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Technical Notes

A novel low-cost device for tool targeting training and microsurgical hand tremor assessment

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ABSTRACT

Background: The spatial accuracy of microsurgical manipulations is one of the critical factors in successful surgical interventions. The purpose of this study was to create a low-cost, high-fidelity, and easy-to-use simulator for microsurgical skills training, which can be made by residents themselves at home.

Methods: In response to the COVID-19 pandemic, we created a device for spatial accuracy microsurgical skills training and implemented it in our resident's training program. We propose a design for basic and advanced models. The simulator consisted of commonly available products.

Results: A low-cost, durable, and high-fidelity basic model has been developed at a total cost of <10 dollars per unit. The model allows trainees to practice the critical microsurgical skills of tool targeting in a home-based setting.

Conclusion: The developed device can be assembled at an affordable price using commercially available materials. Such simulation models can provide valuable training opportunities for microsurgery residents.

Keywords: Microsurgery, Simulator, Surgical education, Surgical simulation, Surgical skills

INTRODUCTION

The surgeon's manual precision can be one of the most important factors influencing the outcome of a microsurgical procedure.

Microsurgical manipulation involves a combination of targeted and coordinated actions. Spatial accuracy is one of the critical factors in successful surgery, as uncontrolled and inaccurate movements of microsurgical instruments can damage tissue, nerves, and important vessels within the surgical field.

In addition, the degree of the surgeon's hand tremor can influence the accuracy of microsurgical manipulations.[4]

For example, internal limiting membrane peeling demands micrometer positioning accuracy.[7]

Both characteristics – the accuracy of the spatial microsurgical action and the degree of microsurgical tremor are parameters that we control during the training process according to our microsurgical training curriculum.

We describe the development of a low-cost and easily constructed simulator for spatial accuracy microsurgical skills training that can be used and created in home-based settings [Video 1].

MATERIALS AND METHODS

Basic model design

In the basic version, the simulator is built around a specially shaped-conductive body. Touching it with the microsurgical instruments closes an electrical circuit and triggers a signal. The body should have the form of a conductive container that can be made from any metal can or box. For example, it can be made from a soda can and aluminum foil.

The crucial part of the container simulates the edges of the surgical wound. Therefore, it can be made in different shapes depending on the training task and should be removable. To provide an electrical connection to the rest part of the conductive container, it should be made of some conductive material: metal sheet, grid, or even cardboard covered with aluminum foil. During training, the user will receive a light or sound warning signal when the instrument touches the edges of the operating window, reinforcing the targeting/precision of the instrument to avoid touching critical structures (nerves and vessels) during surgery.

The conductive container must be wired to the power source. There must be a sound or light source in the same circuit to signal an incorrect action. At the other end of the chain, a flexible wire should be connected to the tool. While there are many ways to accomplish a similar model, we suggest using a LED strip for the light signal.

To build this design, you will need an LED strip, a 9V battery, a power switch, a paper clip stripped of paint for tool connection, wires, a conductive container with an operating window, and a holding box. The components must be electrically connected in series, as shown in the scheme [Figure 1 and Table 1].

The LED strip circuit can easily be improved by connecting a 9V buzzer, if available, in parallel with the strip to receive sound signals along with the light signals.

Advanced model design

Tremor measurement settings

A digital accelerometer and a microcontroller can accomplish the basic version of the simulator.

The simplest, cheapest, and not engineering skill-demanding design for measuring tremors includes the following:

1. A compact digital accelerometer that transmits data using the I2C protocol
2. Arduino board (a family of boards with a fully open architecture and code), speaker or LED array, a power supply for the board (the same 9v battery can power it)
3. A small magnet, wires, and epoxy.

The key component here is the accelerometer, which must be able to distinguish between accelerations of <0.1 g. We used the LIS331DLHTR from ST Microelectronics (Geneva, Switzerland) on its board [Figure 2 and Table 2].

The magnet should be used in place of the paper clip in the previous design, and the same wire should be electrically connected to it. The accelerometer should then be attached to the magnet using epoxy or another method that insulates it from the magnet (we used a 3D-printed base). The accelerometer needs to be wired to the Arduino board using the I2C protocol, and the board must be programmed to send a signal to the LED array or buzzer proportional to the change in acceleration modulus.

In this design of the simulator, the user will still receive a signal when he touches the edge of the operating window and will also receive a signal proportional to the level of tremor of the instrument.

Tremor measurement improvement with PC

You can use a PC to process and display data from an accelerometer. This allows you to perform mathematical operations on the accelerometer data, making the displayed information more useful. To transfer data from the Arduino to the PC and process it, we recommend the freeware "Processing" integrated development environment. Aside

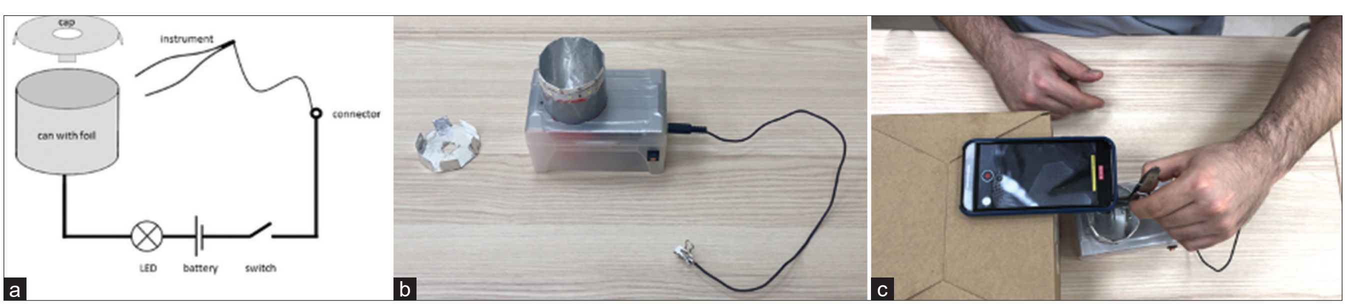


Figure 1: Basic model design. (a) Basic model Scheme. (b) Fully assembled model. (c) The option of using a device with a smartphone camera as a magnification tool.

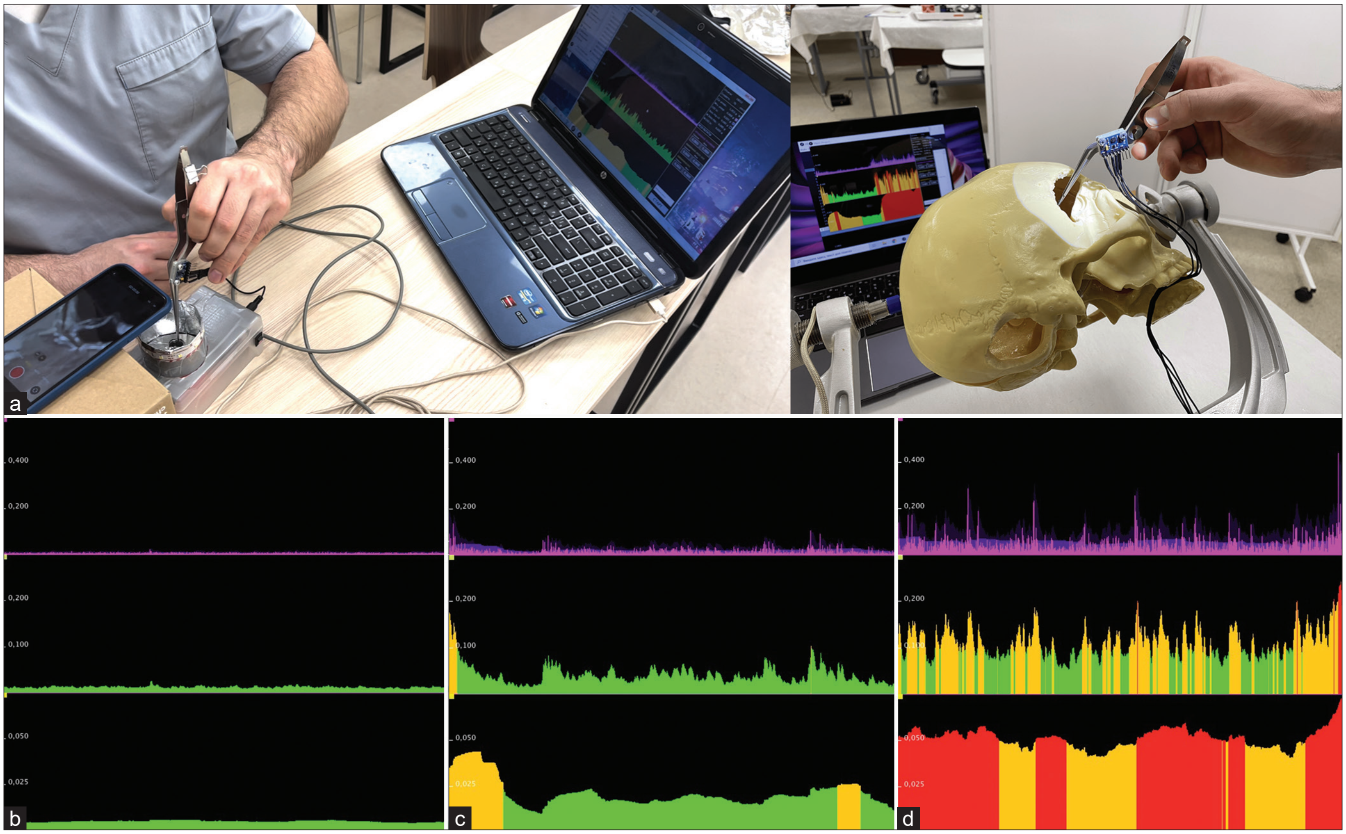


Figure 2: Advanced model design. (a) Using an advanced model for microsurgical training; (b) Levels of microsurgical tremor using elbow support, and wrist support, (c) Elbow support and (d) No arm support.

Table 1: Basic model design. Materials and cost (in US dollars).

Component	Price
LED strip	2
Switch	1
9V battery and battery slot	3
Conductive container	1 (if you use a soda can with foil)
Holding box, wires, and paper clip	Usually <1
Optional: Detachable connector	1
Optional: 9V buzzer	2–3
Total price	8–12

LED: Light Emitting Diode

from the PC and USB cable, this does not increase the cost of the model.

To simulate working under magnification, you can use the following, depending on availability:

1. Surgical loupes
2. A smartphone is placed above the unit and set to camera mode at maximum magnification.

Table 2: Tremor measurement settings. Materials and cost (in US dollars).

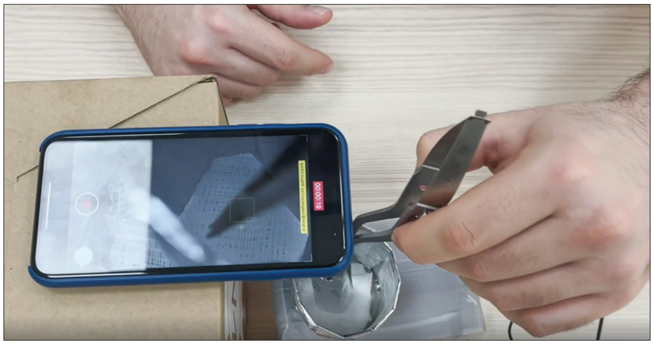
Component	**Price**
Basic model	8–12
Accelerometer Board	10
Arduino board	10
Magnet	1–2
Component for signal (LED array or speaker)	10
Wires, epoxy	1
Total price	45

LED: Light Emitting Diode

RESULTS

Curriculum integration and model validation

The described model has been used by residents at our hospital for 2 years during the COVID-19 pandemic, and we have received nothing but positive feedback, particularly about the advanced version with the accelerometer. We have incorporated these models into our microsurgical curriculum, and they are used in two different scenarios:



Video 1: Example of use of the developed device for tool targeting and microsurgical tremor assessment in the home environment.

Training of spatial microsurgical precision

Models used to develop these basic skills can be surgical gauze, in which a candidate must make incisions and pass a suture above and below adjacent threads.

During the performance of the task, it is necessary to minimize the number of times the microscissors touch the limiting frame of the device that simulates/mimics the surgical corridor (in real intraoperative settings, the surgical corridor is formed by brain tissue, blood vessels, and nerves).

Microsurgical hand tremor assessment

The resident uses various options for grasping microsurgical instruments body and hand positions, focusing on objective indicators of tremor level, and selecting the most appropriate one.

DISCUSSION

Neurosurgery is considered one of the most challenging fields of microsurgery, based on the degree of dexterity and manual skill required by the surgeon.

Neurosurgery differs from other microsurgery in a number of ways: it is longer, it is more time-consuming, the surgical field is narrower and deeper, and the edges of the surgical corridor are often functionally important areas of the brain.

For these reasons, the development of special skills with better precision and control of microsurgical hand tremors is critical.[2,3,5,8]

Simulators have improved trainee performance across multiple surgical specialties.

Studies have shown the benefits of surgical simulation in developing surgical skills in residents, as using the operating theater for training has ethical and financial limitations.[1]

Microsurgical simulators range from inexpensive and affordable, simulating simple surgical scenarios, to extremely expensive and simulating complex intraoperative tasks. The latter is difficult to replicate on a large scale, especially in low-income countries.[9]

The COVID-19 pandemic has brought its adjustments to the microsurgery curriculum. Resident training and progression (development of microsurgical skills) became an issue during the pandemic. Residents in microsurgical specialties were retrained as infectious disease specialists and rotated to other clinics, and access to microsurgical training laboratories was closed. Therefore, we aimed to provide microsurgical skills training at home and outside the hospital.

We faced a challenge to create a convenient, easy-to-use, and inexpensive device for microsurgical skills training in home-based settings.

Here, we describe how we are attempting to use relatively simple technologies to create a novel device for the benefit of microsurgical residents nationwide.

It does not require any supervision, allowing the residents to practice their microsurgical skills independently.

We believe that the use of such a low-cost simulator for training microsurgical skills in confined spaces can assist trainees in the acquisition and maintenance of their skills and can be easily implemented in a variety of microsurgical training programs, allowing the practice of tool targeting.

The model we created has an initial cost of 10 USD. This cost efficiency enables widespread use even in low-income countries.

Among neurosurgical simulation models, we did not find any analogous model that has been described in the literature, which is why we cannot compare the costs.

Devices developed to measure tremors in pathology (Parkinson's disease) are widely used in medicine; however, only a few works investigated tremors during realistic microsurgical conditions.[6,7]

Model benefit

1. Our low-cost, open-source model allows residents to practice basic and complex microsurgical skills in a specified spatial environment, which helps them practice tool targeting and improve the spatial accuracy of their microsurgical motor skills.
2. The device is compact, portable, and simple to use. Trainees can practice their microsurgical skills at home using a mobile phone as a magnifying device.
3. In addition, the model can be fitted with an accelerometer, which allows trainees to measure the level of microsurgical tremor objectively. This data can then be used to find their optimal body position and grip of microsurgical tools to reduce tremors.

4. The model does not require much storage space and is easily transported. It does not require special skills that are not available to microsurgeons.
5. Even in the advanced version with an accelerometer, the device's price does not exceed 45 dollars.

Model limitations

1. The fabrication of an advanced model with an accelerometer necessitates more specialized components and some engineering skills.
2. Surgical loupes or a smartphone are required for the training procedure.

Despite these disadvantages, we believe that the benefits outweigh the limitations.

CONCLUSION

We have created an open, low-cost simulator for microsurgical training and skills acquisition. The model is useful for providing spatial accuracy microsurgical skills training in home-based settings and can be used in resource-constrained situations.

Ethical approval

The Institutional Review Board approval is not required.

Declaration of patient consent

Patient's consent was not required as there are no patients in this study.

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Conflicts of interest

There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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