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Original Article

COMPARISON OF CERVICAL LAMINOPLASTY TECHNIQUES IN BIOMODELS

COMPARAÇÃO DE TÉCNICAS DE LAMINOPLASTIA CERVICAL EM BIOMODELOS

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Image

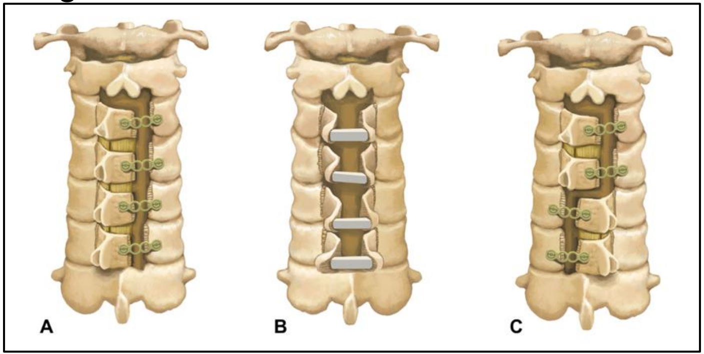


Illustration of the laminoplasty techniques performed in the study. A) Open-door laminoplasty. B) French-door Laminoplasty. C) Two-open-doors laminoplasty.
Source: The authors (2024).

Main Clinical Message

The 3D printing of anatomical structures, based on patient imaging exams, has been used to assist in preoperative planning for minimizing morbidity. Using biomodels can also influence the learning curve, improve surgical techniques, and used in vitro studies.

Perspective

Cervical laminoplasty has already been established as one of the treatment options for spinal canal stenosis and spondylotic myelopathy[1–3] This study hopes to open doors to new comparisons between techniques to provide patients the most appropriate treatment

ABSTRACT - Background: There are several types of laminoplasty reported in the literature, but there are few studies comparing which one expands the canal the most. One of the ways to evaluate this comparison is by applying the techniques in a three-dimensional anatomical model. **Objective**: Define which laminoplasty technique provides the greatest increase in spinal canal dimensions. **Method:** This is an experimental study, a type of clinical trial. Initially, a patient was identified and diagnosed with cervical spinal canal stenosis at multiple levels, of degenerative etiology resulting in myelopathy. 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 twenty 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 were submitted to the laminoplasty surgical procedure, from C3 to C6, according to each technique. All specimens of the study were submitted to tomography, and the cross-sectional area and anteroposterior diameter of the vertebral canal were measured. The data were submitted to statistical analyses (ANOVA analysis) and p-value results < 0.05 were considered as statistically significant. An equivalence or non-inferiority test was applied in the absence of a statistical difference between the groups. **Results:** All techniques increased the dimensions of the spinal canal. OD laminoplasty was superior to FD in the area evaluation (OD: 2.17cm^2; FD: 1.92cm^2) and there was no statistical difference in increased anteroposterior diameter (OD: 10.97mm; FD:10.42mm). TOD laminoplasty (area: 2.30 cm^2; diameter: 11.94 mm) that was superior to FD in both variables. There was no statistical difference between OD and TOD laminoplasty, although the latter tended to further expand the vertebral canal,

based on the equivalence tests. **Conclusion:** The open-door technique expands the cross-sectional area of the spinal canal more than French-door laminoplasty with no significant difference in diameter. Two-open-doors laminoplasty increases the dimensions of the spinal canal more than the French-door, and it tends to be superior to Open-door laminoplasty.
KEYWORDS – Spinal Stenosis. Laminoplasty. Printing, Three-Dimensional, Spine.

RESUMO – **Introdução:** Há diversos tipos de laminoplastia relatados na literatura, mas há poucos estudos que compare qual delas expande mais o canal. Uma das maneiras de avaliar essa comparação é aplicando as técnicas em modelo anatômico tridimensional (3D). **Objetivo**: Definir qual técnica de laminoplastia proporciona maior aumento das dimensões do canal vertebral. **Método:** Trata-se de um estudo experimental, tipo ensaio clínico. Inicialmente foi identificado um paciente com diagnóstico de estenose do canal vertebral cervical em múltiplos níveis, de etiologia degenerativa causando mielopatia. As imagens de ressonância magnética e tomografia computadorizada da coluna cervical do paciente foram importadas para um *software* e impresso o modelo anatômico. No total, foram impressos 20 biomodelos da coluna cervical, idênticos e distribuídos, igualmente, 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, entre C3 e C6, de acordo com cada técnica. Todas as peças do estudo foram submetidas a exame de tomografia e mensurados a área transversal e o diâmetro anteroposterior do canal vertebral. Os dados foram submetidos a análise estatística (teste ANOVA) e valores de $p < 0.05$ foram suficientes para considerar o resultado significante estatisticamente. No caso de ausência de diferença estatística entre os grupos, foi aplicado teste de equivalência ou não-inferioridade. **Resultados:** Todas as técnicas aumentaram as dimensões do canal vertebral. A laminoplastia OD foi superior a FD na avaliação da área (OD: 2,17cm^2; FD: 1,92cm^2) e sem diferença estatística no aumento do diâmetro anteroposterior (OD: 10,97mm; FD:10,42mm). A laminoplastia TOD (área: 2,30 cm^2; diâmetro: 11,94mm) foi superior a FD, nas duas variáveis. Não houve diferença estatística entre a laminoplastia OD e TOD, apesar dessa última ter uma tendência a maior expansão do canal vertebral, baseado nos testes de equivalência. **Conclusão:** A técnica *open-door* expande mais a área transversal do canal vertebral quando comparada com a laminoplastia *french-door*, não tendo diferença significativa no diâmetro. A laminoplastia *two-open-doors* aumenta mais as dimensões do canal vertebral do que a *french-door* e há uma tendência de ser superior a laminoplastia *open-door*.

PALAVRAS-CHAVE – Estenose Espinhal. Laminoplastia. Impressão em 3D. Coluna Vertebral.

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 segmental instability[1,2,3].

The first laminoplasty techniques were developed by Japanese orthopedist. In 1973, Oyama described the Z-shaped expansive laminoplasty [4]. However, it was not well accepted among surgeons at the time due to how difficult it was to perform [5]. Years later, 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 blades [5,6]. This forming a hinge or fracture on “a green stick”, enabling the opening of the spinal canal. A follow-up of 4.5 years showed that most patients obtained good results, with an improvement in the JOA score of 66% and the diameter of the spinal canal increased an average of 5 mm [5]. In 1982, Kurokawa described French-door or double-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, as it involves more osteotomy areas and it promotes increased bleeding [3,7]. Meta-analysis studies show some differences in these two techniques, yet without demonstrating any superiority [3,8,9].

Arantes Júnior et al. (2014)[10] developed a modification of the Hirabayashi technique, whereby two openings are made on opposite sides. 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 this study, 86 patients were included, with a five-year-follow-up period. The diameter of the spinal canal increased (from 11 mm to 17 mm). There were no cases of instability, and 88% functional improvement was achieved on the Nurick scale.

There are nuances in the development of all techniques, and they have achieved satisfactory postoperative results. Nonetheless, the studies that have compared the techniques are restricted to postoperative follow-up, and none of them have compared which technique actually leads to more significant increased dimensions in the spinal canal [3,8,9,11–14].

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

METHOD

The study was approved by the Research Ethics Committee of Evangelical Mackenzie Faculty of Parana – opinion number: 4,023,742. The identity of the collaborating participant in the research was respected and the right to confidentiality was guaranteed.

The Laboratory of Surgical Techniques of the Mackenzie Evangelical College of Paraná, Curitiba, PR. Brazil carried out this experimental study. 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 choose a specific patient who was being treated at the Outpatient Clinic of the Department of Neurosurgery of the Mackenzie Evangelical University Hospital, Curitiba, PR, Brazil, and who was planning to undergo surgery. The selected patient signed the Informed Consent Form and underwent a new CT and MRI examination of the cervical spine.

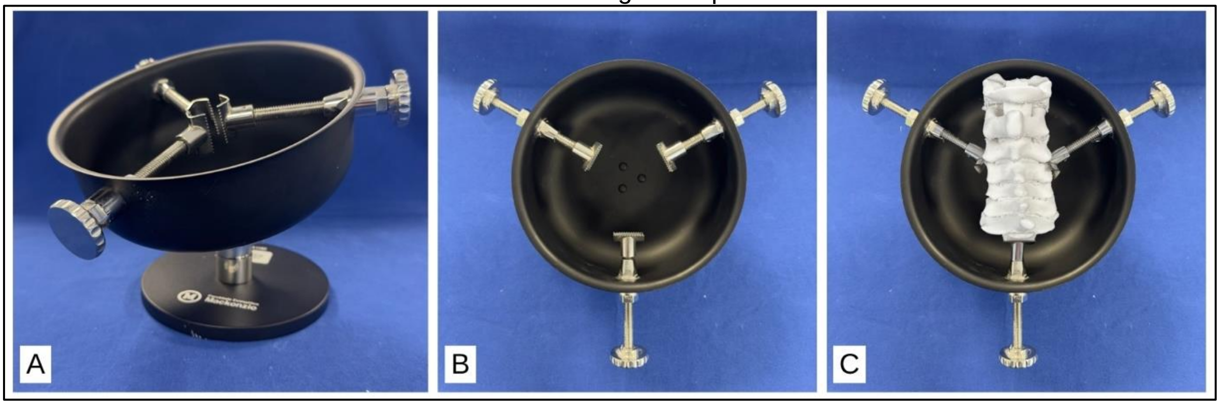
Initially, the CT and MRI images of the patient's cervical spine, in DICOM file format, were imported to the 3D Slicer software to prepare the biomodel. The CT and MRI (T2-weighted sequence) images were superimposed on the sagittal axis. Then, the images were imported to the Cure software and the prototype 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 Ender 5 printer (Creality®). 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-doors laminoplasty group – TOD (n = 05) with specimens submitted to cervical laminoplasty using the two-open-doors technique.

Description of procedures

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

FIGURE 1 – The rigid compartment



Legend: A) lateral view; B) superior view; C) biomodel fastened in the compartment.
Source: The authors (2024).

The procedures were performed while wearing a 3.0 x medical loupe (Surgitel®) with a 75,000 lux attached photophore and an electric drill (BienAir®), set at a speed of 20,000 revolutions per minute (rpm) and with continuous irrigation. 2 mm and 3 mm drill bits 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 2).

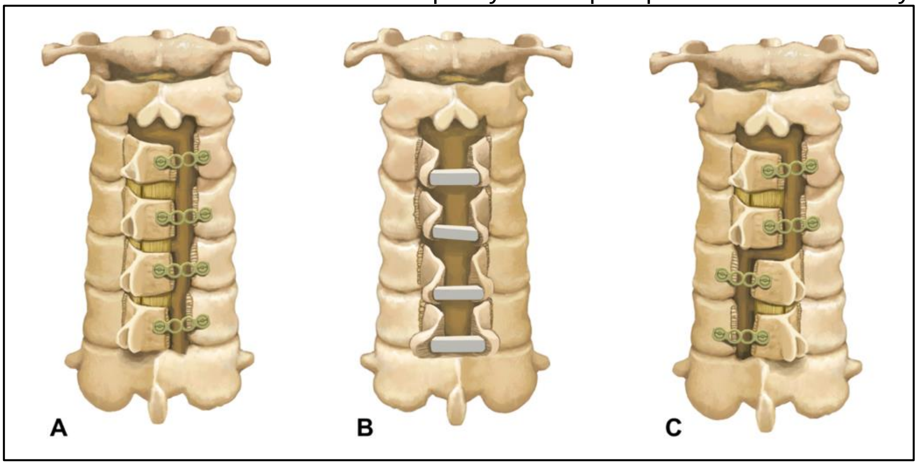
French-door Laminoplasty

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.

Two-open-doors 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 2 – Illustration of the laminoplasty techniques performed in the study.



Legend: A) Open-door laminoplasty. B) French-door Laminoplasty. C) Two-open-doors laminoplasty.
Source: The authors (2024).

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.

FIGURE 3 – The polyethylene foam base.

Source: The authors (2024).

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 GE 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® (Pixeon®, 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 (M1, M2, M3) and recorded in the study protocol.

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

A calculation was performed to define the minimum sample size, based on a pilot project developed by the authors, aided by the G-Power software. The minimum sample size was three biomodels in each group.

The increased diameter and canal area were evaluated by the difference between the mean measurements from the experimental groups and compared to the control group and expressed as a percentage.

The parametric ANOVA test and the Games-Howell post-hoc test were applied to verify the 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 cm^2 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 in the anteroposterior diameter of the spinal canal (TABLE 2).

TABLE 1 – Mean transversal area of the spinal canal (cm^2)

GROUPS	MEAN (DP)	CANAL EXPANSION	p (ANOVA)
CTL	1.52 (± 0.0134)	-	< 0.001
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

Source: The authors (2024).

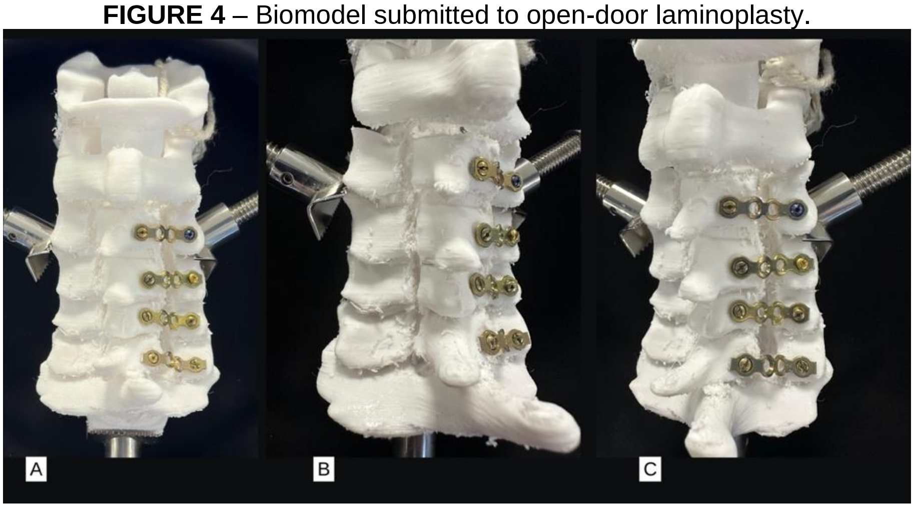
TABLE 2 – Mean anteroposterior diameter of the vertebral canal (mm)

GROUPS	MEAN (DP)	CANAL EXPANSION	p (ANOVA)
CTL	7.78 ($\pm$ 0.0898)	-	< 0.001
OD	10.97 ($\pm$ 0.2968)	3.19	< 0.001
FD	10.42 ($\pm$ 0.4011)	2.64	< 0.001
TOD	11.94 ($\pm$ 0.6970)	4.16	< 0.001

Source: The authors (2024).

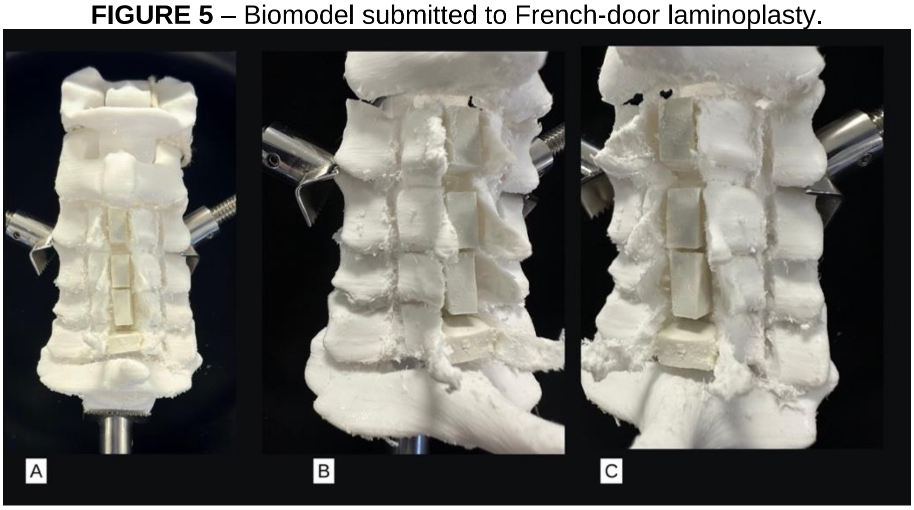
Figures 4, 5, and 6 show the biomodels from each experimental group, and figures 7 and 8 show the tomographic images at the pedicle level and at the disc level, respectively, showing the demarcation of the cross-sectional area, the anteroposterior diameter and the expansion of the vertebral canal.

FIGURE 4 – Biomodel submitted to open-door laminoplasty.



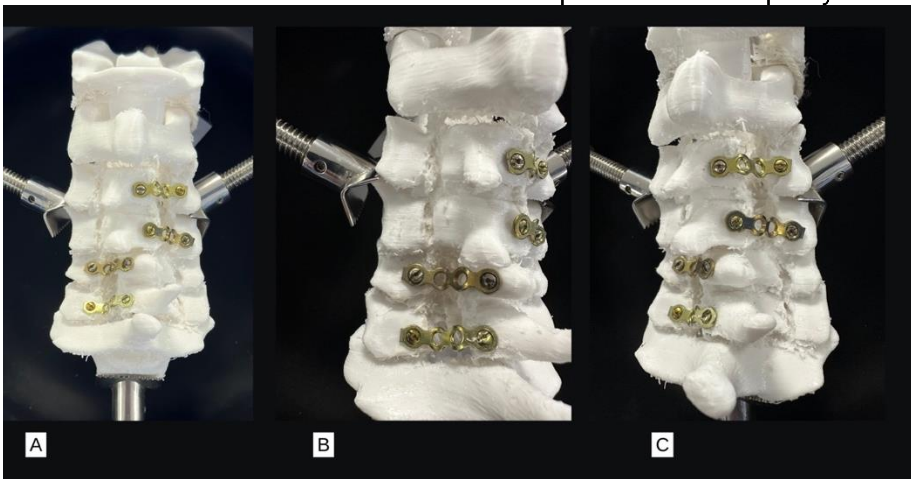
Legend: A) Posterior view. B) Part of the blade where the hinge was formed. C) Opening of the spinal canal and fastening the blades with titanium plates and screws.
Source: The author (2024).

FIGURE 5 – Biomodel submitted to French-door laminoplasty.



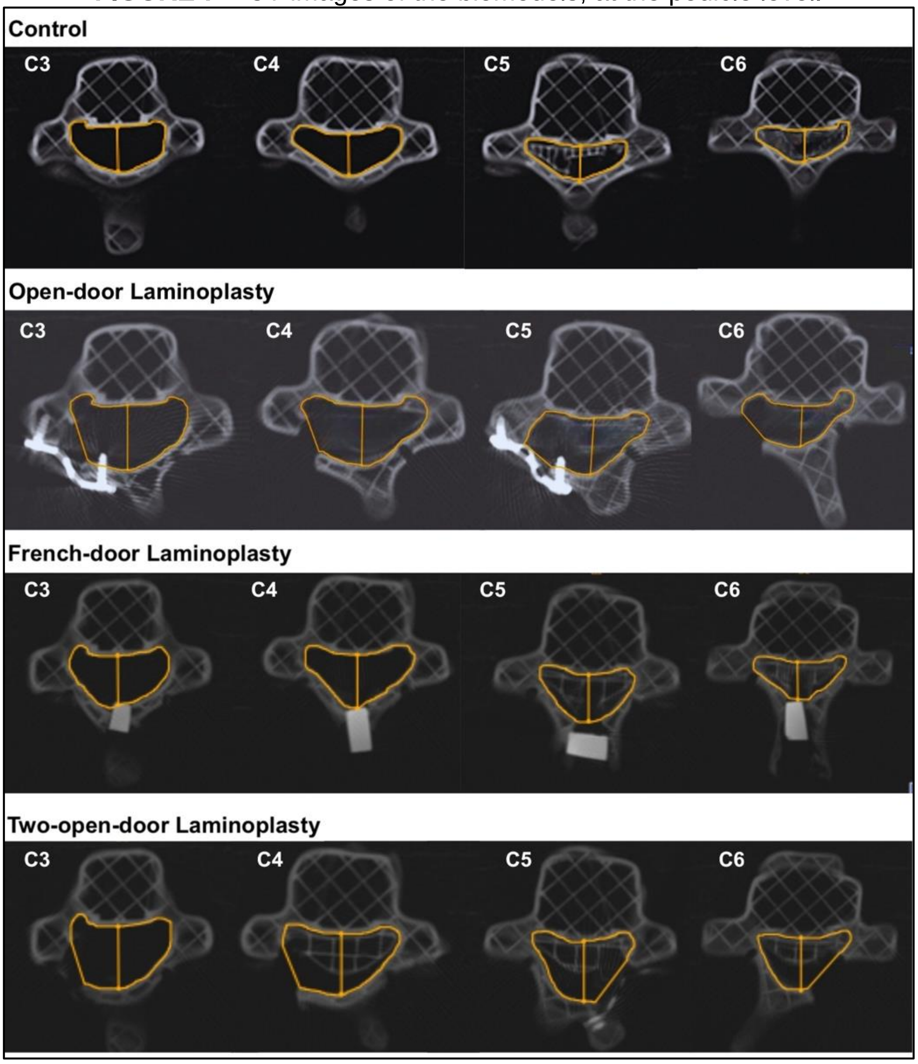
Legend: A) Posterior view. B) Hinge on the left blade. C) Hinge on the right blade.
Source: The author (2024).

FIGURE 6 – Biomodel submitted to two-open-doors laminoplasty.



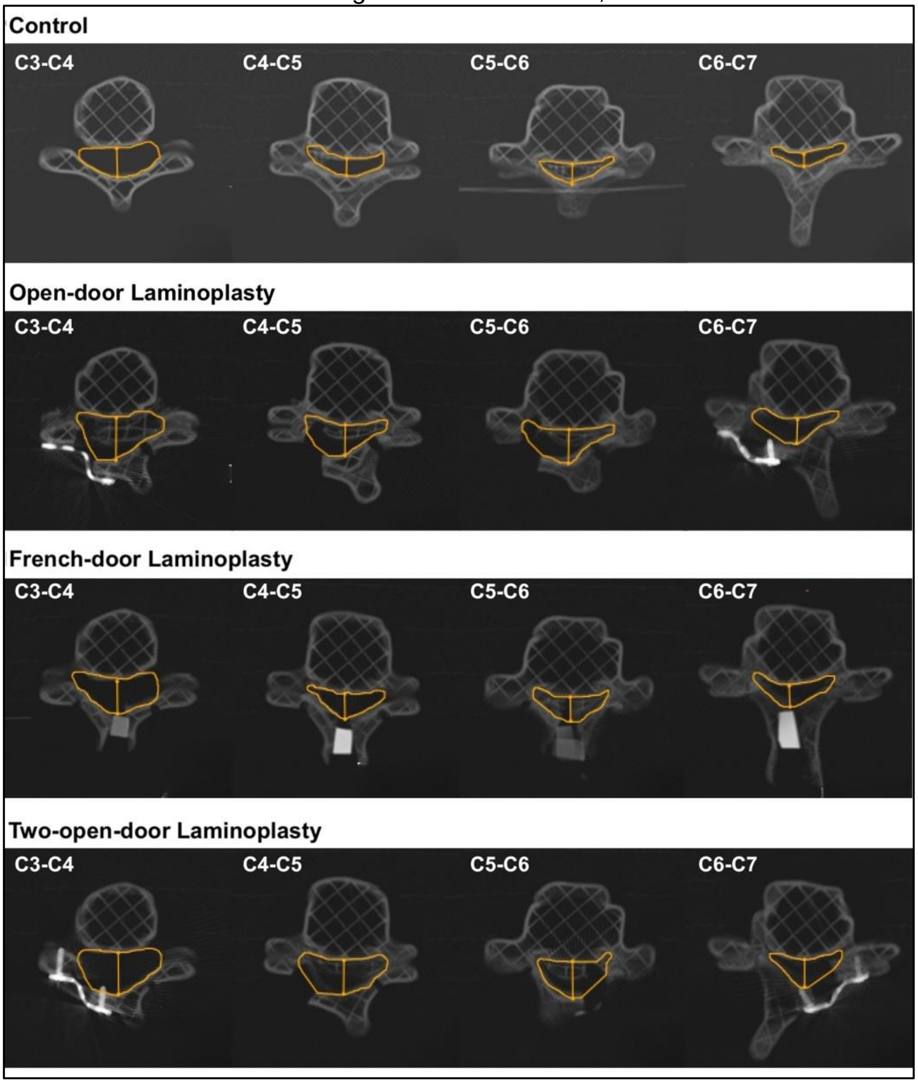
Legend: A) Posterior view. B) Left side – hinge on the C3 and C4 blades and canal opening on the C5 and C6 blades. C) Right side – canal opening in C3 and C4 and hinge in the C5 and C6 blades.
Source: The author (2024).

FIGURE 7 – CT images of the biomodels, at the pedicle level.



Source: The author (2024).

FIGURE 8 – CT images of the biomodels, at the disc level.



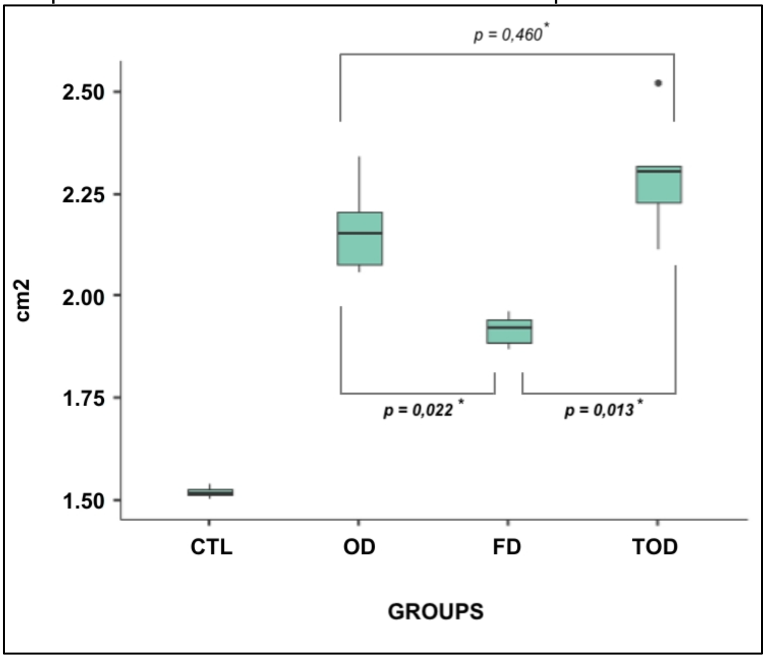
Source: The author (2024).

Comparison between the groups - the spinal canal area

Open-door laminoplasty increased the spinal canal area by 43%, French-door by 28%, and two-open-doors by 51%.

Both open-door and two-door laminoplasty allowed a significant increase in the spinal canal transversal area when compared with the French-door technique. There was no difference between the OD and TOD groups, although the canal area was larger in the second technique (Figure 9).

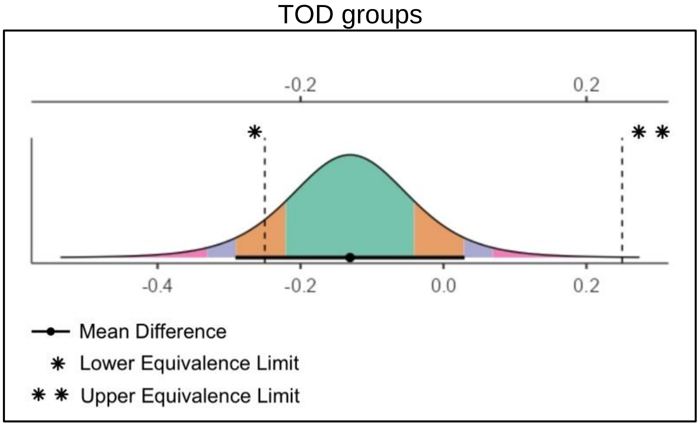
FIGURE 9 – Comparison of the cross-sectional area of the spinal canal between the groups



Source: The author (2024).
* Post-hoc Games-Howell Test

In the equivalence test between the OD and TOD groups, the techniques were observed as not equivalent, as figure 10 shows, the black bar of the X axis (the difference between the mean of the OD and TOD group), which is not fully within the defined equivalence limits.

FIGURE 10 – Equivalence test of the cross-sectional area of the vertebral canal between the OD and TOD groups



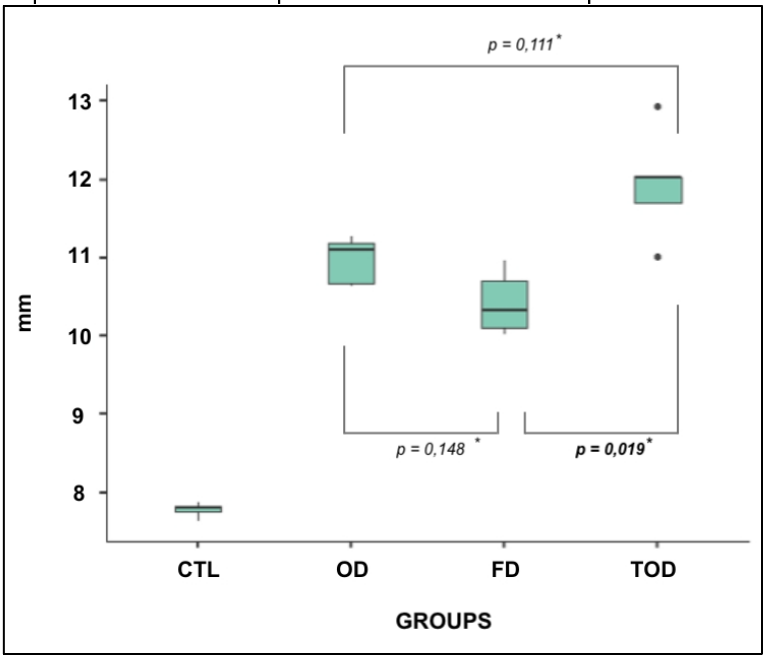
Source: The author (2024).

Comparison between the groups - diameter of the spinal canal

Open-door laminoplasty increased the diameter of the spinal canal by 41%, French-door by 34%, and two-open-doors by 54%.

The two-open-doors technique statistically increased the diameter of the spinal canal compared to the French-door. When compared with open-door laminoplasty, there was an increase of almost 1 mm, but without statistical difference. There was no statistical difference between open-door and French-door laminoplasty (Figure 11).

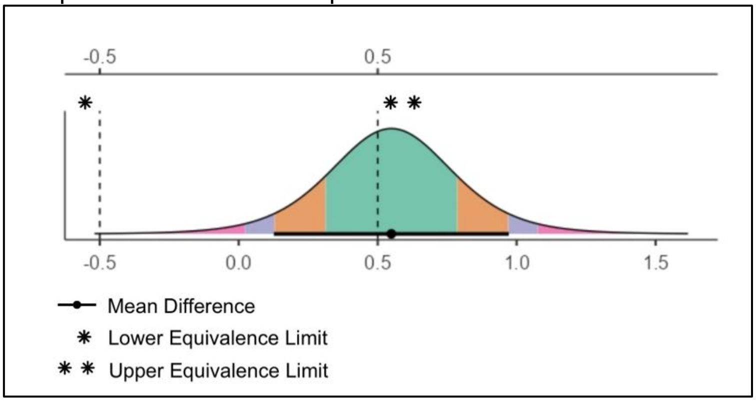
FIGURE 11 – Comparison of the anteroposterior diameter of the spinal canal between the groups



Source: The author (2024).
* Post-hoc Games-Howell Test

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

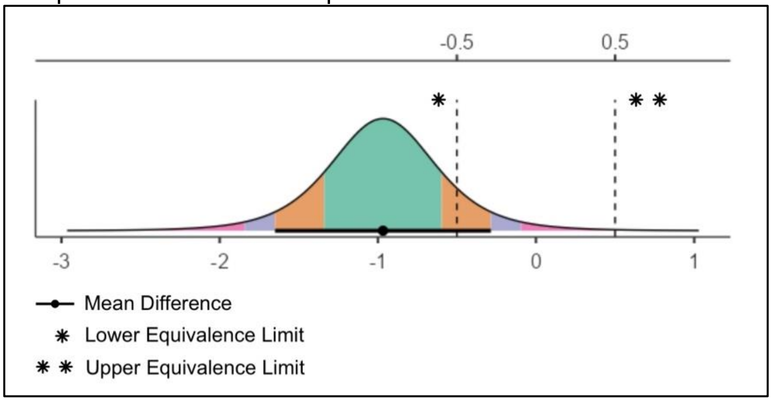
FIGURE 12 – Spinal canal diameter equivalence test between the OD and FD groups



Source: The author (2024).

In the equivalence test between the OD and TOD groups, their difference was observed as being relevant, so the techniques are not equivalent in increasing the diameter of the spinal canal. The difference in the mean of the groups was below the lower equivalence limit, so two-open-doors laminoplasty tends to further increase the diameter of the spinal canal (Figure 13).

FIGURE 13 – Spinal canal diameter equivalence test between the OD and TOD groups



Source: The author (2024).

DISCUSSION

3D printing is considered an industrial revolution and has been widely used in medicine, including even spine surgery[15–21]. It is possible to print personalized models based on CT and/or MRI scans of the patient's spine by employing this technology [22]. It is already evident that these personalized models are beneficial to surgical planning, teaching, and improvement of surgical techniques; clarifying the disease and proposing treatments to patients [23–27].

Cervical laminoplasty in biomodels is feasible and has become an alternative for improving techniques and comparing existing techniques. It inexpensive and avoids ethical conflicts when compared to using cadavers or experimental animals.

The literature is still scanty on the impact from preoperative and postoperative morphometric parameters of the spinal canal and spinal cord on the clinical outcome of patients with cervical spondylotic myelopathy [28]. But some studies show that the postoperative cross-sectional area of the spinal cord, at the site of maximal compression, is a predictor of the surgical outcome of patients – the less the spinal cord area increases after decompression, the worse is the prognosis of the patient [29,30]. It is still controversial whether increased area of the spinal canal influences the increased area of the spinal cord and, consequently, the prognosis [31].

According to Tavares et al. (2021)[32], the change in the volume of the spinal canal is considered a factor that influences postoperative recovery, while the area and diameter are not. However, regardless of the parameter, the authors consider that pre- and postoperative measurements should be considered to assess prognosis. Other authors have shown that increased diameter and area of the spinal canal are directly related to clinical improvement after decompression[31,33,34]. Therefore, based on these findings, it is beneficial to compare how much the spinal canal can increase in size from different types of laminoplasty.

This study observed that all laminoplasty techniques significantly increased the size of the spinal canal (table 1 and table 2), corroborating the findings in the literature that state 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 have shown that there was no statistical difference between some experimental groups. So, in these cases, an equivalence or non-inferiority test was applied. These tests made it possible to determine whether a treatment or procedure was equivalent or not [38].

The French-door 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 French-door and open-door laminoplasty (figure 11). Therefore, it seems that the French-door technique does not increase the vertebral canal globally and may not promote effective decompression of the lateral recess. Observing the non-inferiority or equivalence test (figure 12) when comparing this variable in the OD and FD groups, the techniques were noted as not being equivalent, i.e., the results are different and, in this case, open-door laminoplasty tends to provide a larger canal diameter than French-door. There are extremely few studies comparing the increased dimensions of the spinal canal reported from the main laminoplasty techniques. Nakashima et al. (2014)[35] conducted a randomized study and concluded that open-door laminoplasty significantly increased the diameter of the spinal canal when compared to French-door, corroborating the meta-analysis by Luo et al. (2018)[8] and contradicting the results found in this research. On the other hand, other meta-analyses compared the dimensions of the spinal canal by open-door and French-door laminoplasty and there was no statistical difference between them [3,36].

Two-open-doors laminoplasty was superior to French-door laminoplasty both in terms of area (figure 9) and diameter (figure 11). When comparing it with the open-door, it increased the area by 8% and the diameter by 13%, but with no statistical difference in both variables (figure 9 and 11). When studying the non-inferiority or equivalence test between the OD and TOD groups regarding area (figure 10) and diameter (figure 13), the two techniques were noted as not being equivalent. Therefore, they are not the same in terms of providing increased dimensions of the spinal canal. So, there is a tendency for two-open-doors laminoplasty to provide larger dimensions of the spinal canal, in vitro. Probably, by increasing the N of the sample of these groups, it is possible to achieve some statistically significant differences among them.

There are no randomized studies or meta-analyses comparing two-open-doors technique to other techniques, both in terms of postoperative imaging findings and clinical parameters, as it is a newer technique and not yet widespread worldwide. That is because it statistically provides increased dimensions as open-door laminoplasty. Two-open-doors can be considered an applicable technique in cases of spinal canal stenosis and CSM. And, as described by its creator, this technique allows effective decompression of the spinal canal and clinical improvement of patients. Additionally, they reported that the great differential of this technique is that when performing foraminotomy in C4-C5 bilaterally, there is decreased risk of neuropraxia of the C5 root [10].

Both open-door and two-door 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 regarding surgical data such as the duration of the procedure, amount of bleeding, intraoperative complications, and the clinical outcome of the patients; as these factors can define which one is more appropriate.

Therefore, based on these findings, French-door laminoplasty seems to expand the spinal canal less than the other techniques. The open-door and two-open-doors techniques enlarge the spinal canal similarly, with a tendency to allow for larger dimensions of the canal.

Both open-door and two-door laminoplasty are suitable for fully decompressing the cervical spinal canal, and to define which techniques should be chosen is 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 regarding surgical data such as the duration of the procedure, amount of bleeding, intraoperative complications, and the clinical outcome of the patients, as these factors can define which one is more appropriate.

CONCLUSION

The present study allows us to conclude that the open-door technique expands the cross-sectional area of the vertebral canal more when compared to the French-door laminoplasty and there is no significant difference in diameter, and two-open-doors laminoplasty increases the dimensions of the spinal canal more than French-door and there is a tendency for the superiority of open-door laminoplasty.

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