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Review Article

Neuroendoscopy Training

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Abstract

Neuroendoscopy can be learnt by assisting or doing live human surgery, cadaver dissection with or without augmented pulsatile vessel and cerebrospinal fluid (CSF) perfusion, and practicing on live animal, dead animal model, synthetic models, three-dimensional printing model with or without augmentation with animal, cadaver tissue, pulsatile vessel and reconstructed CSF model, virtual reality (VR) simulator, and hybrid simulators (combined physical model and VR model). Neurosurgery skill laboratory with basic and advanced learning should be there in all teaching hospitals. Skills can be transferred from simulation model or VR to cadaver to live surgery. Staged learning (first with simple model to learn basic endoscopic technique, then animal model, and then augmented cadavers) is the preferred method of learning. Although most surveys favor live surgery and practice on animal models and cadavers as the most preferred training model now, in future VR may also become a favored method of learning. This article is based on our experience in over 10,000 neuroendoscopic surgeries, and feedback from over 950 neuroendoscopic fellows or consultants who attended workshops conducted every 6 monthly since 2010. A literature search was done on PubMed and Google Scholar using (neuroendoscopy) AND (learning), and (neuroendoscopy) AND (training), which resulted in 121 and 213 results, respectively. Out of them, 77 articles were finally selected for this article. Most of the training programs typically focus on microneurosurgical training. There is lack of learning facilities for neuroendoscopy in most centers. Learning of neuroendoscopy differs greatly from microneurosurgery; switching from microneurosurgery to neuroendoscopy can be challenging. Postgraduate training centers should have well-equipped neuroendoscopy skill laboratory and the surgical educational curriculum should include neuroendoscopy training. Learning endoscopy is about taking advantages of the technique and overcoming the limitations of endoscopy by continuous training.

Keywords
- cadaver
- neuroendoscopy training
- physical trainer
- simulation model
- surgical skills
- virtual simulators

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Introduction

Although neuroendoscopy has many surgical indications now, as stand-alone or as an adjuvant, it is surprising that despite many advantages of endoscopic surgery, it is not very commonly practiced by most neurosurgeons. It could be due to lack of facilities at most centers and due to steep learning curve in neuroendoscopy. There are advantages and limitations of neuroendoscopy. The greatest advantage of endoscopy is improved visualization, especially of the corners. The advantages in endoscopic technique also come with some limitations. Limitations of endoscopic surgeries are blind area, difficulty in control of bleeding, difficult bimanual dissection due to limited space and through the defined channels, short focal length, need to learn unique neuroendoscopy skills that are different from microscopic technique, two-dimensional (2D) images, steep learning curve, etc. There is a need to overcome these limitations through continuous learning and practice.

In the learning process of neuroendoscopy, there may be initial enthusiasm for the technique, which gradually fades away (►**Fig. 1**) in most surgeons. Senior author Yad Ram Yadav considers that the learning can be divided into four stages: A = idea of the new technique; B = initial enthusiasm due to advantages of new technique and proper case selection; C = decreased enthusiasm due to difficulties in doing complex cases, secondary to the limitations of the technique —most enthusiasts leave the new technique at this stage; D = overcoming limitations by continuous learning. To learn any technique we have to shorten the C stage, by early learning of techniques to overcome limitations and to persist in learning the technique. Learning endoscopy is about taking advantages of the technique and overcoming the limitations of endoscopy by continuous training.

Limitations of endoscopy can be overcome by proper knowledge of the various causes of these limitations and by practicing new techniques on cadavers, models, by watching live surgeries and attending workshops, and practicing on three-dimensional (3D) printing models, virtual simulators, and hybrid models. These models can be augmented by life-like conditions by simulation of blood flow in vessels using infusion pumps, reconstitution of cerebrospinal fluid (CSF) in spine training, etc.

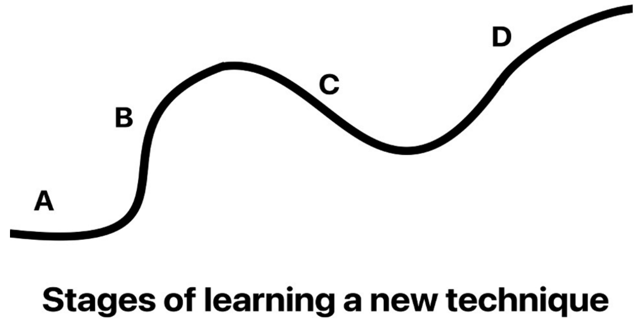

Fig. 1 (**A**) Idea of the new technique. (**B**) Initial enthusiasm due to advantages of new technique and proper case selection. (**C**) Decreased enthusiasm due to difficulties in doing complex cases, secondary to the limitations of the technique; most enthusiasts leave the new technique at this stage. (**D**) Overcoming limitations by continuous learning.

Materials and Methods

This article is based on our experience in over 10,000 neuroendoscopic surgeries, and feedbacks from over 950 neuroendoscopic fellows or consultants who attended workshops conducted every 6 monthly since 2010. Literature search was done on PubMed and Google Scholar using (neuroendoscopy) AND (learning), and (neuroendoscopy) AND (training), which resulted in 121 and 213 results, respectively. Out of them, 77 articles were finally selected for this article (►**Fig. 2**).

Discussion

Neuroendoscopy Training

Learning of neuroendoscopy needs training of both the microsurgical skills[1] and the endoscopic skills. Some of the general principles of neuroendoscopic technique are completely different from microsurgical principles.

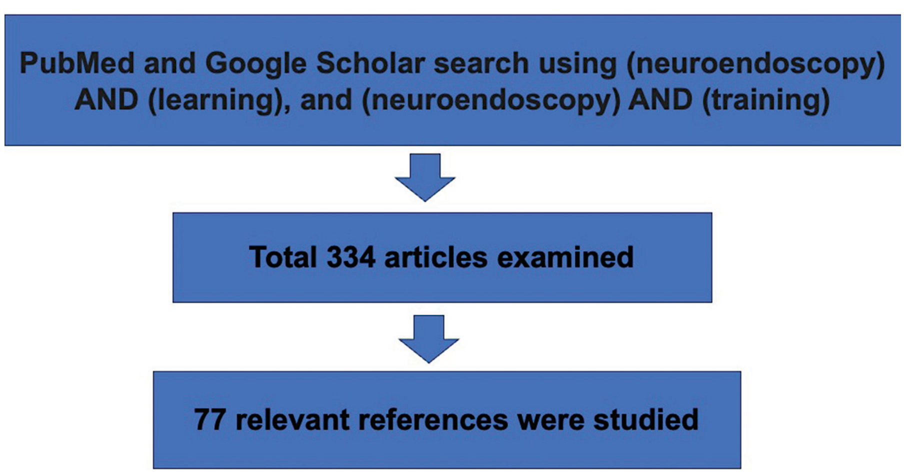

Fig. 2 Literature search on PubMed and Google Scholar using (neuroendoscopy) AND (learning), and (neuroendoscopy) AND (training).

Bayonet-shaped instruments are preferred in microscopic surgery whereas straight instruments are preferred in endoscopy. The surgical target is kept in the center of field in microscopy, whereas target structure can be kept at corner of the field to avoid instrument obstruction by endoscope. There is a blind area in endoscopic surgery, which is not there in microscopy. Orientation may change due to rotation of camera in endoscopy. There is difficulty due to frequent soiling of lens in drilling, which is not there in microscopy. Intermittent irrigation should be done between drilling to avoid lens soiling in endoscopic surgery. Endoscope may obstruct instrument manipulation and there is difficulty in control of bleeding due to lens soiling. There is 2D visualization in endoscopy as compared with 3D visualization in microscope. Transition from microscope to endoscope is difficult. Another obstacle in endoscopy is short focal length, leading to frequent lens soiling. These limitations of endoscopy can be overcome by proper training. Simple procedures should be performed at the beginning of the learning curve, and more complex cases should be done after getting proper experience. Although neurosurgical training is provided at more than 150 training centers across India, the facilities of simulation training for residents are limited. There is a need for more organized neurosurgical simulation training centers in India and worldwide. The neuroendoscopic workshop of 1-week duration is being conducted since September 2010 at our center. It is being regularly organized twice in a year. This consists of 3 days of live surgeries and 2 days of cadaveric dissection for the trainees. During first 3 days, there is a short discussion about the case being operated and a short discussion on the techniques prior to live surgery. Surgeries from two operation theaters are relayed to the seminar hall and there is two-way discussion during surgery. About 12 to 15 live neuroendoscopic surgeries of different types including lumbar spine, cervical spine, craniovertebral region, posterior fossa, endoscopic third ventriculostomy (ETV), deep-seated brain tumors, intraventricular lesions, endonasal surgeries for CSF leak, pituitary and craniopharyngioma, etc. are performed subject to availability of patients. On last 2 days there is cadaveric dissection of brain and spine of 1 day each. A total of 48 trainees are taken per program. This program is very popular, which is reflected by a long waiting list, and it has met the expectations of the trainees.[2] Details about the program is available at https://www.neuroendoscopyjbp.org/Home.aspx#top.

Surgical Skill Training Methods

Endoscopic training can be learned by watching live human surgeries and videos; cadaveric dissection; visiting various departments; using live or dead animal models, synthetic models including 3D printing, laboratory training, virtual simulators, hybrid models, etc.[3–6] Canadian neurosurgeons' survey stressed the need for simulation in ETV for residents.[7] Various training simulators such as Neuro-Endo-Trainer using box trainers[8] and epiduroscopy[9] have been found to be useful in neuroendoscopy. A well-equipped skills laboratory can provide an opportunity for the residents to acquire operative expertise in a similar atmosphere to the operating theater.[10] Training in workshops using step-by-step training programs such as theoretical lectures, video presentations, artificial models, and animal and cadaveric dissections are very useful.[11] Indigenous innovation[2] and interdepartmental coordination can be used to overcome high cost of the instruments.[12] Low-cost exoscopy training using notebook computer, a webcam, and a light-emitting diode (LED) source can be used in resource-constrained situations.[13] Although complications decrease with increasing experience,[14] the surgical learning curve does not plateau. Contrary to popular belief, it can continue for several years depending on the complexity of surgical procedures.[15] Various training models with their advantages and limitations are given in ►**Table 1**. Simulation using various models has the potential in neuroendoscopic training and surgical education. It reduces the harm caused to patients by novices and increases efficiency by reducing the time needed to train in the clinical environment. It also increases the opportunity to repeatedly practice rare procedures in a nonthreatening environment. It can be performed in a tailored way and in controlled environment.

Training on Human

Training on humans is the best method due to similar anatomy and environment. It can be gained by assisting in live surgery performed by experts, watching unedited videos, and visiting another department. Working hour restriction for residents, and limited exposure in routine working hours under expert supervision are the limitations. There is a risk of more complications if a new technique is performed by the beginner. Cadaver training in either formalin-fixed or soft-embalmed cadaver is a useful method of neuroendoscopy learning. Practice on cadavers on the other hand in a less threatening environment with similar anatomy is an advantage. The absence of bleeding or CSF leak, poor availability, and costs are the limitations.

Animal Models

Animals with similar anatomy to humans, such as pig, sheep, and lamb, can be used for practicing transnasal procedures and spine surgeries. A complete training program consisting of different endoscopic procedures such as exploration, membrane fenestration, vessel coagulation, hematoma evacuation, tumor biopsy, and resection can be performed in live anesthetized Wistar rats after creating hydroperitoneum and putting mesenteric membranes, vessels, and the liver in a liquid environment. It is simple, low cost, reproducible, real time, in a live animal tissue.[16] Anesthetized live Wistar rats can also be introduced to a physical trainer with multiple ports to carry out both endonasal endoscopic and port surgeries.[17]

Porcine cadavers (pigs) are good models for lumbar and cervical spine training but religious issues are there. Although there are some anatomical differences, they do not interfere with performing the main surgical steps in the porcine model.[18] Bovine models (sheep like) are easily available and relatively inexpensive. It has no limitations associated with religious issues. These models are reliable for

Table 1 Advantages and limitations of various training models

Advantages of various surgical training methods	Limitations of various training models
Live human surgery: Live human surgery performed by self, assisting the expert, watching unedited videos, etc. is the best method in similar anatomy and environment; considered gold standard; gives hands-on experience	Limited working hours; limited exposure in routine working hours under expert supervision; risk of more complications when new technique is performed by beginner; variability in individual anatomy
Reading surgical books, watching videos, and lectures: Large volume of resources giving insight about methods and techniques is available; user-friendly; can be learnt even when surgeon is away from hospital	Does not simulate operative experience; no hands-on practice
Cadaver training: Cadaver training (wet model) with or without augmentation by vessel perfusion with pulsatile method and reconstitution for cerebrospinal fluid (CSF) and tumor phantom; less threatening environment; similar anatomy	No bleeding or CSF leak in ordinary model; availability; cost
Live or dead animal model: Live or dead animal (wet model) models are comparable to human anatomy; sheep and lamb for nasal and skull base anatomy; sheep for spines; can be augmented by pulsatile vessel, CSF reconstitution, and tumor phantom	Ethics issues; anatomical differences; no bleeding or CSF leak in ordinary dead model; zoonotic diseases
Synthetic: Simple or three-dimensional (3D) models (dry model); basic techniques can be learnt; exactly same model like individual patient using 3D technology can be made; can be augmented by pulsatile vessel, CSF canulation, and tumor phantom	High cost in advanced 3D model; no bleeding or CSF leak in ordinary model
Virtual reality simulator: Computer-based virtual reality simulator (computer-generated virtual operative field with haptic/tactile feedback) is good for basic skills; reusable and modifiable models; better representation of surgical procedure and anatomy; inherent metrics for assessment	Not considered equivalent to live surgery, cadaver, or animal model; high initial cost; haptic feedback not as good as cadaver; unable to give real tissue characteristic feedback
Web-based learning: Good for basic skill; inexpensive; can evaluate knowledge and decision-making	Not considered equivalent to live surgery, cadaver, or animal model; no haptic controls or tactile feedback; need access to computer and the Internet
Hybrid models: Hybrid (Combination of physical and virtual components) model provides real-world training integrating patient-specific characteristics and virtual system	Expensive and limited in use due to high demands of time and effort needed to prepare and run them

head and neck surgery due to similar tissue consistencies and neurovascular structures to humans. Sheep models can be used for endoscopic sinus surgery[19] and cordotomy.[20] Sinus and skull base surgeries can be learnt in lamb head.[21] Swine models for cerebellopontine angle regions can be used. It has structures analogical to humans in the cerebellopontine angle region. Other limitations of animal models are the risk of zoonotic diseases and the absence of bleeding.

Synthetic or Dry Model

Synthetic or dry models are artificial models. These can be simple for basic training or can be made exactly the same as in an individual patient using 3D technology.

Synthetic models can be simple training models for primary surgical technique. Endoscopic training can be obtained by simple simulation models for practicing basic techniques such as deep operative area training by working through a narrow tube. Superficial operative area training, and suturing with the help of surgical gloves, silastic tubes, etc. can be practiced. Dissection using papaya, capsicum, etc.; hemostasis practice; and cutting practice using surgical gloves and silastic tubes can be learnt. Training under high magnification should be practiced. Indigenous inexpensive models can be created using inexpensive things.[2] Commercially available components consisting of a universal serial bus powered video camera, LED source, and a 13-inch laptop can be used to perform skull base endoscopic dissection.[22] The visual feedback of 30° was obtained by displacing the optical axis of the universal serial bus camera by 30°. Spatial adaptation, depth adaptation, and dissection can be performed using simple camera.[23] Surgical model using a borescope connected to a personal computer monitor can be used for training as well as for clinical procedures, particularly in economically challenging environments.[24] A low-cost endoscope camera system with the help of a 34 MP camera with an adjustable focal length coupler and an LED source can be used.[25] Simple model using bell pepper filled with saline can be kept in the plastic skull model and several hands-on procedures can be performed under direct endoscopic visualization using continuous irrigation.[26]

Chicken wings (commercially available in cooking stores) fixed on commercially available skull models can be used to simulate real-life surgical situations such as drilling and the development of manual dexterity.[27] Low-cost, replicable models made up of bovine brain and amniotic membrane units placed in a soda cup inside an expanded polystyrene spherical container can be used for training.[28] The training box with several holes on the top, designed to mimic the nostrils, can be used for different exercises including hand–eye coordination, dexterity with rubber bands, tumor/vascular dissection, and how to raise a flap. Dissection of the orange without damaging the septa can be performed. Chicken wing skin dissection can be practiced, mimicking the dural opening. Arterial and venous dissection can be performed simulating vascular dissection. Sellar drilling using egg model with preservation of yolk during the drilling and egg-white resection keeping the yolk intact (simulating the resection of a pituitary adenoma with gland preservation) can be practiced.[29]

The workshop using a step-by-step training program consisting of artificial models with 2D exoscopic view with subsequent transition to cadaveric animal models was designed mainly for manual skills training in 48 trainees. There was high demand for such a workshop indicating a lack of training activities. Overall satisfaction rate was high, which indicated that the contents of workshops met the expectations of the trainees, regardless of their previous experience. The workshop can be used as a stepping stone for practical development and series of specially focused training workshops on microsurgery and endoscopy.[11]

Three-Dimensional Models

Affordable ETV models using a 3D printer and inexpensive mimetic endoscope can be used to make a skull and a 3D mold of the brain.[30] Artificial cranial base models can be created by selective laser sintering that can accurately reconstruct important surgical landmarks, such as dura mater, venous sinuses, cavernous sinuses, internal carotid arteries, medial and lateral optico-carotid recesses, Vidian canals, and cranial nerves.[31] Exact models using 3D printing can be used for training and surgical planning. These are anatomically accurate and patient specific. Such models aid in resident learning and are useful for operative planning.[32,33] Models using 3D-Slicer plus 3D printing technology can be inexpensive, simple, easy to learn, and a practical technology that is feasible, reliable, and convenient for preoperative planning and minimally invasive surgery.[34]

An anatomical model built of a synthetic thermo-retractable, thermo-sensible rubber combined with different polymers can be used, reproducing surgical situations as if they were real and presenting great similarity with the human brain. It can be used for sinus and skull base training.[35] The realistic training models can help neurosurgeons to improve their skills with no risks.[36] Synthetic models made up of a special type of resin and image guidance can be used as a teaching tool for the training of intraventricular endoscopic procedures such as ETV in an abnormally enlarged ventricle. Resin can be placed in the foramen of Monro region, in the frontal and occipital horns of the lateral ventricles, and within the third ventricle for endoscopic training for lesion resection.

A simulation model for sagittal craniosynostosis can be developed using low-cost materials that allow successive uses.[37] A realistic, relatively inexpensive simulator, using 3D-printed plastic powder-based replica skulls, can allow trainees to learn and practice endoscope-assisted repair of metopic and sagittal craniosynostosis. The model consists of a multilayer scalp (skin, subcutaneous fat, galea, and periosteum), cranial bones with accurate landmarks, and the dura mater.[38]

A brain silicone model mimicking normal mechanical properties and intraventricular structures such as the choroid plexus, veins, mammillary bodies, infundibular recess, and basilar artery encased in the skull and immersed in water can help surgeons to develop the technical and cognitive skills for ETV including dealing with complications. Synthetic thermo-retractable and thermo-sensible rubber combined with many different polymers that present different textures, consistencies, and mechanical resistances similar to many human tissues can be used to shape cerebral ventricles, including all basic structures. This can offer to practice many basic neuro-endoscopic techniques such as navigating the ventricular system to visualize important anatomic landmarks (septal and thalamostriate veins, foramen of Monro, temporal horns, aqueduct, and fourth ventricle), performing third ventriculostomy and choroid plexus cauterization, and resecting intraventricular “tumors” that bleed.[39] Models with fluid-filled ventricle under appropriate tension can be prepared using the 3D rapid prototyping technique, providing a realistic simulation environment for a neuroendoscopy procedure.[40] The 3D-printed simulator facilitates acquiring surgical skills with the neuroendoscope to treat hydrocephalus.[41]

A low-cost, patient-specific, reusable 3D-printed simulator, consisting of vascular structures, choroid plexus, tumor model (composed of polyvinyl alcohol, mimicking a soft-consistency lesion, positioned in different spots of the frontal horn and within the third ventricle), can be used for training in neuroendoscopy.[42] Patient-specific simulator (containing cyst, choroid plexus, and intraventricular veins) based on the magnetic resonance imaging of a colloid cyst and hydrocephalus can be developed to learn instrument handling, critical steps of endoscopic colloid cyst resection, and develop a detailed understanding of intraventricular anatomy.[43] A 3D-printed model for training in intracerebral hematoma removal with the help of a tubular retractor and endoscope or exoscope can be used. Hematoma was simulated by edible gelatine and animal blood.[44]

Fusion of 3D printing and special effects with the help of simulation engineers and a group of special effects experts can be developed via a unique collaboration of neurosurgeons, simulation engineers, and a group of special effects experts for the preparation of efficient models.[45]

Augmented Model

Cadavers can be augmented by pulsatile vessels, reconstitution of the CSF for its repair in addition to intraventricular procedures, tumor phantoms, and artificial hematoma to give life-like appearance. Pulsatile flow system in a vessel[46] can be prepared using an infusion pump that can make the vessel as pulsatile as in a live human.[25] Embalmed, uninjected vessels connected to a pulsatile perfusion pump system filled with artificial blood solution can be used in real-life-like experience for the management of intraoperative vascular injuries.[47] The model can also be augmented by instillation of fluid that can simulate CSF.[48] Intraventricular procedures by CSF reconstitution in fresh human cadavers can be done using an arterial catheter after simple cervical laminectomy and dural opening. Saline can be continuously perfused at physiological CSF pressures to reconstitute the subarachnoid space and ventricles. Neuroendoscopic procedures for identifying the foramen of Monro along with the other structures and performing septum pellucidotomy and endoscopic third ventriculostomy can be performed. Navigation of the cerebral aqueduct, fourth ventricle, prepontine cistern, and suprasellar cistern via the lamina terminalis can be performed.[49]

Reconstitution of both the CSF system and vessels can also be performed[50] in fresh cadavers. Cannulation of the femoral or carotid artery in conjunction with artificial perfusion of the arterial system, and/or cannulation of the intradural cervical spine for intrathecal reconstitution of the CSF system can be performed.[50] Multiple procedures such as endoscopic endonasal approach, endoscopic endonasal CSF leak repair with fluorescein perfusion, insertion of ventriculostomy catheter, spinal laminectomy with dura repair, and intraventricular neuroendoscopy (septum pellucidotomy and third ventriculostomy) can be performed. Intraventricular injectable tumor models can be prepared by contrast-enhancing tumor polymer into the lateral or third ventricle. Endoscopic piecemeal resection of a solid lesion in the lateral or third ventricle can be performed.[51] A cadaver model for hematoma removal can be made for neuroendoscopic learning sessions.[52] Dead animal models such as pigs, sheep, and lamb can also be augmented with pulsatile vessels, CSF reconstitution, tumor phantom, Intracerebral hematoma (ICH), etc.

3D printing model can be augmented with animal or cadaver tissue. Pulsatile vessel and CSF reconstitution, and tumor phantoms can also be added to simulate life-like structures. Synthetic models can be augmented by detachable components, and tissue derived from cadaveric, animal tissues to give a life-like appearance.[53] Detachable components, derived from cadaver or animal tissues, can decrease the cost of a model.[53] Synthetic brain model of hydrocephalus with detachable animal components such as choroid plexus, ependymal veins, and the membranous floor of the third ventricle derived from cadaveric laboratory animal tissues to give a life-like appearance can be used. Detachable components can be changed for every exercise. Ventricles can be filled with saline to give an appropriate transparent medium and connected to a device transmitting pulsations creating conditions similar to live surgeries.[53] Tumor phantoms using an agar–gelatin base, unsalted chicken stock, food coloring for visual mimicry, and iohexol for radiographic mimicry can be used for training in laboratories. Resin-derived polymer can be injected in formalin-embalmed cadaveric head to simulate tumor.[54]

Artificial Intelligence and Virtual Reality Simulator

Virtual reality (VR) simulators can create a computerized environment in which the patient's anatomy is reproduced and interaction with endoscopic handling and realistic haptic feedback is possible. It can be used in planning treatment and for training.[55] VR haptic simulators can improve the skill and confidence of surgical trainees by allowing them to accumulate experience in various tasks under different conditions. It provides a realistic training environment for endoscopic sinus and skull base surgeries.[56] Various existing VR simulators for training neuroendoscopic skills such as endoscopic third ventriculostomy and endonasal transsphenoidal surgery are available. Although VR simulators are effective for procedure-based skills training, the simulators need to include anatomical variations and a variety of cases for improved fidelity. There is a need for multicentric prospective and retrospective cohort studies to establish concurrent and predictive validation for their incorporation into the surgical educational curriculum.[57] Virtual repository of neurosurgical instrumentation has been prepared, which can aid in fostering research collaborations related to neurosurgical instruments and surgical simulation platforms.[58]

Hybrid Simulators

A mixed reality simulation (realistic and virtual simulators combined) for neuroendoscopic surgical training has been developed, which provides a highly effective way of working with 3D data and significantly enhances the learning of surgical anatomy and operative strategies. The combination of virtual and realistic tools can safely improve the surgical learning curve. Physical simulators were made with synthetic rubber of different polymers to simulate the consistencies and mechanical resistance of human tissues.[59]

Adjuvants in Endoscopic Learning

Learning of endoscopy can be facilitated by the use of an exoscope.[60] Channeled endoscopy has certain limitations that can be overcome using a tubular retractor. A combination of a tubular retractor with an endoscope can be used to access and resect deep-seated lesions while preserving and displacing superficial white matter tracts and cortical regions.[61] The help of a microscope can be taken if needed, especially in control of brisk bleeding and complex dissection. Incorporating new technologies such as navigation, robotics, and 3D visualization can be used to overcome some of the limitations of endoscopic techniques.[62]

How to Assess Competency after Training

Total procedural time, hand-motion tracking-derived parameters, and touching surrounding structures can be used to assess competency in surgical skill training. Technical skills tests can be used for assessment and evaluation in neuroendoscopic training. It can distinguish between more and less experienced surgeons irrespective of seniority level.[63] Objective measures related to instrument movements can be computed using automated performance metrics to assess surgical skills.[64]

It was possible to differentiate between the skill levels of novices and experts according to parameters derived from the training system. Quantitative assessment of training progress can be performed by dissection, spatial adaptation, depth adaptation, and performing the A-B-A task (placing an object from A to B and then to A location). Four performance metrics (collision, precision, dissected area, and time) and six kinematic metrics (dispersion, path length, depth perception, velocity, acceleration, and motion smoothness) can be checked.[65]

Electromagnetic tracking devices have been used to analyze the surgeon's hand movements. Movement data (time, distance, number of movements, and speed of movement) can be compared, which provides useful data for the assessment of endoscopic dexterity.[66] Time to hemostasis and mean blood loss can be used as assessment methods in perfusion-based human cadaveric simulation.[67] Global rating scale based on respect to tissue, time and motion, instrument handling/knowledge, flow of operation, depth of perception, and bimanual dexterity can be used as assessment tools in endoscopic procedures. The score is given from 1 to 5; 1 is poor and 5 is good performance.[68]

Residents can be evaluated using a combination of task- and VR-based exercises. The results of 35 residents were studied according to seniority and laboratory credits. The suturing skills of senior residents were better than those of junior colleagues. Similarly, microsuturing scores improved with the increasing laboratory credits. Endoscopic evaluation points correlated positively with previous laboratory training. Senior group of residents showed significant disagreement with the utility of the VR platform for improving surgical dexterity and improving the understanding of surgical procedures. These results show that the combination of task- and procedure-based assessment of trainees using physical and VR simulation models can supplement the existing neurosurgery curriculum. The currently available VR-based simulations are useful in the early years of training, but they need significant improvement to offer beneficial learning opportunities to senior trainees.[69]

Artificial intelligence (AI)-derived metrics was used to determine the learning curves of participants in four groups with different expertise levels (neurosurgeons, seniors, juniors, and medical students) who performed subpial resection. Learning curves using AI-derived metrics provided novel insights into technical skill acquisition, based on expertise level that can be used by the educator to develop more focused formative educational paradigms for neurosurgical trainees.[70]

Comparative Study of Training Models

3D animation and cadaveric videos alone or in combination are better than textbook teaching.[71] Simulation model selection should be based on educational objectives. Basic training with VR simulators may be essential during the early parts of the learning curve for learning anatomy or decision-making. Developing manual dexterity and technical skills could be better learned on the physical simulation model.[72] Cadaveric and animal model training constitutes an indispensable training tool and has greater resemblance to real operative conditions as compared with virtual models. Most educators (95.4%) believed laboratory dissection is an integral component of training and no respondent believed simulation could currently provide greater educational benefit than laboratory dissection in a national survey.[73]

Skill Transfer from One Method to Another Method

Skills can be transferred from simulation-based learning or dry models (synthetic) to a cadaveric model.[74,75] Cadaveric model training has been shown to transfer to the patient.[76]

Skill Laboratory for Training in Neuroendoscopy

Good microneurosurgery skill laboratory should have all facilities such as good surgical microscope, 3D endoscope, surgical drills, operating table with a Mayfield head holder, complete set of microsurgical and endoscopic instruments, imaging facilities, neuronavigation system, surgical robotic system, surgical planning system, neurophysiological monitoring equipment, and VR for training of surgical procedures and visuospatial skills.[77]

Conclusion

Most residency training programs worldwide typically focus on microneurosurgical training. Because learning neuroendoscopy differs greatly from microneurosurgery, switching from microneurosurgery to neuroendoscopy can be challenging. For these reasons, the above-detailed training models and simulators are very beneficial in learning neuroendoscopy.

Authors' Contributions
K.H., M.S., B.P.S.C., J.B., S.R., M.N.S., V.P., J.S., M.S., J.P., and Y.R.Y. contributed substantially to the conception, design of the work, literature search, acquisition of data, analysis and interpretation of data for the work, drafting the work, and final approval of the version to be published.

Conflict of Interest
None declared.

References

1 Yadav YR, Parihar V, Ratre S, Kher Y, Iqbal M. Microneurosurgical skills training. J Neurol Surg A Cent Eur Neurosurg 2016;77(02):146–154
2 Bajaj J, Yadav YR, Pateriya A, Parihar V, Ratre S, Dubey A. Indigenous inexpensive practice models for skill development in neuroendoscopy. J Neurosci Rural Pract 2017;8(02):170–173
3 Yadav YR, Bajaj J, Parihar V, Ratre S, Pateriya A. Practical aspects of neuroendoscopic techniques and complication avoidance: a systematic review. Turk Neurosurg 2018;28(03):329–340
4 Yadav YR, Lucano A, Ratre S, Parihar VS. Practical aspects and avoidance of complications in microendoscopic spine surgeries: a review. J Neurol Surg A Cent Eur Neurosurg 2019;80(04):291–301
5 Yadav YR, Parihar V, Kher Y. Complication avoidance and its management in endoscopic neurosurgery. Neurol India 2013;61(03):217–225

6 Yadav YR, Parihar VS, Ratre S, Kher Y. Avoiding complications in endoscopic third ventriculostomy. J Neurol Surg A Cent Eur Neurosurg 2015;76(06):483–494
7 Haji FA, Dubrowski A, Drake J, de Ribaupierre S. Needs assessment for simulation training in neuroendoscopy: a Canadian national survey. J Neurosurg 2013;118(02):. Doi: 10.3171/2012.10.JNS12767
8 Singh R, Baby B, Damodaran N, et al. Design and validation of an open-source, partial task trainer for endonasal neuro-endoscopic skills development: Indian experience. World Neurosurg 2016;86:259–269
9 Lee JJ, Ko J, Yun Y, et al. Feasibility of the epiduroscopy simulator as a training tool: a pilot study. Pain Res Manag 2020;2020;5428170
10 Sahoo SK, Gupta SK, Salunke P, et al. Setting up a neurosurgical skills laboratory and designing simulation courses to augment resident training program. Neurol India 2022;70(02):612–617
11 Lasunin N, Golbin DA. A workshop for training of basic neurosurgical skills "from microsurgery to endoscopy": a stepping stone for young neurosurgeons. Cureus 2018;10(11):e3658
12 Jha DK, Jain M, Pant I, et al. Endoscopic treatment of hydrocephalus with minimal resources: resource utilization and indigenous innovation in developing countries like India. Asian J Neurosurg 2018;13(03):607–613
13 Yasuda ME, Gagliardi M, Cairoli FR, Renedo D, Iglesias B, Socolovsky M. A novel low-cost exoscopy station for training neurosurgeons and neurosurgery trainees. World Neurosurg 2021;150:31–37
14 Perry A, Graffeo CS, Meyer J, et al. Beyond the learning curve: comparison of microscopic and endoscopic incidences of internal carotid injury in a series of highly experienced operators. World Neurosurg 2019;131:e128–e135
15 Younus I, Gerges MM, Uribe-Cardenas R, et al. How long is the tail end of the learning curve? Results from 1000 consecutive endoscopic endonasal skull base cases following the initial 200 cases. J Neurosurg 2020;134(03):750–760
16 Jaimovich SG, Bailez M, Asprea M, Jaimovich R. Neurosurgical training with simulators: a novel neuroendoscopy model. Childs Nerv Syst 2016;32(02):345–349
17 Fernandez-Miranda JC, Barges-Coll J, Prevedello DM, et al. Animal model for endoscopic neurosurgical training: technical note. Minim Invasive Neurosurg 2010;53(5-6):286–289
18 Amato MCM, Aprile BC, de Oliveira CA, Carneiro VM, de Oliveira RS. Experimental model for interlaminar endoscopic spine procedures. World Neurosurg 2019;129:55–61
19 Delgado-Vargas B, Romero-Salazar AL, Reyes Burneo PM, et al. Evaluation of resident's training for endoscopic sinus surgery using a sheep's head. Eur Arch Otorhinolaryngol 2016;273(08):2085–2089
20 Dalgic A, Caliskan M, Can P, et al. Experimental endoscopic cordotomy in the sheep model. Turk Neurosurg 2016;26(02):286–290
21 Mladina R, Skitarelić N, Cingi C, Chen L, Bayar Muluk N. The validity of training endoscopic sinus and skull base surgery techniques on the experimental head model. J Craniofac Surg 2018;29(02):498–501
22 Dias LA, Gebhard H, Mtui E, Anand VK, Schwartz TH. The use of an ultraportable universal serial bus endoscope for education and training in neuroendoscopy. World Neurosurg 2013;79(02):337–340
23 Espinoza DL, González Carranza V, Chico-Ponce de León F, Martinez AM. PsT1: a low-cost optical simulator for psychomotor skills training in neuroendoscopy. World Neurosurg 2015;83(06):1074–1079
24 Choque-Velasquez J, Miranda-Solis F, Colasanti R, Ccahuantico-Choquevilca LA, Hernesniemi J. Modified pure endoscopic approach to pineal region: proof of concept of efficient and inexpensive surgical model based on laboratory dissections. World Neurosurg 2018;117:195–198
25 Matos-Cruz AJ, De Jesus O. Low-cost endoscope camera system for neurosurgical cadaveric laboratory dissections. World Neurosurg 2022;157:92–95
26 Gomar-Alba M, Parrón-Carreño T, Narro-Donate JM, et al. Neuroendoscopic training in neurosurgery: a simple and feasible model for neurosurgical education. Childs Nerv Syst 2021;37(08):2619–2624
27 Altun A, Cokluk C. Endoscopic training model for intranasal transsphenoidal hypophysis surgery using a skull model and chicken wings. Turk Neurosurg 2020;30(03):377–381
28 Argañaraz R, Sáenz A, Liñares JM, Martinez P, Bailez M, Mantese B. New simulator for neuroendoscopy: a realistic and attainable model. World Neurosurg 2020;134:33–38
29 Sanromán-Álvarez P, Simal-Julián JA, García-Piñero A, Miranda-Lloret P. Multitask box trainer for endoscopic endonasal skull base surgery: ENDOtrainer. World Neurosurg 2017;101:304–307
30 Garling RJ, Jin X, Yang J, Khasawneh AH, Harris CA. Low-cost endoscopic third ventriculostomy simulator with mimetic endoscope. J Neurosurg Pediatr 2018;22(02):137–146
31 Oyama K, Ditzel Filho LFS, Muto J, et al. Endoscopic endonasal cranial base surgery simulation using an artificial cranial base model created by selective laser sintering. Neurosurg Rev 2015;38(01):171–178, discussion 178
32 McGuire LS, Fuentes A, Alaraj A. Three-dimensional modeling in training, simulation, and surgical planning in open vascular and endovascular neurosurgery: a systematic review of the literature. World Neurosurg 2021;154:53–63
33 Ploch CC, Mansi CSSA, Jayamohan J, Kuhl E. Using 3D printing to create personalized brain models for neurosurgical training and preoperative planning. World Neurosurg 2016;90:668–674
34 Zhou L, Wang W, Li Z, et al. Clinical application of 3D-Slicer + 3D printing guide combined with transcranial neuroendoscopic in minimally invasive neurosurgery. Sci Rep 2022;12(01):20421
35 Filho FVG, Coelho G, Cavalheiro S, Lyra M, Zymberg ST. Quality assessment of a new surgical simulator for neuroendoscopic training. Neurosurg Focus 2011;30(04):E17
36 Zymberg S, Vaz-Guimarães Filho F, Lyra M. Neuroendoscopic training: presentation of a new real simulator. Minim Invasive Neurosurg 2010;53(01):44–46
37 Cuello JF, Gromadzyn G, Cicutti S, Roel M, Mantese B, Ruvinsky SD. Results of training with a low-cost simulation model for endoscope-assisted scaphocephaly repair. J Neurosurg Pediatr 2023;32(01):91–97
38 Eastwood KW, Bodani VP, Haji FA, Looi T, Naguib HE, Drake JM. Development of synthetic simulators for endoscope-assisted repair of metopic and sagittal craniosynostosis. J Neurosurg Pediatr 2018;22(02):128–136
39 Coelho G, Zymberg S, Lyra M, Zanon N, Warf B. New anatomical simulator for pediatric neuroendoscopic practice. Childs Nerv Syst 2015;31(02):213–219
40 Waran V, Narayanan V, Karuppiah R, et al. Neurosurgical endoscopic training via a realistic 3-dimensional model with pathology. Simul Healthc 2015;10(01):43–48
41 González-López P, Gómez-Revuelta C, Puchol Rizo M, et al. Development and evaluation of a 3D printed training model for endoscopic third ventriculostomy in low-income countries. Brain Spine 2023;3:101736
42 Licci M, Thieringer FM, Guzman R, Soleman J. Development and validation of a synthetic 3D-printed simulator for training in neuroendoscopic ventricular lesion removal. Neurosurg Focus 2020;48(03):E18
43 Bodani VP, Breimer GE, Haji FA, Looi T, Drake JM. Development and evaluation of a patient-specific surgical simulator for endoscopic colloid cyst resection. J Neurosurg 2019:1–9
44 Zhu J, Wen G, Tang C, Zhong C, Yang J, Ma C. A practical 3D-printed model for training of endoscopic and exoscopic intracerebral

hematoma surgery with a tubular retractor. J Neurol Surg A Cent Eur Neurosurg 2020;81(05):404–411
45 Weinstock P, Rehder R, Prabhu SP, Forbes PW, Roussin CJ, Cohen AR. Creation of a novel simulator for minimally invasive neurosurgery: fusion of 3D printing and special effects. J Neurosurg Pediatr 2017;20(01):1–9
46 Gallardo FC, Bustamante JL, Martin C, et al. Novel simulation model with pulsatile flow system for microvascular training, research, and improving patient surgical outcomes. World Neurosurg 2020;143:11–16
47 Pacca P, Jhawar SS, Seclen DV, et al. "Live cadaver" model for internal carotid artery injury simulation in endoscopic endonasal skull base surgery. Oper Neurosurg (Hagerstown) 2017;13(06): 732–738
48 Christian EA, Bakhsheshian J, Strickland BA, et al. Perfusion-based human cadaveric specimen as a simulation training model in repairing cerebrospinal fluid leaks during endoscopic endonasal skull base surgery. J Neurosurg 2018;129(03):792–796
49 Winer JL, Kramer DR, Robison RA, et al. Cerebrospinal fluid reconstitution via a perfusion-based cadaveric model: feasibility study demonstrating surgical simulation of neuroendoscopic procedures. J Neurosurg 2015;123(05):1316–1321
50 Zada G, Bakhsheshian J, Pham M, et al. Development of a perfusion-based cadaveric simulation model integrated into neurosurgical training: feasibility based on reconstitution of vascular and cerebrospinal fluid systems. Oper Neurosurg (Hagerstown) 2018; 14(01):72–80
51 Ashour AM, Elbabaa SK, Caputy AJ, Gragnaniello C. Navigation-guided endoscopic intraventricular injectable tumor model: cadaveric tumor resection model for neurosurgical training. World Neurosurg 2016;96:261–266
52 Xiong Z, Yan X, Xin C, et al. Intracerebral hemorrhage cadaver model for training in hematoma evacuation under endoscopy. J Clin Neurosci 2019;63:272–277
53 Deopujari CE, Karmarkar VS, Shaikh ST, Gadgil US. Developing a dynamic simulator for endoscopic intraventricular surgeries. Childs Nerv Syst 2019;35(04):621–627
54 Gagliardi F, Chau AM, Mortini P, Caputy AJ, Gragnaniello C. Skull base neuroendoscopic training model using a fibrous injectable tumor polymer and the Nico Myriad. J Craniofac Surg 2018;29 (01):e25–e28
55 Guimarães B, Dourado L, Tsisar S, Diniz JM, Madeira MD, Ferreira MA. Rethinking anatomy: how to overcome challenges of medical education's evolution. Acta Med Port 2017;30(02):134–140
56 Kim DH, Kim HM, Park JS, Kim SW. Virtual reality haptic simulator for endoscopic sinus and skull base surgeries. J Craniofac Surg 2020;31(06):1811–1814
57 Baby B, Singh R, Suri A, et al. A review of virtual reality simulators for neuroendoscopy. Neurosurg Rev 2020;43(05):1255–1272
58 Singh R, Baby B, Suri A. A virtual repository of neurosurgical instrumentation for neuroengineering research and collaboration. World Neurosurg 2019;126:e84–e93
59 Coelho G, Figueiredo EG, Rabelo NN, et al. Development and evaluation of pediatric mixed-reality model for neuroendoscopic surgical training. World Neurosurg 2020;139:e189–e202
60 Parihar V, Yadav YR, Kher Y, Ratre S, Sethi A, Sharma D. Learning neuroendoscopy with an exoscope system (video telescopic operating monitor): early clinical results. Asian J Neurosurg 2016;11 (04):421–426
61 Gassie K, Wijesekera O, Chaichana KL. Minimally invasive tubular retractor-assisted biopsy and resection of subcortical intra-axial gliomas and other neoplasms. J Neurosurg Sci 2018;62(06): 682–689
62 Hahn BS, Park JY. Incorporating new technologies to overcome the limitations of endoscopic spine surgery: navigation, robotics, and visualization. World Neurosurg 2021;145:712–721
63 Nevzati E, Wittenberg B, Burtard C, et al. Development of a technical skills test to improve assessment and evaluation in neuroendoscopic education. World Neurosurg 2020;141: e307–e315
64 Guerin S, Huaulmé A, Lavoue V, Jannin P, Timoh KN. Review of automated performance metrics to assess surgical technical skills in robot-assisted laparoscopy. Surg Endosc 2022;36(02):853–870
65 Lorias-Espinoza D, González Carranza V, Pérez-Escamirosa F, Chico-Ponce de León F, Minor Martinez A, Gutiérrez-Gnecchi JA. Integration of comprehensive metrics into the PsT1 neuroendoscopic training system. World Neurosurg 2021;151: 182–189
66 Smith SGT, Torkington J, Brown TJ, Taffinder NJ, Darzi A. Motion analysis. Surg Endosc 2002;16(04):640–645
67 Shen J, Hur K, Zhang Z, et al. Objective validation of perfusion-based human cadaveric simulation training model for management of internal carotid artery injury in endoscopic endonasal sinus and skull base surgery. Oper Neurosurg (Hagerstown) 2018; 15(02):231–238
68 Breimer GE, Haji FA, Cinalli G, Hoving EW, Drake JM. Validity evidence for the neuro-endoscopic ventriculostomy assessment tool (NEVAT). Oper Neurosurg (Hagerstown) 2017;13(01):60–68
69 Sharma R, Katiyar V, Narwal P, Kale SS, Suri A. Interval assessment using task- and procedure-based simulations: an attempt to supplement neurosurgical residency curriculum. Neurosurg Focus 2022;53(02):E2
70 Ledwos N, Mirchi N, Yilmaz R, et al. Assessment of learning curves on a simulated neurosurgical task using metrics selected by artificial intelligence. J Neurosurg 2022:1–12
71 Benlice C, Elcircevi A, Kutlu B, Dogan CD, Acar HI, Kuzu MA. Comparison of textbook versus three-dimensional animation versus cadaveric training videos in teaching laparoscopic rectal surgery: a prospective randomized trial. Colorectal Dis 2022;24 (08):1007–1014
72 Breimer GE, Haji FA, Bodani V, et al. Simulation-based education for endoscopic third ventriculostomy: a comparison between virtual and physical training models. Oper Neurosurg (Hagerstown) 2017;13(01):89–95
73 Kshettry VR, Mullin JP, Schlenk R, Recinos PF, Benzel EC. The role of laboratory dissection training in neurosurgical residency: results of a national survey. World Neurosurg 2014;82(05): 554–559
74 Kattan E, De la Fuente R, Putz F, et al. Simulation-based mastery learning of bronchoscopy-guided percutaneous dilatational tracheostomy: competency acquisition and skills transfer to a cadaveric model. Simul Healthc 2021;16(03):157–162
75 Butler A, Olson T, Koehler R, Nicandri G. Do the skills acquired by novice surgeons using anatomic dry models transfer effectively to the task of diagnostic knee arthroscopy performed on cadaveric specimens? J Bone Joint Surg Am 2013;95(03):e15, 1–8)
76 Boza C, Varas J, Buckel E, et al. A cadaveric porcine model for assessment in laparoscopic bariatric surgery–a validation study. Obes Surg 2013;23(05):589–593
77 Bernardo A. Establishment of next-generation neurosurgery research and training laboratory with integrated human performance monitoring. World Neurosurg 2017;106:991–1000

