

VALIDATION OF 3D SIMULATOR FOR SPINE ENDOSCOPY TRAINING

VALIDAÇÃO DE SIMULADOR 3D PARA TREINAMENTO DE ENDOSCOPIA DA COLUNA

VALIDACIÓN DE SIMULADOR 3D PARA ENTRENAMIENTO EN ENDOSCOPIA DE LA COLUMNA

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ABSTRACT

Introduction: Endoscopic spine surgery has become increasingly well-known, safe, and a preferred option for both patients and professionals seeking minimally invasive procedures. Thus, there is a progressive search for the improvement of surgical techniques through training on human or animal cadavers and synthetic or virtual simulators. Considering the high cost of these resources, there is a need for accessible training that can be repeated countless times, which would be possible in a three-dimensionally printed lumbar spine simulator, as well as the endoscope, allowing training inside and outside hospitals and laboratories. **Objective:** creation and validation of a dry simulator made in a 3D printer for lumbar spine surgeries, with the aim of facilitating the training of the surgical technique. **Methods:** descriptive study on the use of 3D printing of the lumbar spine model as a simulator. **Results:** at the end of the study, it was possible to develop an endoscopic lumbar spine surgery simulator costing approximately R\$100, as well as its face validation with questionnaires (Likert scale) applied to 10 surgeons in the area. **Conclusion:** We conclude that it is possible to develop and validate a low-budget, printed endoscopic lumbar spine surgery simulator, allowing greater access to resident physicians in training, as well as spine surgeons. **Level of Evidence IV; Expert Opinion.**

Keywords: Education, Medical; Simulation Training; Endoscopy; Spine.

RESUMO

Introdução: A cirurgia endoscópica de coluna tem se tornado cada vez mais conhecida, segura e opção de escolha tanto dos pacientes, quanto dos profissionais, que buscam por procedimentos minimamente invasivos. Assim, procura-se progressivamente o aperfeiçoamento das técnicas cirúrgicas através do treinamento em cadáveres humanos ou animais e simuladores sintéticos ou virtuais. Considerando o alto custo destes recursos citados, destaca-se a necessidade de um treinamento acessível e passível de inúmeras repetições, o que seria possível em um simulador de coluna lombar tridimensionalmente impresso, assim como o endoscópio, permitindo treinamentos dentro e fora de hospitais e laboratórios. **Objetivo:** criação e validação de um simulador seco feito em impressora 3D para cirurgias de coluna lombar, com o intuito de facilitar o treinamento da técnica cirúrgica. **Métodos:** estudo descritivo sobre o uso de impressão 3D do modelo de coluna lombar como simulador. **Resultados:** ao final do estudo, foi possível desenvolver um simulador de cirurgia endoscópica da coluna lombar de aproximadamente 100 reais, assim como sua validação de face com questionários (escala Likert) aplicados com 10 cirurgiões da área. **Conclusão:** concluímos que é possível o desenvolvimento e validação de um simulador de cirurgia endoscópica da coluna lombar, de forma impressa, de baixo orçamento, permitindo um maior acesso aos médicos residentes em treinamento, assim como cirurgiões de coluna. **Nível de Evidência IV; Opinião do Especialista.**

Descritores: Educação Médica; Treinamento por Simulação; Endoscopia; Coluna Vertebral.

RESUMEN

Introducción: La cirugía endoscópica de columna se ha vuelto cada vez más conocida, segura y una opción de elección tanto para pacientes como para profesionales que buscan procedimientos mínimamente invasivos. Así, buscamos progresivamente mejorar las técnicas quirúrgicas mediante el entrenamiento en cadáveres humanos o animales y simuladores sintéticos o virtuales. Considerando el alto costo de estos recursos, se destaca la necesidad de un entrenamiento accesible y que pueda repetirse innumerables veces, lo que sería posible en un simulador de columna lumbar impreso en tres dimensiones, así como el endoscopio, permitiendo el entrenamiento dentro y fuera de hospitales y laboratorios. **Objetivo:** creación y validación de un simulador seco realizado en una impresora 3D para cirugías de columna lumbar, con el objetivo de facilitar el entrenamiento de la técnica quirúrgica. **Métodos:** estudio descriptivo sobre el uso de la impresión 3D del modelo de columna lumbar como simulador. **Resultados:** al final del estudio, fue posible desarrollar un simulador de cirugía endoscópica de columna lumbar con un costo aproximado de 100 reales, así como su validación facial con cuestionarios (escala Likert) aplicados a 10 cirujanos del área. **Conclusión:** concluimos que es posible desarrollar y validar un simulador de cirugía endoscópica de columna lumbar impreso, de bajo presupuesto, permitiendo un mayor acceso a médicos residentes en formación, así como a cirujanos de columna. **Nivel de Evidencia IV; Opinión de Expertos.**

Descriptores: Educación Médica; Entrenamiento Simulado; Endoscopia; Columna Vertebral.

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INTRODUCTION

Lumbar pain due to a herniated disc affects young individuals and brings limiting impairments to work activities.¹ When it does not improve with conservative treatment, surgery presents itself as an alternative.²

With technological advancement, endoscopic spine surgery has become increasingly safe and widespread, with good results and rapid recovery compared to conventional open surgery.³⁻⁶

Given the demand for the video-assisted technique, its improvement is necessary to achieve adequate proficiency, with the least number of complications inherent to the beginning of the learning curve. Training can be conducted with simulations on human or animal cadavers and on synthetic or virtual models. Considering the high cost, ethical restrictions, and limited availability of cadavers, there is a need for more accessible training that allows repetitions.⁷

In this scenario, synthetic models stand out, presenting accessibility, low cost, and the ability to perform an initial stage of training and adaptation, especially triangulation movements, spatial location, and handling of long instruments, without the anatomical references of open surgeries.⁸

3D printing of models is in growing evolution, justified by easy construction and low cost. It presents similar efficiency to virtual reality, mimicking visual and spatial characteristics, without the logistical demand for storage. It provides feedback on its use, maintaining objectives to reduce the number of movements to perform a task and better control of surgical time.^{8,9}

For the proper use of a simulator in training and teaching, in addition to ease of construction, it needs to attract the participant's interest. In light of this, a face validation assesses its realism. Informally, it is possible to determine whether the device in question can represent what it proposes, ensuring feedback on its use.^{10,11}

In this context, this study aims to describe the creation of a low-cost, synthetic 3D printed lumbar endoscopic surgery simulator that is easy to reproduce and handle, as well as to validate its use with specialist doctors.

MATERIAL AND METHOD

This is a cross-sectional experimental study, approved by the Research Ethics Committee of a teaching hospital, under number 81334524.2.0000.5225.

A synthetic simulator of the lumbar spine was developed for training in endoscopy using 3D printing. The model consists of its training box containing the lumbar spine model with its intervertebral disc and the endoscope.

The programs used: "Invesalius 3" for image reconstruction; "Meshmixer 3.5" for model correction and adjustments; "Fusion 3D" for design.

For printing, the printer "Ender 3" was used with polylactic acid (PLA) filament for the spine and endoscope models; type II imported rubber for the mold, non-stick paste and catalyst for the silicone mold of the intervertebral disc; flexible polyurethane foam density 28 dyed with red gouache paint, simulating the adjacent musculature; ethylene vinyl acetate (EVA) paper for the yellow ligament and skin; nylon clamp for the endoscope; and an endoscopic inspection camera of the probe type with LED light and flexible cable (brand Bmax).

For the analysis of the model and opinions on its use, ten orthopedic doctors with experience in video surgery were included, who could not be selected randomly, as they made up the entirety of the available population for the study.

The evaluations took place over 04 consecutive weeks, from October 1 to 30, 2024. The criterion for exclusion was the non-signing of the consent form.

All participants were instructed about the operation of the models and the procedure through a five-minute educational video. The video demonstrated the manipulation of endoscopic forceps, anatomical concepts, and endoscopic procedures. They were positioned in front of the simulator, placed on a Table 1 meter high with a frontal view of the image projection screen, and instructed

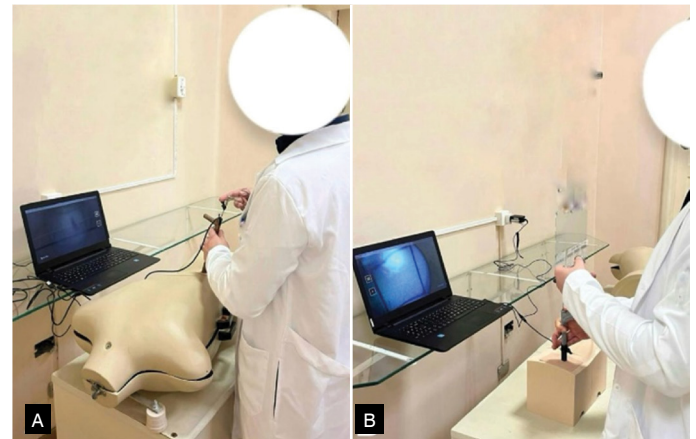
to start the diagnostic endoscopy procedure. The same procedure was performed on the simulator developed in this work and on the mannequin simulator previously developed by Nunes et al.⁷

The instruments were inserted into the simulator through the paramedian portal dorsal to the level of L5-S1. The participant was asked to locate themselves in space, identify the structures and the markings on the yellow ligament, touching each line of the drawn square, and identify the facet joint between L5-S1 (Figure 1). They should also perform the flavectomy to expose and touch the intervertebral disc.

All procedures were supervised, and participants were instructed to stop the activity if they considered the result obtained to be satisfactory or when the time limit of 5 minutes was reached.

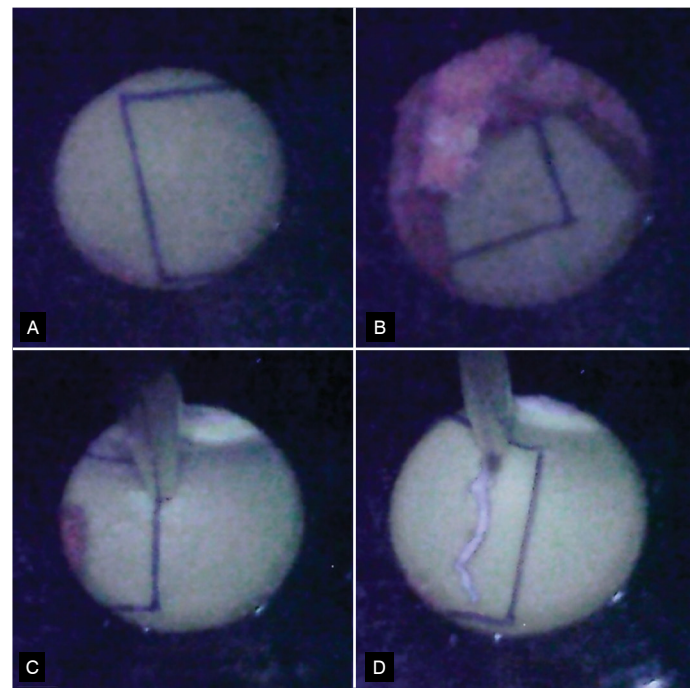
The captured images were transmitted to a computer via USB and recorded in video using Debut Video Capture Software.Ink®. (Figure 2)

In the end, the participants answered a questionnaire, containing: general demographic data (name, gender, age, and time of



Source: Author.

Figure 1. A) Participant performing tasks on the mannequin of Nunes et al.⁷ B) Participant performing tasks on the 3D simulator developed in this study.



Source: Author.

Figure 2. A) Visualization of the markings on the EVA by the camera. B) Visualization of the EVA and the dyed foam. C) Visualization of the surgical instruments by the camera. D) Cut made on the EVA.

experience in video surgery) and an adapted Likert Scale, with a questionnaire addressing the individuals' impressions about the simulator and its applicability in medical education. Ten questions were formulated to be rated on a spectrum of five descriptors between "strongly disagree" and "strongly agree." The questions were:

1. Are the external model and the 3D column capable of assisting in the recognition of anatomical structures in a real surgery?
2. Is the simulator useful in training novice surgeons in the technique of lumbar endoscopy?
3. Does the 3D developed endoscope have a similar appearance to the real endoscope used in surgeries?
4. Are the images generated by the 3D developed endoscope similar to those found during a real surgery?
5. Is the simulator capable of replacing one or more steps of the training conducted in real surgeries?
6. Do you believe that reviewing the surgical steps with this simulator immediately before the surgery can help reduce the number of errors during the operation?
7. Do you consider that the weight of the 3D developed endoscope is similar to that of the real endoscope?
8. Do you believe that using this simulator can encourage undergraduate students to become interested in endoscopic spine surgery?
9. Do you consider that the 3D simulator has greater realism compared to the simulator previously published by Nunes et al., which was assembled from various commercially available materials?
10. Do you believe that this simulator is useful for training surgical maneuvers that can be transferred to real surgery?

Quantitative variables and scores were represented by the median and interquartile range. A significance level of 5% was considered. All analyses were performed using Microsoft Excel® (2013) and R® statistical computing software, version 3.4.4 (2018).

The data were analyzed using IBM SPSS Statistics v.29.0.2 software. The results of quantitative variables were described by mean, standard deviation, median, minimum, and maximum. Categorical variables were described by frequency and percentage. For the analysis of the association between surgeon profile variables and questionnaire responses, a score was defined as the sum of points from the 10 questions. The score ranges from 10 to 40, and the higher the score, the better the surgeon's evaluation of the simulator. For the correlation analysis between the score and other quantitative variables, Spearman correlation coefficients were estimated. P values <0.05 indicated statistical significance.

RESULTS

It was possible to develop a lumbar endoscopy simulator for approximately R\$100.00. Table 1 presents the materials used with their values in reais (R\$). Figures 3 and 12 show the final model. Figure 2 shows the image displayed on the screen during the use of the simulator.

Model

A model of the back was created based on the model by Nunes et al. (Figure 4),⁷ with a top opening of 30 mm in diameter, serving as a monoportal for the interlaminar technique, for the entry of the endoscope, following the measurements in Figure 5.⁷ Above the top opening, cut EVA (8 x 10 cm) was applied to simulate the skin.

Table 1. List of materials used and their respective values.

Material	Value
Material printed in PLA	
3D column simulator	R\$50.00
3D endoscope simulator	
Nylon clamp	R\$1.00
Yellow ligament	
EVA	R\$4.00
Camera	R\$50.00
Gouache paint	R\$5.00
Foam	R\$30.00
Total	R\$140.00



Source: Author.

Figure 3. Final model.



Source: Image provided by Nunes.

Figure 4. Synthetic model by Nunes et al.⁷

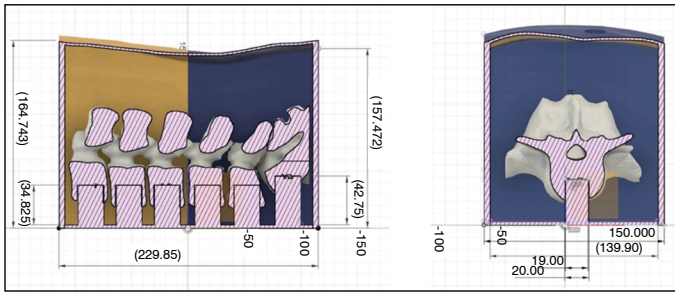
The creation of the 3D model of the spine was based on a CT scan of a mature lumbar spine skeleton, over 18 years old, considered normal, in which there was no exposure, patient identification, or possibility of tracking. Measurements were used to produce synthetic lumbar vertebrae from L1 to S1 in PLA and attached to a base measuring 229.85 mm in length and 139.90 mm in width, added to the lid, the same back mentioned, with semicircles cut on the side with a diameter of 10 mm to facilitate the disassembly of the pieces. (Figures 5 and 6)

Intervertebral disc

A circular mold was also made and printed in PLA filament with the measurements from Figure 7, using Imported Type II Mold Rubber and Catalyst.

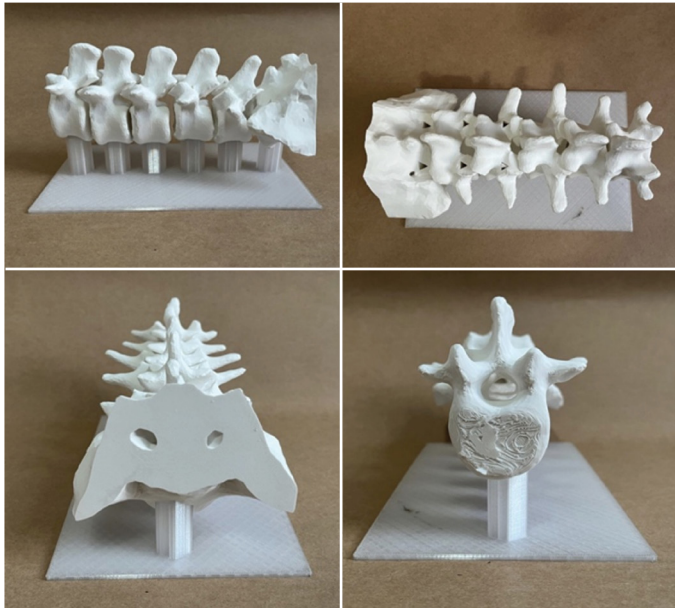
Yellow ligament

Yellow EVA paper was used, cut out, and a square measuring 10



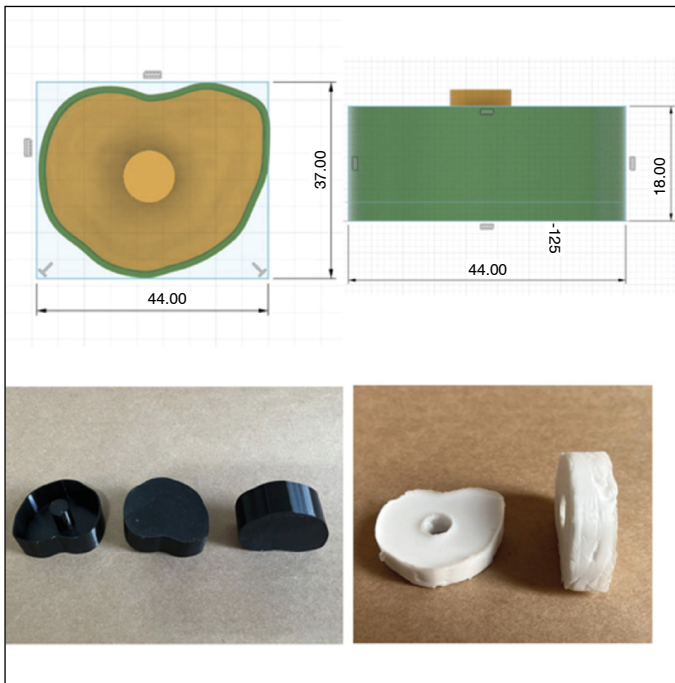
Source: Author.

Figure 5. Measurements used for creating the 3D model.



Source: Author.

Figure 6. Printed model of the column.



Source: Author.

Figure 7. The upper part contains the measurements for printing. The lower part shows the printed molds and the rubber disc.

x 8.5 cm was drawn, delimiting the space between two blades of the L5-S1 segment, just like in the simulator by Nunes et al.⁷ (Figure 8)

Endoscope

The conventional endoscope that is easy to print was chosen. Designed and printed measuring 259.54 mm in length, 67.24 mm in height, 12.50 mm in diameter, with its end cut at an angle of 25 degrees. For the entry of working instruments, its interior has an opening of 4.2 mm in diameter (Figure 9). Printed in 2 halves, longitudinally, separated to allow fitting at its end for an endoscopic inspection camera of the probe type with LED light and flexible cable, whose image is mirrored on a computer, tablet, or mobile device via USB. Attached to the camera, the endoscope is closed with a nylon clamp. Its measurements for printing were proportional to the actual endoscope. The working sleeve was also designed and printed proportionally to the endoscope, allowing its entry and exit, with diameters of 16 and 13 mm, external and internal, respectively. The endoscope and the working sleeve together weigh 47 grams. (Figures 10, 11 and 12)

The total cost of materials used was R\$140.00 (approximately 28 dollars).

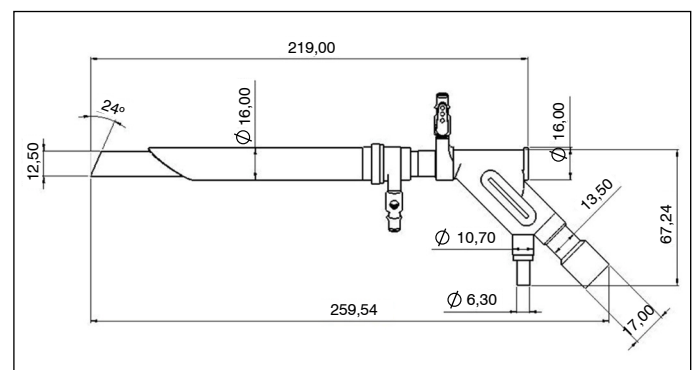
The sample in the study consisted of 10 orthopedic surgeons with experience in video orthopedic surgery, all male. The average age was 40 years. The average time of experience in video surgery was 10 years. (Table 2)

From the questionnaire, the responses with the highest agreement among participants were about the simulator serving as an incentive for graduates and being a good training source. However, the greatest disagreement lies in the device's ability to replace the training steps of real surgery. Meanwhile, the topic with the highest



Source: Author.

Figure 8. EVA simulating the yellow ligament.



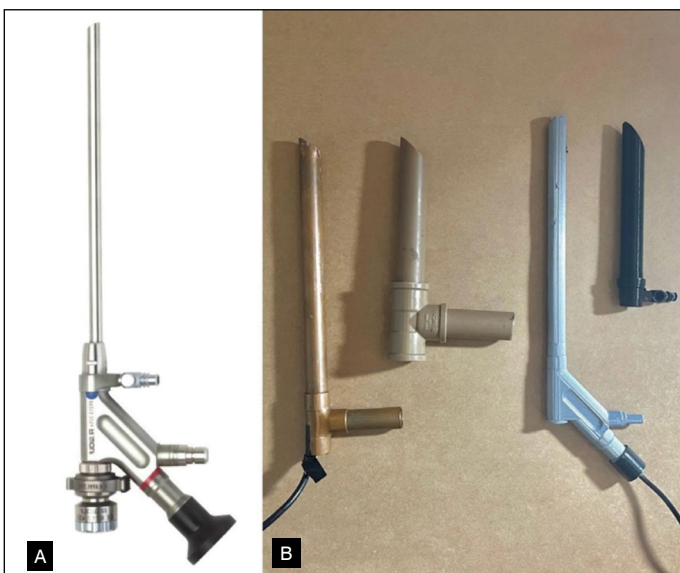
Source: Author.

Figure 9. Measurements for the printing of the endoscope.



Source: Author.

Figure 10. An endoscope printed with an attached camera.



Source: Author.

Figure 11. A) Real endoscope B) Comparison between endoscope and sleeve in copper and PVC by Nunes et al.⁷ with the model developed in 3D printing.

disapproval was regarding the comparative weight of the printed endoscope. (Table 3)

The variables related to the surgeon’s profile (age, training time, and time performing surgery) were evaluated, and it was confirmed that there is no correlation between them ($p > 0.05$); however, positive and moderate correlations with the score were found. This indicates that younger participants may assign lower scores, that is, worse evaluations. On the other hand, older participants may assign higher scores, that is, better evaluations. However, no statistical



Source: Author.

Figure 12. A) Simulator by Nunes et al.⁷ B) Final set of the 3D simulator.

Table 2. Profile variables of the participants.

Variable	n	Mean	Standard deviation	Median	Minimum	Maximum
Age (years)	10	40.5	13	35.5	29	67
Medical training time (years)	10	15.1	12.9	9.5	5	40
Surgery practice time (years)	10	10.7	12.6	6	1	34

significance was found in these correlations due to the small number of participants. (Figure 13)

For the validation analysis, a score was calculated equal to the sum of the points from the questions, with the number of points according to the response options: 0 = strongly disapprove; 1 = disapprove; 2 = indifferent; 3 = approve; and 4 = strongly approve. Considering the 10 questions, the score can vary from 0 to 40. The higher, the better the evaluation of the simulator. Thus, a positive validation of the simulator in question is found. (Table 4)

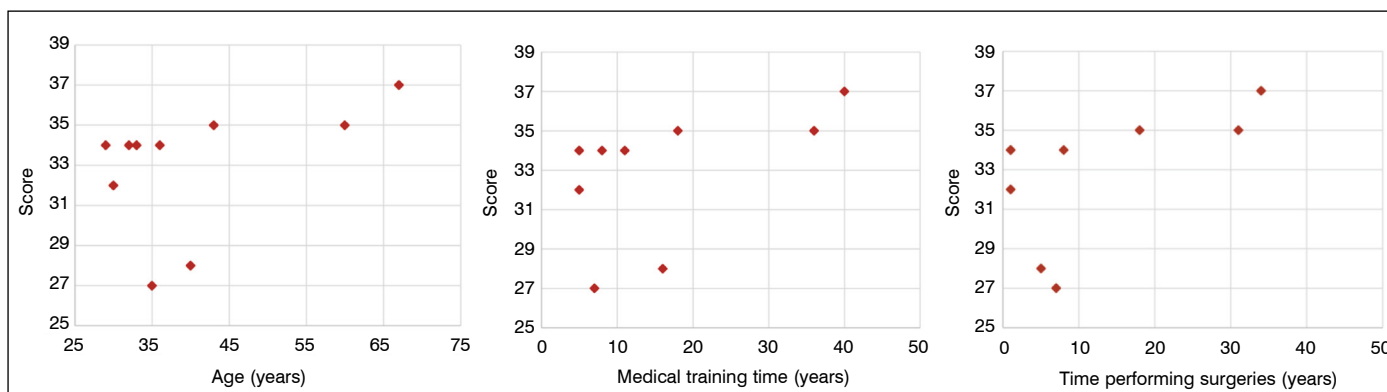
DISCUSSION

Among the numerous advantages of minimally invasive surgeries, endoscopy has been gaining ground.^{2,4} In the context of medical education, surgical training on patients is controversial due to potential unwanted errors, putting their health at risk. Moreover, reliance on exclusive training on patients can hinder learning efficiency.⁸ On the other hand, minimally invasive techniques have been associated with long learning curves, requiring a minimum of approximately 72 cases performed to gain certain experience with a low complication rate.^{9,10}

In a validation study of a low-cost simulator for shoulder arthroscopy training, the study demonstrated the improvement of participants’ skills as tasks were repeated. In the end, the simulator was considered a beneficial tool in shoulder arthroscopy training by all members.¹¹ This research corroborates one of the main advantages of the simulator developed here, which allows for numerous training repetitions on a low budget, highlighting what was confirmed by

Table 3. Percentages of participants according to their responses to each of the questions.

Question	Answer				
	Strongly disapprove	Disapprove	Indifferent	Approve	Strongly Approve
P1 - Is the external model and the 3D column capable of assisting in the recognition of anatomical structures in a real surgery?				60%	40%
P2 - Is the simulator useful in training novice surgeons in the technique of lumbar endoscopy?				40%	60%
P3 - Does the 3D developed endoscope have a similar appearance to the real endoscope used in surgeries?				70%	30%
P4 - Are the images generated by the 3D developed endoscope similar to those found during a real surgery?				90%	10%
P5 - Is the simulator capable of replacing one or more steps of the training conducted in real surgeries?	20%		10%	40%	30%
P6 - Do you believe that reviewing the surgical steps with this simulator immediately before the surgery can help reduce the number of errors during the operation?			10%	50%	40%
P7 - Do you consider that the weight of the 3D developed endoscope is similar to that of the real endoscope?	10%	20%		60%	10%
P8 - Do you believe that using this simulator can encourage undergraduate students to become interested in endoscopic spine surgery?				20%	80%
P9 - Do you consider that the 3D simulator has greater realism compared to the previously published simulator, which was assembled from various commercially available materials?				40%	60%
P10 - Do you believe that this simulator is useful for training surgical maneuvers that can be transferred to real surgery?				10%	90%



Source: Author.

Figure 13. Scatter diagrams of the score and the variables age, medical training time, and time performing surgeries.

Table 4. Descriptive statistics of the score.

	n	Mean	Standard deviation	Median	Minimum	Maximum
Score (sum of points)	10	33	3.2	34	27	37

100% of participants who found it useful in training beginners in endoscopic technique.

Each service that proposes to teach surgical techniques uses different training models: inanimate, virtual reality, live animals, human or animal cadavers, aiming to resemble tissue and anatomical conditions. When employing virtual reality, the trend is to deal with high costs and maintenance periods; live animals require special facilities, ethical concerns, and present anatomical differences, and cadavers, whether human or animal, have restricted availability, are for single use, pose infection risks, and involve ethical concerns.¹² Meanwhile, the synthetic simulator discussed here is characterized by low cost, easy access, and repetitive practices, as there is no tissue damage from manipulation and reproducibility, being a printed object. However, without neglecting the necessary similarities for basic training. Thus, highlighting the result of 100% approval from participants regarding the formed image of the created endoscope,

which has a shape similar to the real one, and the possibility of training surgical maneuvers that can be transferred to reality.

Nunes et al⁷ created a training model for flavectomy, positioning a synthetic lumbosacral column inside a mannequin with a dorsal circular access for the entry of surgical material. For the endoscope and shirt, copper pipe and PVC pipe were used; the total set was made up of simple materials, totaling an expense of R\$464.60. The work was one of the pioneers in the development of new endoscopic spine surgery simulators made from low-cost materials, serving as a foundation for the development of our simulator. Prioritizing a reduced budget, we showed a model created with approximately R\$100.00, and of reduced size, which makes it even more portable and easy to transport, also allowing training in accessible locations, for example, at home. The ease of printing in specific sizes and angles stands out. The developed 3D model surpasses the simulator made of simple materials in cost, ease, precision, and reproducibility. However, it requires access to a 3D printer and planning programs, which can hinder the dissemination of the modality.

In relation to the printed endoscope, when compared to that of Nunes et al.,⁷ it is more similar to the real one in size and angles, without the need for manual cuts of the metal components. These details manage to bring a greater sense of realism, a fact confirmed by the response of 100% of the participants, who considered the

endoscope to have a similar appearance to the real endoscope. However, in a context of novice surgeons, the transfer of skills may be hindered by the weight difference between the simulator and the real device, with the former being much lighter.

In this scenario, in the meta-analysis by Corsoti et al.¹³ where the physical compatibility of the simulator with the development of surgical skills in medical students was evaluated, it is stated that low-cost simulation associated with not necessarily high physical similarity is a viable option for teaching and learning skills. This agrees with the average resulting from the participants, considering the high scores of the evaluations, our simulator presented itself as a viable option for training surgeons.

According to McDougall,¹¹ who highlights the importance of validating simulators in his study, to have competence validation, performance on a simulator must predict, or at least correlate with, an individual's performance in the operating room. From the questionnaire applied, 90% of the participants considered that reviewing the surgical steps with the 3D simulator immediately before surgery can help reduce the number of errors during the operation. And 100% of the participants approved the simulator as useful in training beginners in the technique of lumbar endoscopy. In the study with the arthroscopic simulator by Tashiro,¹⁴ the importance of evaluating the skills of surgical interns is emphasized so that they can understand their degrees of improvement based on their scores and time spent performing tasks. Thus, our simulator could assist in the evaluations of training surgeons, visualizing the performance of each one, since 100% of the participants believe that this simulator is useful for training surgical maneuvers that can be transferred to reality.

In the validation study of an arthroscopic simulator by Dau L. et al.,¹⁵ the author stated that participants would be able to improve their surgical skills as they repeated their tasks on the simulator. Such training is also possible in the created simulator; however, it was not the subject of this study to follow the learning curve of the participant and their evolution over time.

The item with the greatest disagreement in the questionnaire was about the ability of the 3D simulator to replace one or more steps of the training conducted in real surgeries, in which 20% of the participants strongly disapproved. The gold standard of training remains practice on cadavers, as it features faithful anatomy and

equivalent tactile sensation, fundamental factors in the transfer of basic surgical competencies to a complete procedure. For example, Kulcheski et al. questioned in their study whether the simulator by Nunes et al. would replace training on cadavers, receiving an 80% negative response, since training on cadavers provides tactile feedback and greater realism.^{7,16-18} The results found in this study go against the literature, as few disapproved when a higher disapproval was expected. This can be explained by the enchantment with the simulator technology, especially among participants with less training time, due to having had less contact with endoscopic surgery, and by the fact that it is designed for the initial training of students and residents, who could benefit more than those who are more experienced.

Among the limitations of this study, it is worth mentioning the lack of representation of some soft tissue structures (subcutaneous, musculature, innervations, and vascularization) as it is a dry and rigid model, thus not compatible with anatomy in its integrity. The objective of this study was not to explore other modalities of validation such as construct, concurrent, and transfer validation, where it is observed whether the acquired skill can be transferred to the real environment. It was not tested by resident doctors or medical students, who would be a group of interest for the use of this model and could provide important feedback information for its use in a graduation environment. Despite 3D technology being increasingly developed, it can still be a limitation for places without the resources to acquire a printer. It becomes possible, in the future, to have new projects that include training in graduation or medical residency environments.

CONCLUSION

We conclude that it was possible to develop a simulator for the technique of endoscopic lumbar spine surgery, printed in 3D, with a low budget and reproducible, with a unit cost of approximately R\$100.00.

Moreover, its face validation was achieved with 100% of participants approving its use for identifying anatomical structures and training surgical maneuvers that could potentially be transferred to the real environment.

CONFLICT OF INTEREST

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

CONTRIBUTIONS OF THE AUTHORS

Each author made an individual and significant contribution to the development of this article. ÁLK: methodology, supervision, and intellectual contribution; LHM: writing, data collection, literature review, research project design; LS: methodology; ESF: review and editing; XSG: intellectual concept and review.

DATA AVAILABILITY DECLARATION

The contents underlying the research are available in the manuscript.

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