RESEARCH ARTICLE

Developing a non-cadaveric brain tumour surgery lab in resource-constrained settings

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Abstract

Objective: To develop the country's first brain tumour surgery lab in resource-constrained settings, for training young neurosurgeons and residents.

Methods: A workshop was developed using mixed-fidelity models for assessing and training a participant's psychomotor skills, hand-eye coordination, and teaching the principles of brain tumour surgery. Affordable non-cadaveric models were used to compare and contrast the benefit of each teaching model. Within the existing space for wet labs at our institution, 8 different dissection stations were set up with adequate space for 2 people to work at a time. Each station was equipped with an operating room-Caliber microscope, a lighting system and a camera linked to a screen and high-powered electric drills and basic surgical equipment.

Results: Our team was able to develop and use 3D-printed skull models and animal brain models for training in complex approaches and craniotomy.

Conclusion: Surgical simulation training, in a cost-effective manner, provides the benefit of training residents and students in neurosurgical techniques in a safe, controlled environment leading to improvement in skills and technique.

Keywords: Neurosurgery, surgical oncology, simulation training, Brain Neoplasms, Craniotomy, Skull

(JPMA 74: S-3; 2024) **DOI: https://doi.org/10.47391/JPMA.S3.GNO-02**

Introduction

The Accreditation Council for Graduate Medical Education (ACGME) tracks the progress of neurosurgical residents using the volume-outcomes model; the number of procedures performed is correlated with improved training and ultimately, patient outcomes.[1] Technical proficiency is imparted through real-world experience and competency-based programmes. As these skill sets mature, residents are expected to take on more responsibilities in the operating room (OR) in order to become independent surgeons.[2] Most neurosurgery residency programmes all over the world follow this approach.

The master-apprentice system of consultants teaching procedures newly-graduated surgical trainees on patients hampers the quality and safety standards of a healthcare centre. In the modern era of neurosurgery, there are greater limitations in place to protect patients and improve outcomes. In order to continue surgical education in line with current restrictions and standards, anatomical and surgical skills labs in neurosurgery have been developed as link to the volume-outcomes model and accelerate residents through the required learning curve.[3,4] Residents are able to master anatomical nuances and approaches, for example through skull base and micro neurosurgery labs, in controlled environments before being given the opportunity to develop further competencies in the operating room.[5,6] This includes cadaveric simulations and the use of operating room tools and microscopes for near-perfect surgical simulation. Simulations allow surgical trainees to practice, make errors and learn without negatively impacting any patients. In a safe setting, this practice builds confidence as young neurosurgeons polish their psychomotor skills. Many companies have even developed non-cadaveric virtual simulators and virtual reality applications for further training in settings where ethical access to cadavers is not available.[7]

The transferability of the volume-outcomes model to resource-constrained settings is difficult. Within our own centre and experience, issues have been faced in residents' case numbers and developing clinical independence, as is similar in programmes across the world.[8] The COVID-19 pandemic has only widened this gap in resident education and digital platforms are being employed as a solution.[9,10] Digital didactic lectures and

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conferences are not sufficient for developing hand-eye coordination and neurosurgical skills that are the cornerstone of residency. The solution is investing in neurosurgical labs in low-and middle-income countries (LMICs). Investing in Simulation-Based Training (SBT), low- or high-fidelity, permits surgical residents to perfect their abilities through milestone achievements on the learning curve. At this current time, Virtual Reality (VR) high fidelity systems are unsustainable in LMICs as the costs outweigh any foreseeable returns.[10] Therefore, in resource-constrained settings, we developed the country's first brain tumour surgery lab for the training of young neurosurgeons and residents. We hope to build on our current model in order to improve the quality of neurosurgical training in LMICs.

Methods

It is with this dilemma in mind that our centre developed the country's first brain tumour surgery lab (BTSL) at the Aga Khan University Hospital, Karachi, with a pilot training module for young neurosurgical residents and aspiring medical students. Our focus was primarily non-cadaveric training with graduated levels of complexity. This ensured skills assessment, supervision, and feedback for the participant. Using the existing space for wet labs at our institution, 8 different dissection stations were set up with adequate space for 2 people to use at a time. Each station was equipped with ample space as shown, an operating room-Caliber microscope, and a lighting system, equipped with a camera that linked to a screen at every station. This allowed us to teach various procedures and microscopic techniques to all members of the group. High-powered electric drills and basic surgical equipment was provided at every station (Video 1).

With a focus on brain tumour surgery, a curriculum was developed for both medical students interested in neurosurgery and neurosurgery residents, with recommended reading and references to "Getting Ready for Brain Tumour Surgery" by Michael Sabel.[11] The junior curriculum focused on skull anatomy, surgical techniques and approaches in neuro-oncology, orientation to surgical tools, and interpretation of CT/MRI scans for brain tumours. The senior curriculum was tailored to focus on advanced craniotomy approaches and micro neurosurgical techniques. After initial didactic sessions, groups would be advanced to dissection tables. Dissection models and sessions were developed using non-cadaveric prototypes, with the addition of our innovation: three-dimensional (3D) printed skulls, produced locally at cost-effective rates (Figure 1).

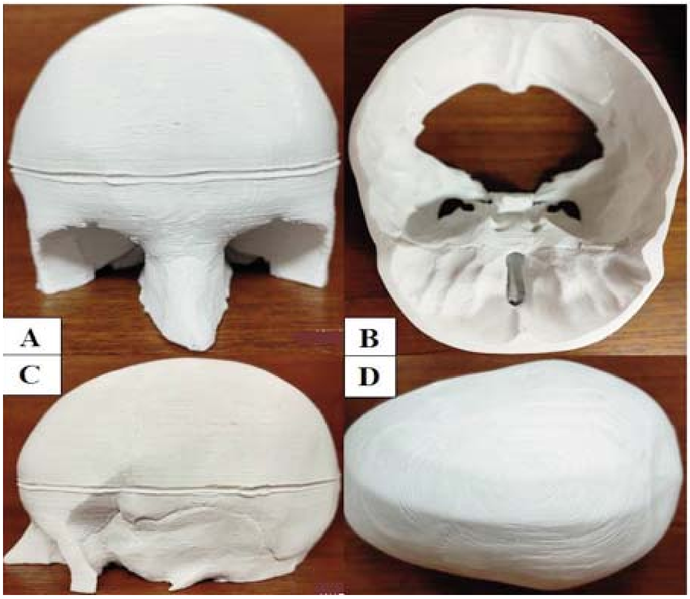

Figure: 3D printed skull model, (A) frontal view, (B) axial cross-section, (C) lateral view, (D) superior view.

Results

Day 1: Coconuts as a prototype for skull craniotomy

Participants were each given ample opportunities to practice and demonstrate basic burr hole procedures on the coconut followed by completion of the 'craniotomy' by use of high-powered drills, similar to the ones used on skulls. Coconuts proved to be adequate models for craniotomy training. Once the shell was pierced, the underlying soft texture would cause the drill to automatically disengage, as is seen when using these drills on real patients. However, the outer shell was more difficult to pierce than the calvarium when using high-powered drills in an OR setting. This comparable experience was incredibly useful in a low-fidelity model.

Day 1: Capsicums as a model for microsurgical techniques

Participants were given tasks to use micro dissectors and micro-forceps on capsicums under an operating microscope. The 'operating surgeon' had to delicately dissect individual targets (capsicum seeds) from their roots without causing damage to adjacent 'tissue', and retrieve it successfully – thus simulating brain tumour resection and dissection. Microsurgical suturing was also taught and practiced on surgical gauze, under the microscope.

Day 2: 3-Dimensional (3D) printed skulls for craniotomy

After graduating from low-definition models, participating students and residents were given 3D printed skull models that were developed to specifications almost perfectly similar to the human skull. Craniotomy and burr hole procedures were elaborated on in the junior curriculum, with attention to approaches in surgical neuro-oncology. Residents were instructed on more complex approaches, with complexities of craniotomy discussed. Groups were given tasks to identify and perform key approaches in craniotomy for brain tumours with evaluation of the performance.

Day 2: Micro neurosurgery skills on animal (goat) brains

Similarly, groups were then given individual animal models using goat brains that had been kept preserved. Under microscopic vision, key anatomical structures were identified, with attention to major lobes, sulci and gyri, arterial structures, and microsurgical dissection of the brain. Neurosurgery residents were taught and performed corticectomy procedures, dissection of the Sylvian fissure, and approaches to deeper structures of the brain. Microsurgical dissection was practiced.

Discussion

Surgical training using simulation was a necessary inspiration from the airline industry teaching their pilots using flight simulators. A study at Yale University showed a remarkable decrease of 30% in operating time and 85% decrease in operative errors by adopting 'criterion-based simulator training'. In today's time, a surgeons' competency is determined by their patient outcomes; better only to be achieved by dedication and diligence. SBTs provide that edge to surgeons by building on their skills.[12]

Our SBT via the brain simulation training lab is a key step in building capacity for surgical training within an LMIC such as Pakistan. As mentioned previously, the ACGME currently requires neurosurgery residents to log 60 "craniotomy for brain tumour" adult population cases where the resident is senior resident surgeon or lead resident surgeon.[1,13] In order to develop the skills necessary for a resident to be able to perform at such a level, they need adequate training in controlled environments that only surgical labs can provide.[14] Our simulation provided gradual development of skills through the use of low-fidelity (coconuts and capsicum model) to high-fidelity (3D printed skulls, animal brains) models of training (Table 1). Residents can be taught complex approaches to cases they may not previously

Table -1: Cost-Benefit analysis of simulation models

Model	Cost	Analysis	
		Skills assessed	***Limitations***
Coconut	PKR400 (USD 2.48)	Hand-eye coordination with craniotome and electric saw	Coconut shells are tougher to penetrate than human skulls
		Performing a standard craniotomy	Cannot assess if damage done to underlying structures – a key consideration in performing craniotomy
Capsicum/Bell Pepper	PKR100 (USD 0.62)	Fine-movements with hands, hand-eye coordination using instruments, and dexterity under microscope	Structures are well-defined in capsicum, whereas more difficult to differentiate grossly in cortical brain
		Familiarity with focusing and zooming in with the microscope	Does not assess the importance of avoiding nearby vascular structures
		Principle of the inverted pyramid in micro neurosurgery	
3D printed skull	PKR10,000 (USD 61.96)	Advanced craniotomy principles including constructing a bone flap, considerations for individual approaches	Relatively higher cost than other models
		Complex skull base approaches	Time required for printing
		Principles of keyhole cranial surgery	3D printers may not be widely available at every institute
Animal brain	PKR500 (USD 3.10)	Handling brain tissue with microsurgical instruments	Difference in structures from human brain
		Principles of subpial resection and sulcal anatomy	

have experience with, and hone their technical and surgical awareness before entering the OR. We hope to develop this programme and lab further to include complex skull base approaches and greater use of our 3D printed models.

3D printed skulls that are cost-effective as well as accurate depictions of surgical anatomy can also be used in improving surgical planning and accuracy. Anatomical 3D printed models are useful in-patient education regarding their disease, developing preoperative tactile memory for surgeons, and allowing accurate planning of surgical technique and anticipating challenges before the surgery. It has also been used in surgery as an anatomical reference in avoiding perioperative complications, guiding surgical manoeuvres, and improving patient outcomes.[15]

Participants were given an evaluation form at the end of our workshop for feedback on the organization, execution, and areas needing improvement of our training lab. Pre- and post-workshop skills analysis forms can be used to further objectively identify the benefit of this workshop, strengthening the evidence of setting up more of such workshops at a higher frequency and a bigger level. The use of a modified Objective Structured Assessment of Technical Skills (mOSATS) for neurosurgery skills workshops has been justified in the literature.[16] Our next step will be to establish the benefit of the BTSL through quantitative analysis of participants' skills before and after a workshop.

We hope this will serve as a model for further development of surgical labs in LMICs. Analysing our costs, we can see that the major cost will be in buying a functioning operating microscope. This can be done on a budget as we were able to use older models that have been retired from use. Refurbished drills can be used and can usually be obtained at reduced prices or donated from companies for laboratory use. Drill bits that have been lightly used before can be used as well. Microsurgical instruments for laboratory are generally available at low prices from surgical instrument companies. Coconuts and capsicums were available at market rates. Animal brains were similarly procured from local butcheries and stored in fridges. Our model is more affordable than what is currently used in surgical labs in HICs (higher-income countries). Cadaveric specimen can cost upwards of USD 2500 per specimen with additional shipping costs.[1] Our 3D-printed skull model was also comparatively cheaper to produce in comparison with available models from local companies and online-based producers.

Table-2: Summary of recommendations.

▶Low-cost surgical simulations can accentuate the training of neurosurgical residents in basic and advanced skills – these are a major 'link' in developing the independent surgeon in times of greater quality control and patient safety in LMICs.
▶In resource-constrained settings, there is a dearth of complexity in surgical training which is often difficult to teach and overcome without compromising patient care – residents can have a first-hand, free-hand experience in brain tumour surgery in order to 'jumpstart' the learning curve and get ahead.
▶3D-printed skull models are a gateway in developing tactile memory and psychomotor skills for the young neurosurgeon in particular. Surgical strategy of approaches that can be repeated numerous times on an accurate model, as we have shown, can be a key factor in ensuring safe and precise surgical techniques.
▶Ultimately, our patients will benefit in the developing world – training can move away from 'practice on the patient' models towards controlled-environment, graduated surgical training with a near-perfect simulation allowing transference of skills learnt in the lab to the OR.

Conclusion

One of the pillars of building neurosurgical capacity in LMICs is training programmes. As studied previously, neurosurgical residencies in resource-constrained settings need a jump-start in order to improve patient outcomes and train the surgeons of tomorrow. We believe that pioneering training approaches such as the brain tumour surgery lab at our institution is the way forward.

Recommendations: Summary is shown in Table-2

Disclaimer: None.

Conflict of Interest: None.

Funding Disclosure: None.

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