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Original Article

Enhancing microsurgical skills in neurosurgery residents of low-income countries: A comprehensive guide

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ABSTRACT

Background: The main objectives of this paper are to outline the essential tools, instruments, and equipment needed to set up a functional microsurgery laboratory that is affordable for low-income hospitals and to identify cost-effective alternatives for acquiring microsurgical equipment, such as refurbished or donated instruments, collaborating with medical device manufacturers for discounted rates, or exploring local suppliers.

Methods: Step-by-step instructions were provided on setting up the microsurgery laboratory, including recommendations for the layout, ergonomic considerations, lighting, and sterilization processes while ensuring cost-effectiveness, as well as comprehensive training protocols and a curriculum specifically tailored to enhance microsurgical skills in neurosurgery residents.

Results: We explored cost-effective options for obtaining microsurgery simulators and utilizing open-source or low-cost virtual training platforms. We also included guidelines for regular equipment maintenance, instrument sterilization, and establishing protocols for infection control to ensure a safe and hygienic learning environment. To foster collaboration between low-income hospitals and external organizations or institutions that can provide support, resources, or mentorship, this paper shows strategies for networking, knowledge exchange, and establishing partnerships to enhance microsurgical training opportunities further. We evaluated the impact and effectiveness of the low-cost microsurgery laboratory by assessing the impact and effectiveness of the established microsurgery laboratory in improving the microsurgical skills of neurosurgery residents. About microsutures and microanastomosis, after three weeks of training, residents showed improvement in "surgical time" for ten separate simple stitches (30.06 vs. 8.65 min) and ten continuous single stitches (19.84 vs. 6.51 min). Similarly, there was an increase in the "good quality" of the stitches and the suture pattern from 36.36% to 63.63%.

Conclusion: By achieving these objectives, this guide aims to empower low-income hospitals and neurosurgery residents with the necessary resources and knowledge to establish and operate an affordable microsurgery laboratory, ultimately enhancing the quality of microsurgical training and patient care in low-income countries.

Keywords: Low-income countries, Microsurgery laboratory, Microsurgical skills, Neurosurgery

INTRODUCTION

Microsurgery plays a crucial role in neurosurgery, enabling intricate procedures with precision and minimizing damage to surrounding tissues. It is an essential skill that neurosurgery residents must acquire during their training (ideally after a long training in the laboratory) to ensure optimal patient outcomes.[23,26,28,34] However, the availability of well-equipped microsurgery laboratories and resources is often limited, particularly in low-income countries where healthcare facilities face numerous financial constraints. The development of a low-cost microsurgery laboratory tailored to the specific needs of neurosurgery residents in low-income countries is a critical step toward bridging this gap. By providing access to affordable training facilities and equipment, residents can develop their microsurgical skills, ultimately improving patient care within resource-limited settings. This comprehensive guide aims to outline the necessary steps and objectives involved in establishing such a laboratory. The microneurosurgery laboratory is commonly referred to as "the neurosurgeon's gym," and we completely agree with this term because we believe that all sustainable and reliable success requires arduous previous training.

The final goal and main objective of our work are to show how to establish a basic microsurgery laboratory with the resources available, that could be easily replicable in low-resource hospitals/low-income countries; the whole process took over six months. We describe the usefulness and functionality of our laboratory by exposing some examples and the level reached in microsutures, filling techniques, microdissections, and anatomical-descriptive photographs accumulated over 16 weeks of carrying out the different practices.

There are multiple modalities of surgical training, among which stand out: (1) training in laboratory animal specimens; (2) training in cadaveric specimens, human organs, and tissues in the laboratory; (3) training in simulators of various types (Virtual reality, mannequins, 3D anatomical models, and robotic surgery); and (4) training and development of skills in the operating room, directly on the patient during the surgical act under the supervision of experienced neurosurgeons. This last modality was the traditional method for a long time and still predominates in countries of medium and low resources and most of Latin America due to the low medical-scientific development and the lack of investment from governments in the health sector for scientific research purposes, specifically microsurgical training laboratories.[18] Due to this, currently, our main objective is the significant flattening of the learning curve that is carried out during the surgical techniques directly on the patients without adequate prior training, which is not correctly allowed by the principles of current bioethics, as we mentioned before. In contrast, we cannot talk about eliminating this learning curve completely because each surgery and theoretical knowledge complement each other as the basis of any surgery. The third training modality mentioned is based on advanced technology, such as simulation and planning in virtual reality and 3D anatomical models made from multimaterial materials.[14,37,41,43] 3D endoscopic anatomical models for training,[11] use of robotic devices and/or specific training devices, and use of high precision imaging techniques for neuronavigation, in combination with minimally invasive procedures and stereotaxis seem to be the future of training in neurosurgery undoubtedly. However, so far, this modality is costly and definitely out of reach of the majority of the population from medium and low-income countries, meaning that the majority of occasions are well outside the reach of many hospital centers in Latin America, being found by country regulations, in large research hospitals and some private hospitals with interest in this modality.

The first two modalities involve the microsurgery laboratory, of which we rule out the first modality, as explained before, since it is not possible to maintain and acquire animal specimens due to financial constraints in the vast majority of our hospitals. Microsurgical techniques have historically relied on the use of live animal models.[2,39] However, even with adequate facilities, practices with live animals can be difficult due to bioethical aspects. In addition, there is no substantial evidence to justify the use of live animal models over other training models.[8]

Below, we present the steps for the creation of a low-cost, basic microsurgery laboratory in a second-level hospital with zero funds designated for microsurgical training (similar to the vast majority of hospitals in countries with medium and low resources), as well as the final result (our laboratory and some examples of our work) and future objectives in the medium and long term.

MATERIALS AND METHODS

Basic hospital equipment

Initially, we used easily accessible hospital and low-cost materials such as latex sheets/gloves, silicone tubes, gauze, microstructures of various calibers, probes, catheters, disposable surgical gowns, disposable surgical fields, needles, syringes, masks, and compresses. Most of this is provided by our institution through formal requests well-requisitioned and scientifically justified, in which it was emphasized that this material does not represent a significant expense compared to the outcome of improved microsurgical skills from trainees, which subsequently improves patient care prognosis, decreases hospital stay, and surgical time, which will ultimately benefit the entire hospital. Another part of the material was donated directly from the warehouses of our hospital, and the rest from the maternal and child hospital, being surplus material that was overbought, in disuse, or expired after the COVID-19 pandemic. We were also provided with containers and bags for medical waste by our institution. In almost any hospital, the acquisition of these resources can be achieved through a well-founded request with the support of the department head, as in our case.

Non-departmental economic resources

On the initiative of our group of residents, the collection of money from a part of the scholarships of each of the residents (18 residents in total), as well as some complementary economic donations by some of our most junior neurosurgeons and one of our senior neurosurgeon, by doing this, it was possible to obtain $ 1,408 that allowed the following basic material to be purchased: Carpentry custom made wood tables, a wooden bench made, low-cost high chairs from the department store, trays, plastic and storage containers, a cooler, a small second-hand refrigerator, a fan, a high-speed motorized craniotome for dental use, and basic low-cost microsurgical material which were purchased online [Figure 1a]. Some residents donated a couple of boxes of cigarettes, which were helpful in practicing fine movements. Another of our residents donated part of his own microsurgery material. Furthermore, purchased with this resource were the supplies to perform the filling techniques, which were as follows: bottles of liquid latex, red and blue acrylic paint, belts, and some specific microstructures. Another item purchased online at low cost was an endoscopic fiber optic plumbing camera with integrated light capable of being projected on mobile devices, tablets, screens, or PCs.

Microscopes

Two old model microscopes were donated by a senior neurosurgeon, which requires an external light source for their operation; a junior neurosurgeon donated a used small benchtop stereoscopic binocular microscope with arm and light emitting diode light included and a resident donated a similar benchtop stereoscopic microscope [Figures 1b-d]. Microscopes can be obtained by donation as we did, and although, in our country, it is more difficult for an institution to donate an old or discontinued microscope, in the same way, that it is difficult for the industry to donate to suppliers because they do not obtain a mediate benefit; however, this option can become plausible as mentioned in the work of Liu *et al*.[22] in 2015. We have considered the use of the low-cost exoscope as an alternative equipment for laboratories because the prices of microscopes are out of reach for a large volume of institutions around the globe; this equipment allows easy mobility and does not require much space.[9,12,30]

Borrowed material

There is a tripod for the camera and a semi-professional camera owned by one of the residents to obtain high-quality anatomical photographs; if, in some instances, it is not available, you can perform the same process with a mobile phone of whichever has the better-quality camera, subsequently is easy to make an edition resulting in very high-quality work. In case you do not have a semi-professional camera or do not have experience in editing photographs from mobile device cameras, a plausible option would be to hire a professional photographer and make the payment through the economic collection as mentioned before or offer that the photographs will be published in journals that will contribute significantly to the development of microneurosurgery. At the moment, we have a light source and an optical fiber cable that adapts to the source, borrowed and owned by one of our senior neurosurgeons. There are also borrowed telescopic magnifiers owned by some residents on those occasions when the light source is not available. After preparing a properly requisitioned and justified request, we are waiting for a donation of two portable light sources

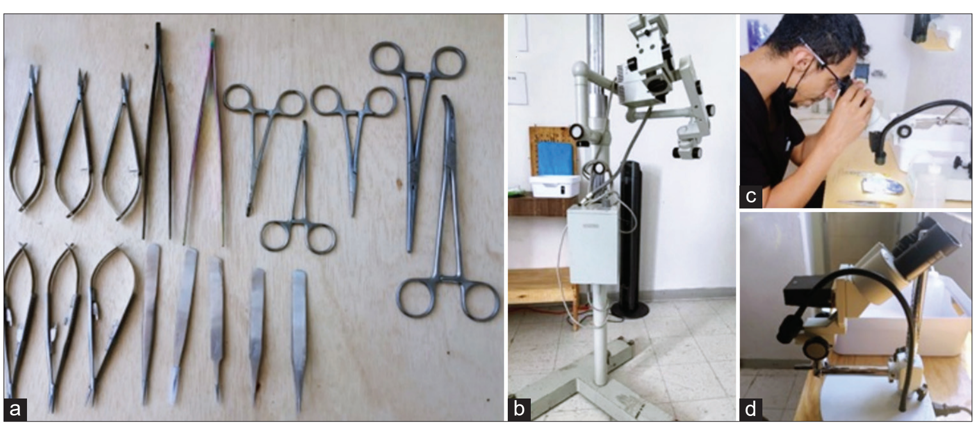

Figure 1: (a) Microsurgical instrument set. (b) Basic low-cost microsurgical material which was purchased online. (c and d) Stereoscopic binocular microscope with arm and light emitting diode light included and a resident donated a similar benchtop stereoscopic microscope.

from our institution. We know that the option of "loaning material" is not ideal and, in many cases, can be difficult to achieve; however, in our experience so far, it has worked as a complement to the operation of the laboratory.

Space for the establishment of the laboratory

One of the greatest difficulties, without a doubt, is obtaining the space to establish the laboratory; in our case, before an initial denial from the hospital authorities, we presented our project again through a more formal request that got us a small hospital room in a disused room in another hospital apart from ours, this caused the relative difficulty of moving between one hospital to another. After several months of effort, we presented our advances to our hospital authorities. Finally, we were given a large space that was, for a long time in disuse, away from the hospitalization area, located within our own neurosurgery department next to the residents' office.

It is hard work to find a suitable space. Once found, it is equally challenging to achieve authorization from the institutions, so it is advisable, before looking for the space, to have at least the bases and foundations of the project as well as the objectives; this will help in convincing the corresponding authorities since, most of the times, these are doctors with administrative positions who are not related and unfamiliar with the subject. This becomes even more complicated when it comes to purely administrative authorities outside the medical area, who have little understanding of the importance of microsurgery. It is necessary to look for disused spaces in hospitals, which, when used for this purpose, do not affect the hospital's workflow in any way. Ideally, it should be at least within the headquarters itself, away from the hospitalization areas, and be a prominent place with sinks (or at least a large sink), a bathroom, a good ventilation system or large windows (preferable), and a dedicated area for temporary storage, control, and management of infectious biological hazardous waste (medical waste).

Placental biological specimens

Placental specimens are easily accessible in any hospital that has an established gynecology and obstetrics service and can be obtained through local agreements with such service whenever necessary, as well as respecting the biosecurity guidelines when handling these specimens as they are medical waste.

Brain specimens product of autopsy

As in many hospitals, access to cadaveric specimens for study purposes can be very challenging, so we submitted a legal document to the hospital scientifically justifying the project. This legal document followed the federal health law of the country and the guidance of the pathology department regarding the proper use and disposal of organic material. The resident's job consists of brain extraction during the autopsy, fixation process, vessel repletion, macro, and microscopic study, meticulously caring for the specimen in each phase, and the cutting and final inclusions of lamellae are done by the pathological anatomy service.[10,38] In this document, each of the processes of the brain specimen is detailed and recorded in a specific and meticulous way; however, it is not part of the present work and leaves the objectives of this, so only mention of it is made. Even if it does not take long for residents to understand the altruism of body donors and the educational contributions they have made to their education and career preparation, it is important to instill in residents a deep respect for the incredible gift of learning that donors have given to science.[3] To obtain cadaveric specimens, it is necessary to know widely and exhaustively the federal and local laws of each country and state regarding its use for academic and study purposes, knowledge of the protocols for the final disposal of cadavers, organs, and human tissues, as well as the internal regulations of the hospitals since this varies from one country to another and even from one state to another within the same country. In our case, it was also necessary to widely know the laws and regulations on pathological anatomy laboratories and the process of autopsies. This can represent one of the greatest difficulties, depending on the laws and regulations as well as agreements between services in each hospital, state, and country [Figure 2].

Figure 2: Access to cadaveric specimens for study purposes can be very challenging, so we submitted a legal document to the hospital scientifically justifying the project. This legal document followed the federal health law of the country and guidance of the pathology department regarding the proper use and disposal of organic material.

RESULTS

We took on the task of searching publications and bibliography on microsurgery; in our search, we found the "Practical Manual of Vascular and Nervous Microsurgery"[32] of Dr. Muñoz Cobos and Lecona Butrón, whom we contacted and obtained his authorization as authors to use his manual. We used this manual as a guide to make our list of necessities with some modifications to adapt it to our infrastructure and other changes adapted to our possibilities. The most important and fundamental part is the proper knowledge of the materials and regulations of the laboratory as well as the ergonomics of the equipment and surgeon.[5,7,22,25,29,39,43] There is infinite bibliography on microsurgery that can be very useful simply by searching keywords such as "microsurgery," "microneurosurgery," and "neuroanatomy," and "microsurgery laboratory," "microsurgical skills," and "microsurgery manual" in databases of articles and scientific publications. Our list consists of 16 practices divided into four items with each type of material and specimens: (1) practices with inanimate material; (2) practices with biological specimens (placental vessels); (3) practices with brain specimens product of autopsy; and (4) practice with 3D printing skull models. The practices were carried out with a frequency of 1 practice per week for 16 weeks by neurosurgery residents of our service all grades as well as some neurosurgeons, achieving with this not to affect or alter the activities corresponding to the previous routine of the residency.

Practices with inanimate material

These practices were divided into three subgroups: (a) microsuture, (b) fine movements, and (c) microanastomosis. Each of these subgroups, in turn, consists of two practices. For microsuture practices, we used latex gloves stretched on wooden plates cut with a central hole or tensioned in large plastic lids, on which the 10 mm "incision" was marked [Figure 3a] and cut with microscissors to perform microsutures, initially with nylon 7-0, followed by microsutures with nylon 10-0 in incisions of 5 mm, ten separate stitches and ten continuous stitches are made with both sutures. For the practices of fine movements, a cigarette adhered with an adhesive cloth to the work tray was placed under microscopic vision [Figures 3b-d]. The tobacco leaves are removed one by watchmaker's tweezers until the cigarette is completely emptied, without breaking the wrapping paper as it deepens (Empty two cigarettes for each resident). It continued by doing consecutive single stitches through the fibers of gauze under microscopic vision for at least 30 min; finally, the microsuture practice was repeated, and the timed duration was compared with those of the first microsuture practice. Summing up:

- Microsutures 1 (With latex glove stretched on a wooden plate or lid)

Figure 3: (a) Residents donated part of his own microsurgery material. (b-d) Some residents donated a couple of boxes of cigarettes, helpful in practicing fine movements.

- Fine movements 1 (With cigarette and tobacco leaves)
- Fine movements 2 (With gauze)
- Microsutures 2 (We repeat the practice of microsutures and compare the improvement in quality and time)
- Microanastomosis 1 (term-terminal in silastic tube)
- Microanastomosis 2 (laterolateral in silastic tube, longitudinal repair).

For the practices of microanastomosis, silastic tubes were used (caliber/diameter of the neonatal proximal catheter of ventriculoperitoneal shunt) fixed with adhesive cloth to the working tray and cross-sections were made for termino terminal anastomosis, and longitudinal cuts of 10 mm for longitudinal repair,[19] in this practice time, were not taken into account, but the quality of the microanastomosis, finishing the practice until obtaining microanastomosis without leakage of liquid, to make the training as real as possible, we have developed a 3D printed skull model with a silicone brain 1:1 scale and adapted the silastic tubes.[13]

Practices in biological specimens (placental vessels)

After the acquisition of placental specimens, we used the technique of repletion with liquid latex and acrylic paint, with red color for the arteries, and blue color for the veins.[33] The goal was to differentiate the superficial venous drainage and deep surface arteries with blue and red colors. Furthermore, we simulated the Sylvian fissure by placing a placental specimen folded on itself inside a 3D-printed skull to add depth practice under the microscope [Figures 4a and b].[15] After each use, these specimens were handled as medical waste according to the hospital's protocol. Summing up:

- Placental vessel filling technique
- Microdissection of placental vessels
- Simulation of microdissection according to the disposition of cerebral vessels
- Sylvan Valley microdissection simulation; in addition, it is possible to simulate clipping aneurysms with Fogarty catheters and tumor resection with colored silicone.[15,35]

Practices in brain specimens obtained after the conclusion of the autopsy

In cases of autopsy, after the adequate extraction and detailed macroscopic analysis were finished by the forensic department, rigorous selection criteria were established in accordance with our previously mentioned agreement with this department; furthermore, each specimen (two brains) was fixed.

Descriptive anatomical photographs of the cerebral vasculature were obtained, including cerebral vasculature, arachnoid, and vessel microdissection exposed the anatomy of the cerebral cortex, also the lateral and basal faces [Figures 4c and d], and lastly, detailed photographs of the brainstem. After this process, each specimen was returned to the pathological anatomy service for cutting, inclusion, and lamination. The whole process followed official norms according to the federal laws of our country. Finally, the final product consisted of one hemisphere for each specimen that would be deposited in medical waste bags after use and before being discarded, it was subjected to freezing by the Klingler method, taking advantage of the sagittal section for taking photographs of the medial aspect of the brain and allowed the process of dissection of white fibers always with their respective photographs [Figure 5a] to finally be discarded following hospital protocol for its management as medical waste. This is how we got the most out of each specimen:

- Cerebral vessel filling technique;[33] in addition, it is possible to simulate clipping aneurysms with Fogarty catheters and tumor resection with colored silicone[15,35]
- Macroscopic Study and Microdissection of Grooves, Gyres, and Cerebral Vessels
- Ventricular puncture workshop
- Approaches (e.g., amygdalohippocampectomy) without damaging the anatomical structures of interest for the inclusion of the autopsy lamellae
- Klingler method and white fiber dissection.

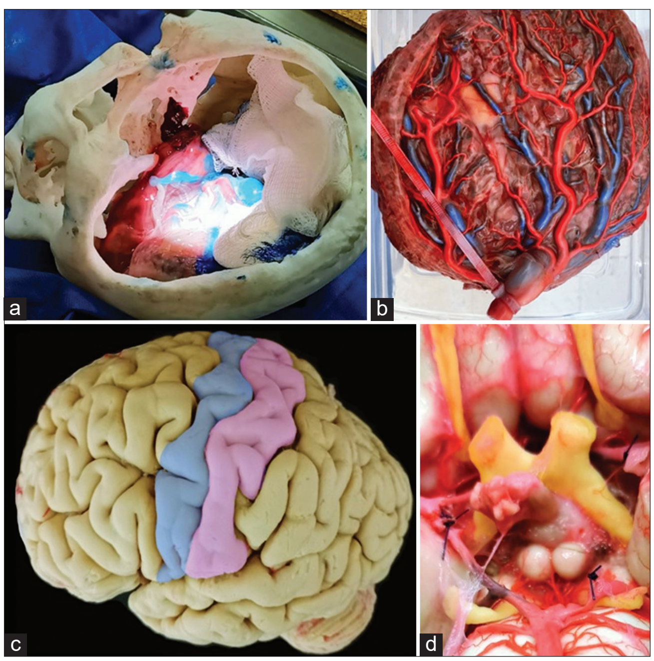

Figure 4: (a) Model of a skull printed in 3D dental resin. (b) Placental specimens are easily accessible in any hospital that has an established gynecology and obstetrics service and can be obtained through local agreements with such a service whenever necessary. (c) Cadaveric specimen donated by the institute of pathological anatomy. (d) Cadaveric specimen in which latex and dye were injected into the blood vessels.

Practices in 3d printing models

We developed a self-made 3D skull model using volunteers for 3D skull modeling. This method offers a convenient and cost-effective alternative for 3D-printed skulls; these models allow the execution of different approaches during drilling workshops. Through our experience, we have found that dental resin is the material that more closely resembles bone in terms of its properties and characteristics.[36]

Basic microsurgery laboratory in a second-level hospital

The dissection stations should mimic the operating room environment.[22] At present, our laboratory consists of four workstations; two main stations and two secondary stations, each equipped with the following [Figure 5b]: (1) an old surgical microscope (Main stations) with a shared light

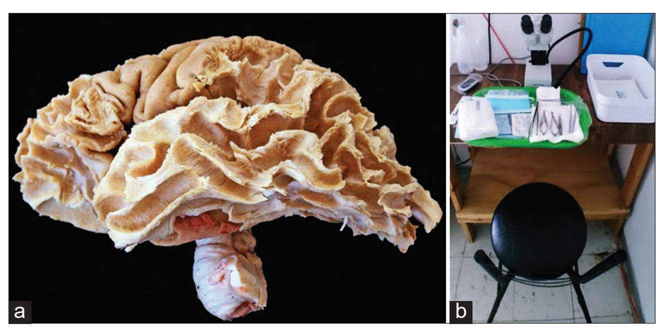

Figure 5: (a) Cadaveric specimens are used for white matter dissection. (b) Work area for white matter dissection.

source or sometimes replaced by telescopic magnifiers; (2) a small used benchtop stereoscopic microscope (Secondary stations); (3) a work table; (4) a high chair; (5) a work tray; (6) a material container; (7) basic set of microsurgery (microscissors, Castroviejo needle holder, watchmaker's clamp, and microsutures 7-0 and 10-0); (8) a copy of the practical manual of vascular and nervous microsurgery and related bibliography; (9) a set of compresses, gloves, disposable gowns, disposable surgical fields, and gauze masks; (10) wooden board for dissection of animal specimens (In disuse since we do not have adequate space or conditions to keep animal specimens); and (11) one 3D printing skull model (Main stations). We also have a small room within the laboratory used for temporary storage and preservation of biological specimens, where 10% of biological specimens are adequately preserved in formaldehyde. Both rooms are divided by a sliding door, allowing the division of our work and storage space (this includes sutures, forceps, syringes, an endoscopic camera, and a light source). We have a washing and specimen preparation station consisting of a large tray, and part of the facilities are complemented with material for these purposes (probes, catheters, physiological solution, containers with formaldehyde, acrylic paints, liquid latex, sutures, belts, as well as surgical soap and container for washing surgical instruments). We have a small library consisting of a table and a wooden bench where we place all of our bibliography related to microsurgery, surgical neuroanatomy, and neurosurgical approaches. Finally, we have an anatomical and scientific photography station consisting of a desk covered with non-reflective black fabric and a cardboard box that is covered with the same type of fabric that reduces decrease brightness and light reflection to obtain better photographs with the semi-professional and tripod camera or with the mobile devices of the residents.

Microsuture, fine movements microanastomosis

Time and quality of skills were made in 3 weeks. After timing 11 residents when performing microsutures for the 1st time of ten separate simple stitches and ten continuous single stitches, the average times for each type of suture obtained were 30.06 min and 19.84 min, respectively; in addition, we analyzed the quality, firmness, and resistance of the stitches, the distance between stitches and adequate knot, classifying them in three categories, as good quality 36.36%, fair quality 36.36% if features one failed feature, and poor quality 27.27% if two or more of the features failed.

After this, the practices of fine movements were performed. Then, the time and quality of the microsutures were timed again, obtaining a notable decrease in the "surgical time," is the new averages of 21.4 min and 13.33 min, for the separate single interrupted and continuous single stitches, respectively, after three weeks the average decrease to 8.65 min for the separated single stitches and 6.51 min for the continuous single stitches. There was also an increase in the quality of the stitches and the suture pattern, reducing the space between each stitch and finding more resistant knots; good quality 63.63% and regular quality 36.37% improved significantly after the aforementioned weeks. In addition, there was a marked improvement in the technique and handling of the microsurgical instruments, with many of the residents describing greater self-confidence [Figures 6 and 7; Table 1]. Finally, after studying and practicing the triangulation technique, microanastomosis was carried out without a time limit until no leakage was observed in the totality of the cases [Figure 7]. Another low-cost alternative is the dissection and replication of the microanastomosis in a cadaveric animal model of a chicken wing, finishing the practice in the same way until making a microanastomosis without leakage.[7,8]

Placental vessels

A satisfactory and high-quality replenishment was obtained in all the specimens used after a brief explanation and support of video material on the technique, as well as advice by

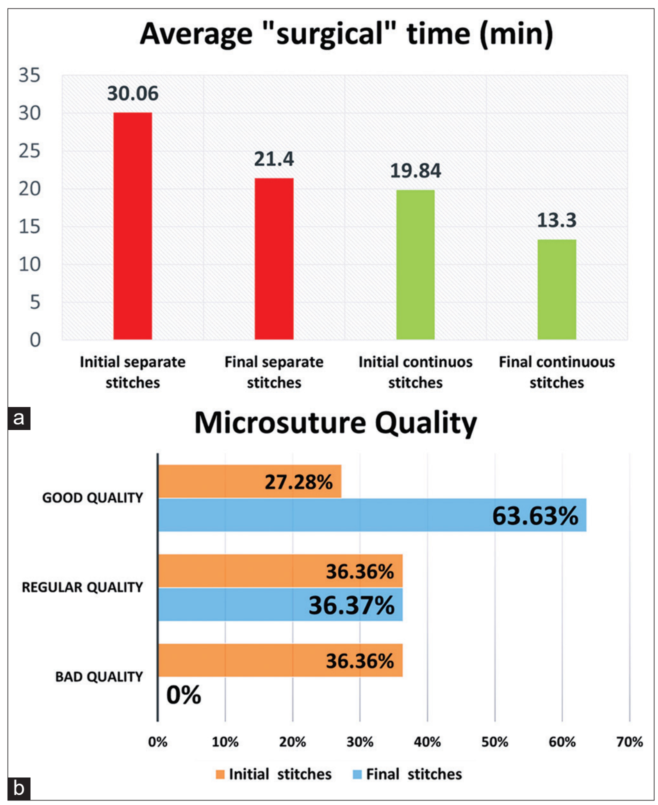

Figure 6: (a) It shows the average "surgical" time. A decrease in the average "surgical" microsuture was obtained, with an average decrease of 8.65 min for the separated single stitches and 6.51 min for the continuous single stitches. (b) It shows the improvement in the quality of the stitches, according to the mentioned parameters, after the microsuture and fine movement practices.

Table 1: Initial and final results after performing the practices of microsuture and fine movements. A decrease in the average "surgical microsuture" was obtained, as well as an increase in the quality of the stitches improving the suture pattern, reducing the space between each stitch and finding more resistant stitches.

Microsuture practice	Initial separate stitches	Initial continuous stitches	Final separate stitches	Final continuous stitches
Average "surgical" time (min)	30.06	19.84	21.4	13.3
Bad quality	36.36%	36.36%	0%	0%
Regular quality	36.36%	36.36%	36.37%	36.37%
Good quality	27.28%	27.28%	63.63%	63.63%

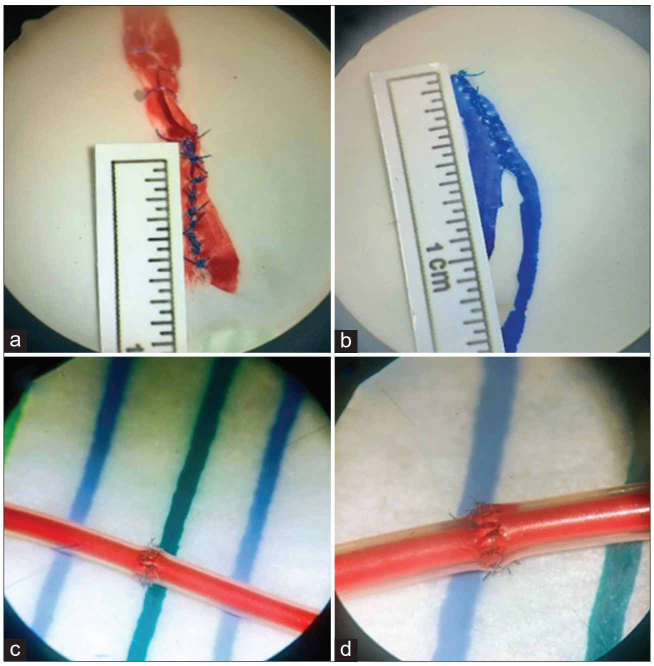

Figure 7: (a and b) Suture on a latex glove, the coloring of the area to be sutured. (c and d) The synthetic sanguineous vessel was sutured under a microscope.

telephone from a vascular and skull base neurosurgeon with experience in the field. In addition, an adequate simulation was obtained for the practice of microdissection in a small and deep space by placing specimens inside 3D printing skull models [Figures 4a, b, and 8].

Descriptive anatomical photographs of the cerebral vasculature and white fibers

Multiple anatomical-descriptive photographs have been obtained from this work, which can be used as an important source of reference and anatomical study and laboratory library. Figure 9 shows examples of anatomical descriptions of the Sylvian fissure on the lateral face, the inferior frontal gyrus, the parietal lobe, and the anatomy of the pineal region, as well as the white fiber dissection of the superior longitudinal fasciculus and uncinate fasciculus.

DISCUSSION

Establishing an affordable microsurgery laboratory in low-income countries presents numerous challenges due to limited resources and financial constraints. Hosain[16] reported that "the ideal training model should be without ethical issues, realistic, inexpensive, easily available, and similar or close to the clinical setting." Many authors have shown the importance of cadaveric studies to improve the understanding of neuroanatomy and neurosurgical approaches.[4] It should be noted that the title of this paper mentions "low-resource countries" precisely because many hospitals with low or no resources for microsurgical training are located in low- and middle-resource countries. It is for all this that is not a space for training and development of microsurgical skills in our hospital; we took on the task of developing a microneurosurgery laboratory with basic instruments, mainly with non-departmental resources, complemented with donations from our senior neurosurgeons, as well as basic hospital material provided by our institution; initially, the most difficult aspect was to get the space for the allocation of the laboratory, which after much persistence was finally also provided by our institution. This comprehensive guide aims to address these challenges by outlining the necessary steps and objectives involved in setting up a specific need-tailored laboratory that can be specific to residents' needs regardless of the year of training.[6,20,27,42] This guide fulfilled our objectives, that consisted of identifying key deficiencies in our center equipment required, obtaining and providing guidance in cost-effective sources of microsurgical equipment, offering strategies for laboratory setup and optimization, developing training objectives and creating a curriculum, incorporating simulation and virtual training resources, and establishing quality control protocol while at the same time facilitating access to knowledge sharing and collaboration. By achieving these objectives, the guide aims to empower low-income hospitals and neurosurgery residents to enhance their microsurgical skills and improve patient care.

Another important challenge in establishing microsurgery laboratories is the limited availability and high-cost equipment and resources. Hopefully, we addressed enough of this challenge by providing recommendations

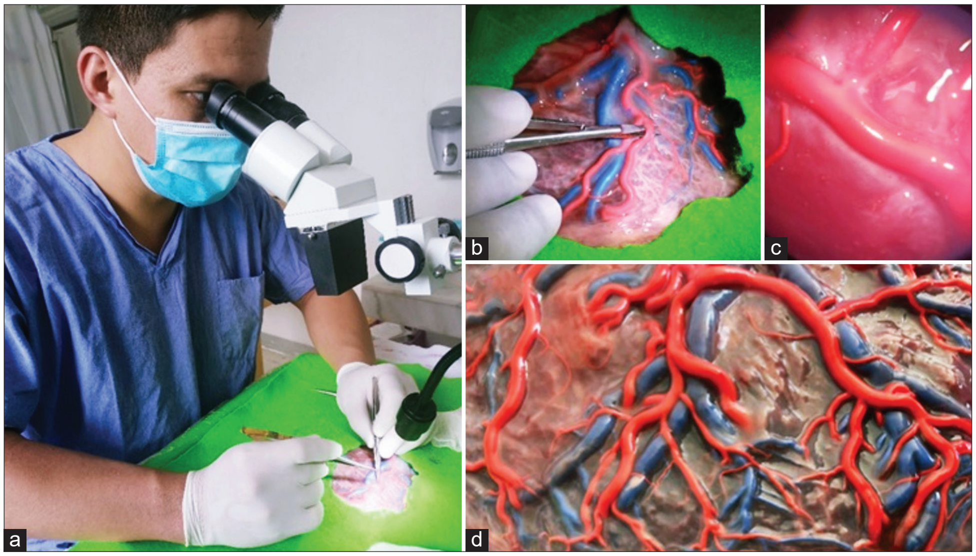

Figure 8: (a) Resident in neurosurgery practicing micro suturing under a direct microscope. (b-d) Blood vessels in the placenta are filled with blue and red latex and dyes.

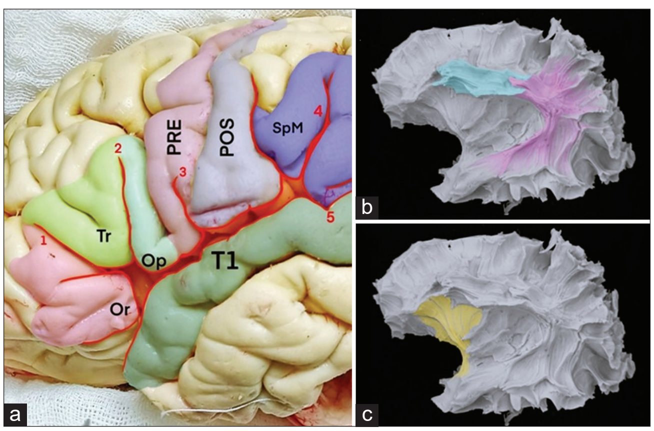

Figure 9: (a) Specimen of the cerebral hemisphere in which the lateral sulcus can be observed. (b and c) With the Klinger technique, the arcuate fasciculus can be observed in one of the cerebral specimens. Or: pars orbitalis; Tr: pars triangularis; Op: pars opercularis; PRE: precentral gyrus; POS: postcentral gyrus; SpM: supramarginal gyrus; T1: superior temporal gyrus.

for affordable alternatives, such as refurbished or donated instruments, collaborating with medical device manufacturers for discounted rates, and exploring local suppliers. By leveraging these cost-effective options, low-income hospitals can overcome financial constraints and acquire the necessary equipment for their microsurgery laboratory. Another important aspect discussed in this guide is the setup and optimization of the microsurgery laboratory. Recommendations are provided for the layout, ergonomic considerations, lighting, and sterilization processes to ensure a safe and efficient learning environment. These suggestions must consider the potential problem of limited space and aim to maximize the functionality of the laboratory while keeping costs low. The development of training protocols and a tailored curriculum is crucial for enhancing microsurgical skills in neurosurgery residents.[22]

This guide emphasizes the importance of comprehensive training, including skill-building exercises, progressive learning modules, and hands-on training techniques that can be implemented within the laboratory. In addition, the integration of simulation-based training and virtual reality tools is explored as a cost-effective option to augment the microsurgical training experience. By incorporating these innovative training methods, residents can further enhance their skills in a controlled and immersive environment. Quality control plays a significant role in maintaining the effectiveness of the microsurgery laboratory. This guide highlights the importance of regular equipment maintenance, instrument sterilization, and protocols for infection control. By establishing and following these guidelines, hospitals can ensure a safe and hygienic learning environment for residents, minimizing the risk of personnel contamination and keeping patients safe.

Furthermore, this guide emphasizes the value of knowledge sharing and collaboration. It provides strategies for fostering partnerships with external organizations or institutions that can provide support, resources, or mentorship. The increasing use of virtual reality research, virtual meetings, online education initiatives, and telehealth, initially introduced out of necessity during the COVID-19 pandemic, represent interesting tools to expand their knowledge and research among low-income country residents.[1,17,21,24,31,40] By networking and exchanging knowledge with experts in the field, low-income hospitals can enhance their microsurgical training opportunities and stay updated with the latest advancements.

The impact and effectiveness of the established microsurgery laboratory can be evaluated through a well-designed evaluation framework. This guide suggests gathering feedback, tracking progress, and measuring outcomes to improve the training program continuously. By assessing the impact of the laboratory on improving microsurgical skills and reducing morbidity rates and complications associated with neurological surgeries, hospitals can further refine their training protocols and curricula. We have a consensus on what was mentioned by Joseph *et al*.,[19] that is to say that "there is a need to build homogenous assessment tools and validate the role of simulation in education and patient safety." As Professor Yasargil mentioned, "The younger generation of neurosurgeons will have spent more time in laboratory training, deepening their knowledge of neuroanatomy, and gaining experience in surgical techniques."[44] This inspired our work to bring microsurgery to any low-income countries/low-resource hospitals, so we considered the existence of a hospital training neurosurgery residents without a proper laboratory for microsurgical training unacceptable.

CONCLUSION

Establishing an affordable microsurgery laboratory in low-income countries is a challenging but achievable goal. This guide has outlined what we believe to be some key steps and objectives involved in setting up a low-cost microsurgery laboratory tailored to the specific needs of neurosurgery residents. We emphasize the importance of identifying cost-effective alternatives for equipment sourcing, such as refurbished or donated instruments, collaborating with manufacturers for discounted rates, and exploring local suppliers. These strategies can help overcome financial barriers and ensure the availability of necessary equipment. Hopefully, this comprehensive guide could serve as a roadmap for establishing an affordable microsurgery laboratory in low-income countries. By addressing the challenges, providing recommendations, and offering strategies, this guide aims to empower neurosurgery residents and show these countries that by enhancing the microsurgical skills of trainees, there is better patient care, fewer complications, and shorter hospital stays.

Ethical approval

This study was approved by the Bioethics Committee of the RUDN University, Russian Academy of Sciences named after B.V. Petrovsky, Moscow, Russian Federation (Jan 10th, 2022).

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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