometric parameters of the spinal canal and spinal cord on the clinical outcome of patients with cervical spondylotic myelopathy (CSM)²⁸. However, some studies show that the postoperative cross-sectional area of the spinal cord at the site of maximal compression is a predictor of surgical outcome — the smaller the increase in spinal cord area after decompression, the worse the patient's prognosis^{29,30}. It remains controversial whether an increase in spinal canal area influences the increase in spinal cord area and, consequently, the prognosis³¹.

The change in spinal canal volume is considered a factor that influences postoperative recovery, whereas area and diameter are not; however, regardless of the parameter, preoperative and postoperative measurements should be considered to assess prognosis³². Other authors have shown that increases in spinal canal diameter and area are directly related to clinical improvement after decompression^{31,33,34}. Therefore, it is beneficial to compare how much the spinal canal can increase in size from different types of laminoplasty.

The present study showed that all laminoplasty techniques significantly increased the size of the spinal canal, corroborating findings in the literature indicating that cervical laminoplasty, regardless of the selected technique, is effective for treating cervical canal stenosis^{10,14,35-37}. Therefore, studying and practicing cervical laminoplasty in the laboratory, in biomodels, is valid. This can help to improve the techniques of spine surgeons in their training and provide an alternative to cadaver training.

The results showed no statistically significant difference between some experimental groups. Therefore, in these cases, an equivalence or non-inferiority test was applied. These tests made it possible to determine whether a treatment or procedure was equivalent³⁸.

The FD laminoplasty increased the area less than the other techniques when evaluating the cross-sectional area (Figure 9). On the other hand, when analyzing the diameter of the spinal canal, no statistical difference was found between the FD and OD laminoplasty

(Figure 11). Therefore, it appears that the FD technique does not enlarge the spinal canal as uniformly and may not promote effective decompression of the lateral recess. When the non-inferiority or equivalence test was applied to compare this variable between the OD and FD groups (Figure 12), the techniques were found not to be equivalent — that is, the results differed and, in this case, open-door laminoplasty tended to provide a larger canal diameter than French-door. Very few studies have compared the increase in spinal canal dimensions reported with the main laminoplasty techniques. Nakashima et al. (2014)³⁵ conducted a randomized study and concluded that OD laminoplasty significantly increased the diameter of the spinal canal compared with FD, corroborating the meta-analysis by Luo et al. (2018)⁸ and contradicting the results of the present study. In contrast, other meta-analyses compared the dimensions of the spinal canal between OD and FD laminoplasty and found no statistically significant difference between them^{3,36}.

TOD laminoplasty was superior to FD laminoplasty both in terms of area (Figure 9) and diameter (Figure 11). When compared with OD, it increased the area by 8% and the diameter by 13%, but with no statistically significant difference in either variable (Figures 9 and 11). When the non-inferiority or equivalence test was applied between the OD and TOD groups for area (Figure 10) and diameter (Figure 13), the two techniques were found not to be equivalent. Therefore, they are not the same in terms of providing increased dimensions of the spinal canal. Thus, there is a tendency for TOD laminoplasty to provide larger spinal canal dimensions, *in vitro*. It is likely that, by increasing the sample size of these groups, statistically significant differences among them could be demonstrated.

This study was carried out *in vitro*, and one question that may be raised is whether soft tissues could interfere with the results. The authors believe this is unlikely, since the laminae were fixed with

plates and screws or held open by a piece of latex, in the case of French-door laminoplasty. This prevents occlusion of the spinal canal. Indeed, the authors use this same fixation technique in their patients.

There are no randomized studies or meta-analyses comparing the TOD technique with other techniques, either in terms of post-operative imaging findings or clinical parameters, as it is a newer technique and not yet widespread worldwide. Nevertheless, it statistically provides an increase in dimensions comparable to that of OD laminoplasty. TOD can be considered an applicable technique in cases of spinal canal stenosis and CSM. Moreover, as described by its developer, this technique allows effective decompression of the spinal canal and clinical improvement of patients. The authors also reported that the key advantage of this technique is that, when bilateral C4-C5 foraminotomy is performed, the risk of C5 root neuropathia is reduced 10.

Both OD and TOD laminoplasty are suitable for fully decompressing the cervical spinal canal, and the selection of these two techniques should be based on the need to perform foraminotomy at the C4-C5 level and the surgeon's familiarity with the technique. Further *in vivo* research should be carried out to compare these two techniques with respect to surgical data such as duration of the procedure, amount of bleeding, intraoperative complications, and clinical outcome, as these factors may determine which technique is more appropriate.

CONCLUSIONS

The present study supports the conclusion that the OD technique expands the cross-sectional area of the spinal canal more than FD laminoplasty, with no significant difference in diameter. TOD laminoplasty increases the dimensions of the spinal canal more than FD, and there is a tendency toward superiority over OD laminoplasty.

CONFLICT OF INTEREST

All authors declare no potential conflict of interest related to this article.

CONTRIBUTIONS OF THE AUTHORS

Each author made a personal and significant contribution to the development of this article. FAAJ: conceptualization and methodology; AAAJ: methodology and formal analysis; RB: methodology; RRF: formal analysis; GHWC and PHSN: investigation; JMRf and OM: supervision. All authors contributed to the preparation of the original draft and to the review and editing of the manuscript. All authors approved the final version of the manuscript.

DATA AVAILABILITY DECLARATION

The data underlying this research are contained within the manuscript.

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