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A Novel Electronic Spine Trainer for Endoscopic Minimally Invasive Spine Surgery

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Abstract

Background Traditional endoscopic spine training using cadavers and animal models faces limitations due to availability and ethical concerns, while existing synthetic models are often too simplistic or expensive. There is a need for a more accessible and affordable training solution.

Objective This study aims to develop and evaluate a low-cost, indigenous electronic model for training surgeons in minimally invasive spine surgery.

Methods A Foley catheter wrapped with a copper coil and covered with plastic cling film was used. This was placed through a foam and wooden spoon, which simulated the lamina and ligamentum flavum. An electronic circuit with an alarm, a light-emitting diode, and a direct current source was connected. The surgeon aimed to cut the wooden spoon and foam without injuring the cling film. Forty-five neurosurgeons tested the model. The differences between the time duration and the number of errors during the first and third attempts were analyzed. Participants also rated the model on a Likert scale of 1 to 5.

Results The mean duration of successful exercise during the first and final attempt was 24.51 and 19.03 minutes. The mean errors also reduced from the first to third attempt, which were 2.15 and 0.44, respectively. The correlation between experience and the response on the Likert scale was weakly negative. The correlation between experience and the number of errors was moderately negative.

Conclusion The novel electronic model for minimally invasive spine surgery provides a low-cost, accessible, and effective means for surgeons to practice endoscopic spine surgery skills.

Keywords
- academic training
- minimally invasive surgical procedures
- motor skills
- neuroendoscopy
- spine

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Introduction

Endoscopic minimally invasive surgery (MIS) for spinal procedures continues to increase in indications and complexities.[1–5] Surgeons aspiring for neuroendoscopy must develop a unique skill set due to factors such as limited field of view and lack of stereoscopy compared to microscopic techniques.[6] Achieving proficiency in endoscopic spine surgery can be challenging, with a steep learning curve and a required number of cases to become proficient.[7] To avoid complications during the learning process, it is vital for surgeons to practice these skills beforehand.

While cadavers are often considered the best option for skill development, their limited availability is a significant obstacle. Moreover, using animal models raises ethical concerns. Thus, artificial models have emerged as viable alternatives to cadavers and animals.[8,9] These models have demonstrated their ability to improve surgeons' comfort and proficiency during spine surgery.[10]

Synthetic models have traditionally been used to improve surgical skills for laparoscopic and neuroendoscopic surgeries, and they have been found to be useful for assessing visuospatial ability and tailoring individualized laparoscopic programs.[11] However, synthetic models for spine surgery are either too simplistic or too expensive.[12,13] An ideal model for training should be low-cost, provide adequate practice, and give feedback to the surgeon when mistakes are made. It should also be accessible to all surgeons and easy to reproduce. To address this need, we have developed a novel indigenous electronic model for minimally invasive spine surgery that provides neuroendoscopic and spine training, as well as feedback during error making. Our model is low-cost and has been tested by spine surgeons to determine its utility in improving surgical skills for minimally invasive spine surgery.

Methods

This was a prospective observational study, conducted at a tertiary care center for neurosurgery. The procedures were followed by the ethical standards according to the Helsinki Declaration, and the institutional review board permission was taken (IEC/2023/8089). To design the model, a Foley catheter was wrapped with a copper coil and then covered twice with plastic cling film of 10.5-μm thickness to represent the spinal cord and the dura mater (as shown in ►**Fig. 1A**). This set was then placed inside a foam material that acted as a simulation for the ligamentum flavum, and a wooden spoon was pasted on top of it to simulate the lamina. The spoon was marked with lines to indicate the designated cutting area. One end of the copper coil was connected to an electronic circuit with an alarm, a light-emitting diode (LED), and a resistance of 220 Ω (as shown in ►**Fig. 1B**). A direct current of 9 V was attached to the working instrument Kerrison or disk forceps. To simulate endoscopic surgeries, the system was placed under a clay utensil (as shown in ►**Fig. 2**). The surgeon held a borescope in their nondominant hand, which was connected to a computer monitor (as shown in ►**Fig. 3A**). The surgeon aimed to cut the wooden spoon in the designated area and cut the underlying foam without damaging the cling film. If the cling film was injured or excessive pressure was applied by the Kerrison, the current was transmitted to the copper coil, completing the circuit and raising the alarm and LED (as shown in ►**Fig. 3B**).

The model was tested by neurosurgeons with 0 to 5 years of postresidency neuroendoscopy experience. Based on our prior experience and using power analysis from existing literature, a sample size of 45 was deemed suitable.[14] The examiners were not involved in the model-building process to avoid any bias. The objective evaluation was performed by measuring the time duration and number of errors made to complete the task of excising the wooden spoon and foam.

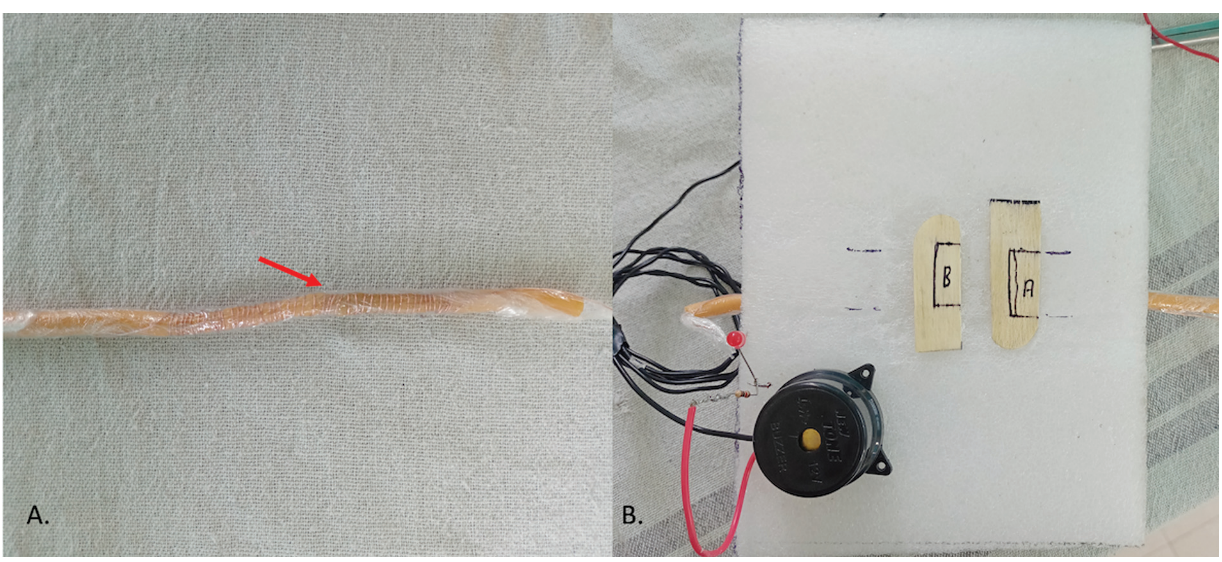

Fig. 1 (**A**) A Foley catheter is tightly wrapped with a copper coil, which is further wrapped twice with a cling film of 10.5-μm thickness. The *red arrow* shows the copper coils. (**B**) The Foley catheter wrapped with copper coil is passed across a foam. A wooden ice-cream stick is pasted on top of it. In a series an alarm, light-emitting diode, and a resistance of 220 Ω were attached to the copper coil.

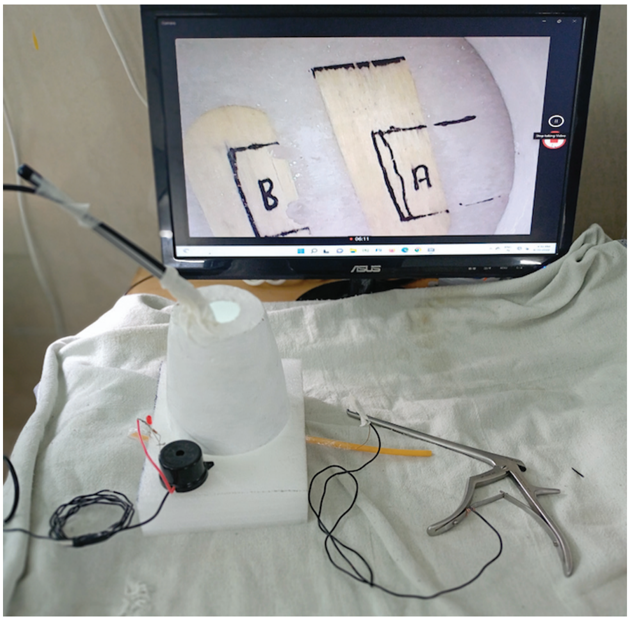

Fig. 2 The assembly is placed under a clay utensil. A direct current of 9 V is attached to the Kerrison rongeur, and during the procedure whenever the cling film is broken or excessively pressed, the circuit gets completed and the alarm is triggered.

The error was defined as raising of the alarm due to either excessive pressure or rupture of the film. The hypothesis was that the exercise would improve the performance of the surgeons by reducing the time duration and errors between the first and third successful attempts. The subjective evaluation was done by the participants rating the model on a Likert scale of 1 to 5, with 1 indicating "not useful" and 5 indicating "most useful."

The paired *t*-test was used to analyze the time difference and number of errors between the first and third successful attempts, and a *p*-value of less than 0.05 was considered statistically significant. The correlation between the experience (years after residency) and the rating of the Likert scale was determined using Pearson's correlation. Similarly, the correlation between the experience and the number of errors made to perform the exercise successfully was also analyzed.

Results

Forty-five neurosurgeons with varying levels of experience, ranging from recent graduates to those who had completed residency 5 years ago, tested the model three times. Each exercise was repeated until the procedure was successfully completed, resulting in a total of 153 alarms raised during testing.

The mean duration of successful exercise in the objective evaluation was 24.51 (standard deviation [SD] = 3.51) minutes during the first attempt, which decreased to 19.03 (SD = 3.17) minutes during the final attempt. The model met our hypothesis, and this difference was statistically significant ($t(44) = 28.83$, $p \leq 0.001$). Similarly, the mean number of errors during the first attempt was 2.15 (SD = 0.82), which fell to 0.44 (SD = 0.58) on the third attempt. This was also statistically significant ($t(44) = 15.15$, $p \leq 0.001$).

The correlation between experience and response on the Likert scale was weakly negative ($r = -0.11$), with most responses being either 4 or 5. The correlation between experience and the number of errors to perform successfully in the first and third attempts were moderately negative ($r = -0.47$ and –0.48, respectively), as visible in ►**Fig. 4**.

After one use, the model could be reproduced in approximately 2 minutes. The total cost of the model excluding the computer and borescope was around 150

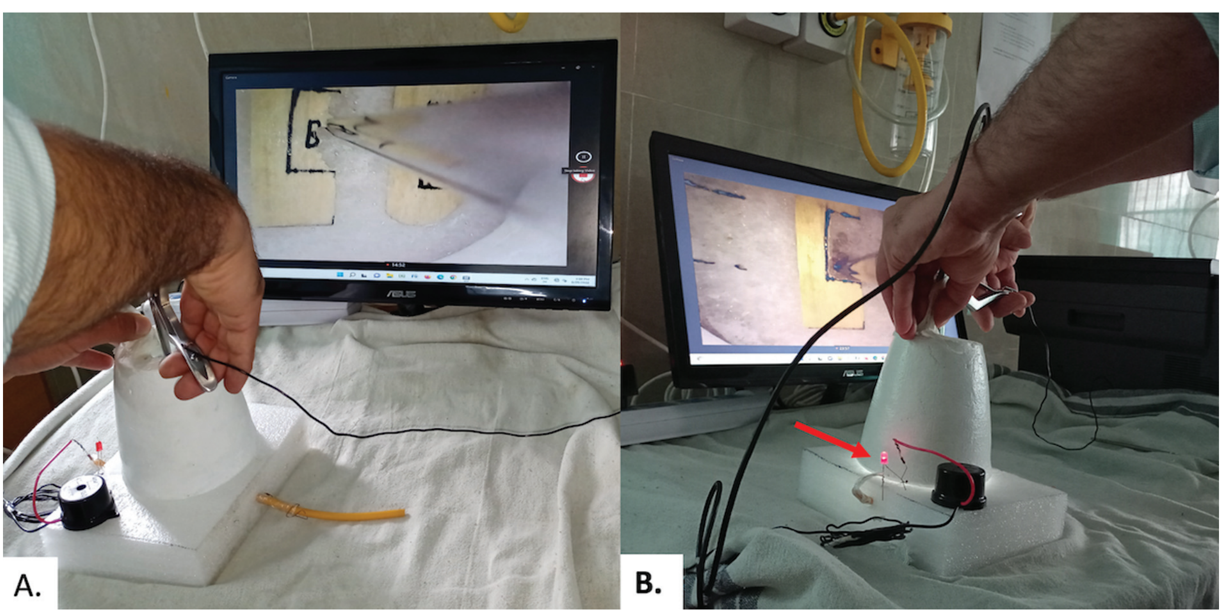

Fig. 3 (**A**) The surgeon holds the camera in the nondominant hand and performs simulated laminectomy and ligamentum flavum resection using the rongeur. (**B**) The light-emitting diode is lightening (*red arrow*) when there was a breach of the cling film.

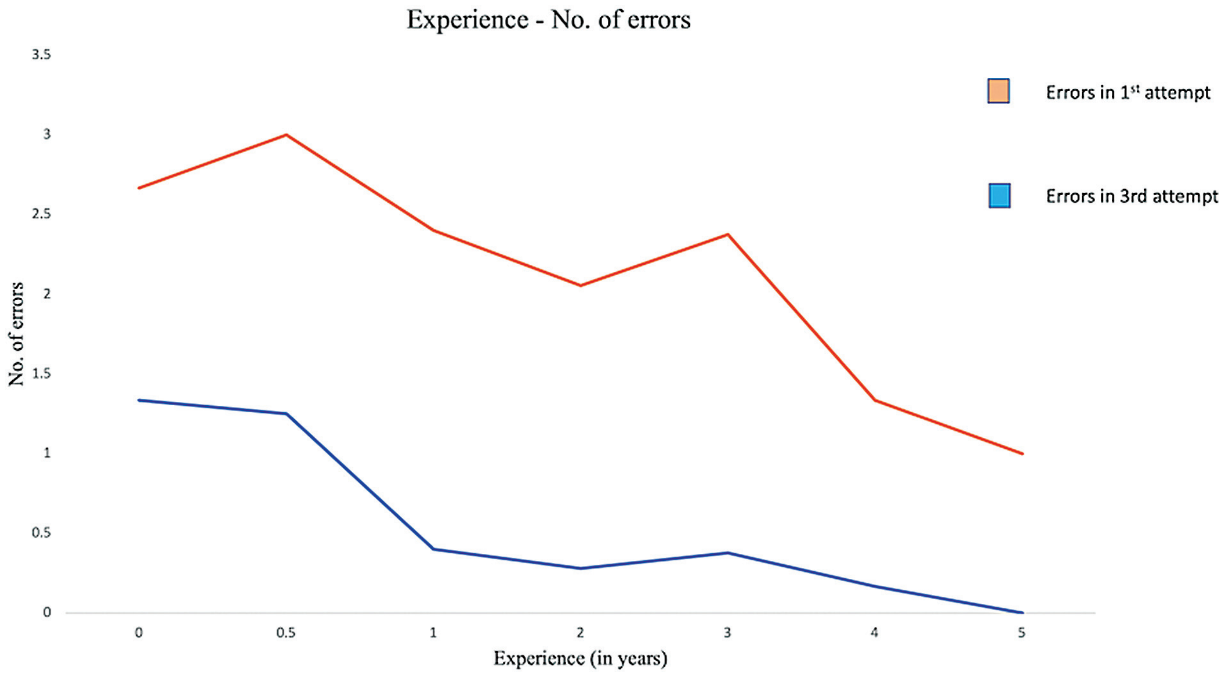

Fig. 4 Graphs showing the relation between the experience (in years) and the number of errors made during the first and the third attempts. Experienced surgeons made fewer errors during both the first and third attempts, the correlation of which was moderately negative ($r = 0.47$ and 0.48, respectively). The *orange line* shows the errors in the first attempt and the *blue shows* the errors in the third attempt.

Indian rupees (less than US$2). The cost of reproduction of the model after a use was minimal.

Discussion

Minimally invasive endoscopic spine surgeries have been increasingly used in recent years for both simple and complex spine surgeries.[1–4,15,16] This technique offers several advantages over traditional open spine surgeries, including smaller incisions, less pain, shorter hospital stays, and faster recovery times.[17–19] However, one of the limitations of this technique is its steep learning curve, which requires extensive initial training on cadavers, animals, or synthetic models.[7]

Unfortunately, these training models are not always readily available due to cost and ethical concerns. Therefore, the development of indigenous and inexpensive training models is highly desirable. The model developed in this study offers a simple, reproducible, and low-cost solution to this problem. It can be easily constructed from commonly available materials and can be used in any setting, including offices, labs, or operating rooms.

One of the unique features of this model is the alarm system, which provides feedback to both the trainee and the assessor. This feature is particularly useful for detecting errors and guiding the trainee toward corrective actions. This model not only detects the tearing of the plastic film but also provides a distinct advantage by alerting the surgeon when excessive pressure is applied to the dural sac—an innovative feature absent in any other models reported in the literature. The researchers could not find any other spine trainer in the literature that provided feedback in this way, making this model a novel and valuable addition to the field of minimally invasive spine surgery training.

The study used both objective and subjective criteria to evaluate the effectiveness of the model. The objective criteria included the duration and number of errors to complete the task, while the subjective criteria involved a Likert scale rating of the model's usefulness. The model was tested multiple times, and the results showed a significant reduction in the duration of the exercise and errors between the first and final attempts. Additionally, the correlation between experience and response on the Likert scale was not present, indicating that the model was well liked by surgeons of all levels of experience.

While the study had several strengths, including validation by peer neurosurgeons and the use of both objective and subjective criteria, there were also some limitations. For example, the lack of tissue consistency for both bones and soft tissues was a potential limitation. It is also important to note that this model is not a replacement for actual surgeries, and its translation to actual surgeries was not tested. However, it can still be a useful tool for orienting surgeons and helping them to work under the endoscopic vision and improve their skills, which will ultimately lead to better outcomes in actual surgeries.

Another limitation of the model is the lack of cerebrospinal fluid (CSF). While CSF starts leaking as soon as the dura is torn in actual surgeries, the researchers circumvented this problem by introducing the alarm system. The alarm arose whenever the plastic film was exposed to excessive pressure or tearing. However, some commercially available spine models have a fluid system for this purpose, which may be a better alternative.[13] Nevertheless, the cost of commercially available models is several times higher than the cost of the model presented in this study. While this study did not assess long-term learning, it is important to note that, as with any skill development, consistent and repeated practice is essential for mastery.

Overall, the principle of this model has great potential for use in other surgeries, such as nasal surgeries or laparoscopic surgeries. Additionally, with the widespread availability of computers and smartphones, this model can be used in conjunction with these devices to provide a portable and cost-effective training tool. In the future, the model could be further upgraded by introducing 3D-printed lamina and ligamentum flavum to simulate actual patient scenarios. The step-by-step instructions provided in this study make it easy for others to build on this model and develop more sophisticated training models in the future.

Conclusion

The indigenous spine model with an alarm system provides a valuable tool for training in minimally invasive endoscopic spine surgeries. It has the potential to reduce the learning curve, improve surgical skills, and increase accessibility to training resources. The model's reproducibility, ease of use, and feedback system make it a promising option for both daily practice and lab training during workshops.

Authors' Contribution

J.B., Y.R.Y., D.B., D.S., and C.G.P. developed the concept and design of the study. Data collection was done by J.B., S.V., V.C., S.J., V.C., and L.K.B. Analysis and interpretation of results were done by J.B., S.R., J.P., M.S., and K.H. Draft manuscript preparation was done by J.B., Y.R.Y., D.B., S.V., V.C., M.S., S.R., and V.S.P. All the authors reviewed the results and approved the final version of the manuscript.

Conflict of Interest

None declared.

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