CUSTOMIZED BIOMODEL OF THE CERVICAL SPINE FOR LABORATORY LAMINOPLASTY TRAINING

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Original Article

CUSTOMIZED BIOMODEL OF THE CERVICAL SPINE FOR LABORATORY LAMINOPLASTY TRAINING

BIOMODELO PERSONALIZADO DA COLUNA CERVICAL PARA TREINAMENTO DE LAMINOPLASTIA EM LABORATÓRIO

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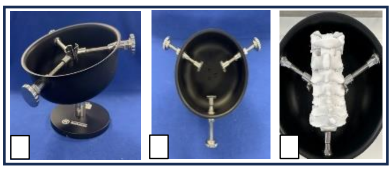
Image



The rigid compartment: A) lateral view; B) superior view;
C) biomodel fixed in the compartment

Central Message
There are many ways to use 3DP in spine surgeries. The education of patients and health professionals is necessary in surgical planning and intraoperative applications, such as the making of customized guides to introduction screws and the elaboration of specific implants for patients. So, the use of a biomodel of the cervical spine for surgical training of laminoplasty is appropriated.

Perspective
Cervical laminoplasty is already established as one of the treatment options for spinal canal stenosis and spondylotic myelopathy. It is a challenging procedure for spine surgeons in training, due to anatomical details that can be distorted by spinal degeneration and technical details such as the correct way to dribble the blades. That's why laboratory training becomes a necessary practice.

ABSTRACT - *Background*: Additive manufacturing has been developed as a promising innovation for many areas, including medicine. There are many ways to use it in spine surgeries and the use of biomodels in the laboratory to study and training of cervical laminoplasty has not yet been reported in the literature. ***Objective*:** To evaluate the use of a biomodel of the cervical spine for surgical training of laminoplasty. ***Method*:** This is an experimental study. Were printed 10 identical biomodels of the cervical spine based on CT and MRI scans of a patient diagnosed with spondylotic cervical myelopathy. The additive manufacturing method used was fused deposition modeling and the raw material chosen was polyatic acid. The sample was divided into 2 groups: control (n = 5; the biomodels were submitted to CT scanning) and open-door (n = 5; the biomodels were submitted to open-door laminoplasty and postoperative CT). The area and anteroposterior diameter of the vertebral canal were measured on CT scans. ***Result*:** The time for printing each piece was 12 h. During the surgical procedure, the support of the biomodels was sufficient to keep them static. The use of drill was feasible; however, continuous irrigation was mandatory to prevents the heating of the plastic material. The raw material used allowed the CT study of the biomodels. It was observed an increase the dimensions of the vertebral canal in 24,80% (0.62 cm^2) in the area and 24,88% (3.12 mm) in the anteroposterior diameter. ***Conclusion*:** The cervical spine biomodels can be used for laminoplasty training, even using thermosensitive material such as PLA. The use of continuous irrigation is essential during the use of the drill.
KEYWORDS – Cervical. Laminoplasty. Three-dimensional printing. Spondylotic myelopathy.

RESUMO – ***Introdução***: A manufatura aditiva tem se desenvolvido como inovação promissora para muitas áreas, incluindo a medicina. Existem muitas maneiras de utilizá-la em operações de coluna, e o uso de biomodelos em laboratório para estudo e treinamento de laminoplastia cervical ainda não foi relatado na literatura. ***Objetivo***: Avaliar a utilização de um biomodelo da coluna cervical para treinamento cirúrgico de laminoplastia. ***Método***: Trata-se de estudo experimental. Foram impressos 10 biomodelos idênticos da coluna cervical baseados em exames de tomografia computadorizada e ressonância magnética de um paciente com diagnóstico de mielopatia cervical espondilótica. O método de manufatura aditiva utilizado foi a modelagem por deposição fundida e a matéria-prima escolhida foi o ácido poliático. A amostra foi distribuída em 2 grupos: controle (n = 5; os biomodelos foram submetidos à tomografia computadorizada) e *open-door* (n = 5; os biomodelos foram submetidos à laminoplastia *open-door* e tomografia pós-operatória). A área e o diâmetro anteroposterior do canal vertebral foram medidos na tomografia. ***Resultado***: O tempo de impressão de cada peça foi de 12 h. Durante o procedimento, o suporte utilizado para fixar o biomodelo foi suficiente para mantê-los estáticos. O uso de broca mostrou-se viável; porém, a irrigação contínua foi mandatória para evitar o aquecimento do material plástico. A matéria-prima utilizada permitiu o estudo tomográfico dos biomodelos. Observou-se aumento das dimensões do canal vertebral em 24,80% (0,62 cm^2) na área e 24,88% (3,12 mm) no diâmetro anteroposterior. ***Conclusão***: Os biomodelos da coluna cervical podem ser utilizados para o treinamento de laminoplastias, mesmo utilizando material termossensível. O uso de irrigação contínua é essencial durante o uso da broca.

PALAVRAS-CHAVE – Cervical. Laminoplastia. Impressão tridimensional. Mielopatia espondilótica.

INTRODUCTION

Additive manufacturing, or three-dimensional printing (3DP), has been developed as a promising innovation for many areas, including medicine.[1–3] The first research involving this technology dates to the late 1970s, but it was in 1984 that physical engineer Charles Hull invented and patented the first 3DP device.[2,4]

There are many ways to use 3DP in spine surgeries. The education of patients and health professionals, in surgical planning and intraoperative applications such as the making of customized guides to introduction screws and the elaboration of specific implants for patients.[2,5,6]

The first spinal biomodel was developed by Paul D'Urso et al.[7] to study five complex cases of spinal deformity and enabled more assertive surgical planning and facilitated patient communication and education about the disease and proposed treatment. Later, other authors were able to apply the biomodels as surgical planning and patient education.[5,8,9]

The use in the laboratory for the study and training surgical techniques of procedures involving the cervical spine has not yet been reported in the literature. In addition, it is necessary to ascertain whether the use of biomodel is feasible, as the type of raw material used may undergo modifications with the use of metal drills or fixing brackets.

The objective of this paper was to evaluate the use of a biomodel of the cervical spine for surgical training of laminoplasty.

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.

This is an experimental study carried out at the Laboratory of Surgical Techniques of the Mackenzie Evangelical College of Paraná, Curitiba, PR. Brazil. The first step was to identify a patient diagnosed with spinal canal stenosis of degenerative etiology causing spondylotic cervical myelopathy. To choose this index case, a search was made in the database of patients who were being treated at the Outpatient Clinic of the Department of Neurosurgery of the Mackenzie Evangelical University Hospital, Curitiba, PR, Brazil, and who were planning surgery. The selected patient agreed to the Informed Consent Form and underwent a new CT and MRI examination of the cervical spine.

To make the biomodel, initially the CT and MRI images of the patient's cervical spine, in DICOM format, were imported into the 3D Slicer software. The CT and MRI (T2-weighted sequence) images were superimposed on the sagittal axis. Then, the images were imported into the Cure software and the prototype was printed.

The additive manufacturing method used was fused deposition modeling (FDM) and the raw material chosen was polyatic acid (PLA). Printing was done on the Creatlity Ender 5 printer. Ten identical biomodels were printed and divided into 2 groups: control group – CON (n = 05) with specimens not submitted to any surgical procedure, only to computed tomography, and open-door laminoplasty group – OD (n = 05) with specimens submitted to cervical laminoplasty using the open-door technique.

Description of procedures

The biomodel was placed in a rigid compartment and fixed with the aid of 3 metal clips (Figure 1). The surgical procedure performed was open-door laminoplasty.

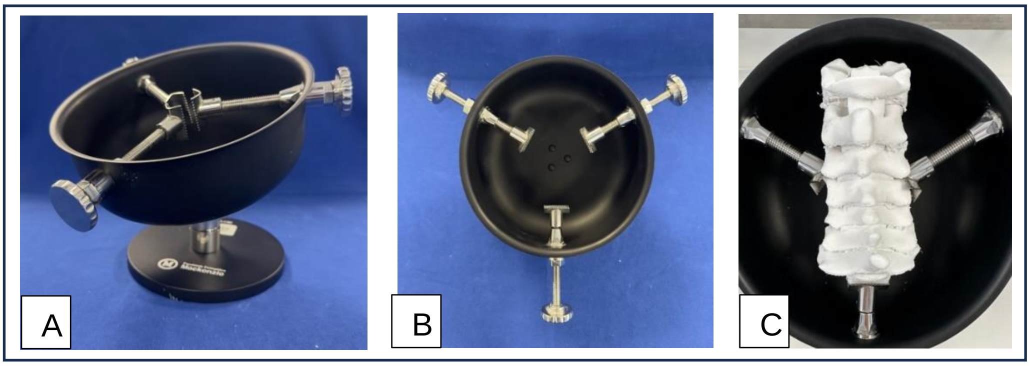


FIGURE 1 – The rigid compartment: A) lateral view; B) superior view; C) biomodel fixed in the compartment.
Source: The authors (2024)

The procedures were performed with a 3.0x magnification surgical magnifier (Surgitel brand) with a 75,000 lux photophore attached and electric drill (BienAir brand / OsseoDuo model), configured at a speed of 20,000 revolutions per minute (rpm) and with continuous irrigation. Circular, cutting, 2 mm and 3 mm cutters were used.

The procedure was initiated by resection of the ligament between C2-C3 and C6-C7, using 2-mm drills. Subsequently, laminotomy was performed with 3-mm C3, C4, C5 and C6 drills on the right side, and partial osteotomy of the laminae on the contralateral side to elaborate the hinge. The channel was opened, and titanium plates were fixed between the laminae and the lateral masses with screws (Figure 2).

FIGURE 2 – Open-door laminoplasty in the biomodel.
Source: The authors (2024)

Postoperative CT

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

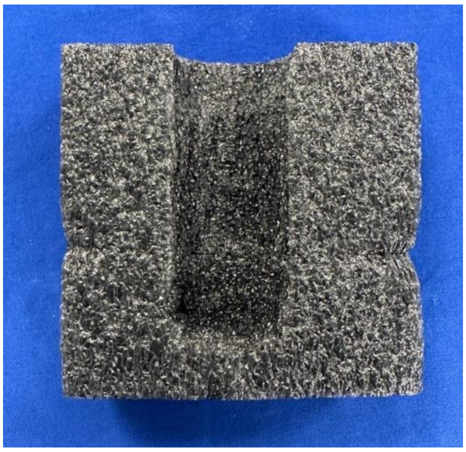


FIGURE 3 – The polyethylene foam support.
Source: The authors (2024)

All studies were conducted using a single protocol. Contiguous 1.25 mm scans of the 3D models were acquired in 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 by means of 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 have magnification capabilities and an electronic caliper, allowing for accurate and reproducible measurements.

All measurements were performed only once, by 3 different radiologists (M1, M2, M3) and recorded in the study protocol.

The measurements obtained from the vertebral canal were the anteroposterior diameter and the area at the levels of the C3, C4, C5 and C6 pedicles in the axial axis.

Statistical analysis

The distribution of normality was verified by the Shapiro-Wilk test and the results were reported using the mean (± standard deviation). Next, the parametric Student's t-test was applied. Homogeneity validations with the Levene test were checked for homogeneity and, if necessary, Welch's correction was applied. For all tests, values of $p<0.05$ were considered sufficient to reject the null hypothesis and consider the result statistically significant. All statistical analyses, construction of graphs and tables were performed using the statistical software JAMOVI version 2.5.0, which is based on the R language.[10,11]

RESULT

The approximate time for printing each piece was 12 h. To avoid possible crashes or failures during printing, the computer and printer were connected to a UPS. During the surgical procedure, the support of the biomodels was sufficient to keep them static.

The use of drill was feasible; however, the use of continuous irrigation was mandatory. This prevents the heating of the plastic material and consequently deformity of the biomodel. The raw material used allowed the CT study of the biomodels.

It was observed that there was an increase the dimensions of the vertebral canal in 24,80% (0.62 cm^2) in the area (Table 1) and 24,88% (3.12 mm) in the anteroposterior diameter (Table 2).

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

	Control (n = 5)	**Open-door (n = 5)**	
C3	2.26 (± 0.0493)	2.81 (± 0.142)	< .001
C4	2.04 (± 0.0760)	2.66 (± 0.172)	< .001
C5	1.62 (± 0.0403)	2.23 (± 0.332)	0.014 *
C6	1.59 (± 0.0865)	2.29 (± 0.190)	< .001
Overall	1.88 (± 0.0326)	2.50 (± 0.159)	< .001 *

***=**Welch's correction
Source: The authors (2024).

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

	Control (n = 5)	**Open-door (n = 5)**	
C3	11.23 (± 0.1404)	14.25 (± 0.929)	< .001
C4	9.90 (± 0.2193)	12.93 (± 0.637)	< .001
C5	8.56 (± 0.1655)	11.39 (± 0.872)	< .001
C6	7.98 (± 0.3400)	11.58 (± 0.708)	< .001
Overall	9.42 (± 0.0916)	12.54 (± 0.382)	< .001 *

***=**Welch's correction
Source: The authors (2024).

DISCUSSION

Biomodels have already been applied in the education of residents in spinal surgeries, especially for the introduction of pedicle screws and the study of the patient's anatomy in complex cases.[12–15] However, there is not even a study described in the literature on the use of biomodels for surgical technique training in the cervical spine.

Cervical laminoplasty is already established as one of the treatment options for spinal canal stenosis and spondylotic myelopathy.[16–18] It is a challenging procedure for spine surgeons in training, due to anatomical details that can be distorted by spinal degeneration and technical details such as the correct way to dribble the blades. That's why laboratory training becomes a necessary practice.

Medium-sized experimental animals and human corpses can be used for this training, but there are ethical and financial issues that make the process bureaucratic and difficult, especially in developing countries.[19] Therefore, the 3D printing of personalized anatomical models, simulating an existing disease in the patient, is an interesting alternative for this purpose.[20]

The construction of the biomodel based on the superimposition of the CT and MRI images is a fundamental point to allow the impression of the details of the intervertebral disc and ligamentum flavum. This allowed the actual simulation of spinal canal stenosis, as seen in the CT images obtained in the control group.

Among the various modalities of 3D printing, FDM technology is one of the most widely used techniques. One of the advantages is its relative simplicity and low cost compared to the other technologies, making it accessible for educational use. However, it has some limitations, such as the need for supports for complex structures and the low melting point of the material used.[2,20] In fact, this was the greatest fear during the procedures of this study due to the use of drills cutters and the high rotation. But this was easily circumvented by keeping the engine at 20,000 rpm and continuous irrigation with water at room temperature (approximately 22 ºC). Another factor that was taken into account in the choice of PLA is that this plastic is radiopaque, making it possible to study the results and effectiveness of the experimental surgical procedure by tomography.

Several studies report the benefit of 3D printing in spine surgery. The 3D model can make the placement of pedicle screws, by the freehand technique, safer and with acceptable accuracy, thus reducing operating time, estimating blood loss, and reducing intraoperative fluoroscopy during surgery.[13] A meta-analysis conducted by Katiyar et al.[12] proven improvement in pedicle screw placement accuracy using custom guides with additive manufacturing. This same review showed that studies that used 3D models of the spine in preoperative planning considered it useful and observed an increase in the accuracy rate of screw placement of 89.9%. Lu et al.[21] have developed guidelines for the introduction of cervical pedicle screws and have shown that the method significantly reduces the duration of the operation and radiation exposure for members of the surgical team. Feng et al.[14], in a randomized study with 6 patients, evaluated the positioning of lateral mass screws implanted with the aid of guides printed by additive manufacturing and concluded that these screws were better positioned than those implanted without guides. Sugawara et al.[15] had successful in 3D printing guides for C1 and C2 screw implants. There is also applicability of customized guides for percutaneous thoracolumbar screw implantation and minimally invasive procedures.[22–26]

In the results of this research, it can be observed that the measurement of the dimensions of the vertebral canal increased statistically at all levels, suggesting that the training of laminoplasty in a biomodel is feasible. This corroborates the importance of additive manufacturing in the field of spine surgery and medical education. This study opens the door to the application of further research using other surgical techniques for the training and improvement of spine surgeons, such as instrumentation of the posterior cervical spine (lateral mass screws, pedicle screws of C2 and C7, interlaminar of C2, transarticular C1-C2) and study of other types of laminoplasty.

CONCLUSION

Cervical spine biomodels can be used for laminoplasty training, even using thermosensitive material such as PLA. The use of continuous irrigation is essential during the use of the drill.

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