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A Review of Physical Simulators for Neuroendoscopy Skills Training

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Key words

- Neuroendoscopy
- Neurosurgery
- Physical trainers
- Simulation
- Skills training
- Synthetic simulators

Abbreviations and Acronyms

2D: Two-dimensional
3D: Three-dimensional
CT: Computed tomography
EETS: Endoscopic endonasal transsphenoidal surgery
ETV: Endoscopic third ventriculostomy
MRI: Magnetic resonance imaging
SIMONT: Sinus Model Oto-Rhino Neuro Trainer

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■ BACKGROUND: **Minimally invasive neurosurgical approaches reduce patient morbidity by providing the surgeon with better visualization and access to complex lesions, with minimal disruption to normal anatomy. The use of rigid or flexible neuroendoscopes, supplemented with a conventional stereoscopic operating microscope, has been integral to the adoption of these techniques. Neurosurgeons commonly use neuroendoscopes to perform the ventricular and endonasal approaches. It is challenging to learn neuroendoscopy skills from the existing apprenticeship model of surgical education. The training methods, which use simulation-based systems, have achieved wide acceptance. Physical simulators provide anatomic orientation and hands-on experience with repeatability. Our aim is to review the existing physical simulators on the basis of the skills training of neuroendoscopic procedures.**

■ METHODS: **We searched Scopus, Google Scholar, PubMed, IEEE Xplore, and dblp. We used the following keywords "neuroendoscopy," "training," "simulators," "physical," and "skills evaluation." A total of 351 articles were screened based on development methods, evaluation criteria, and validation studies on physical simulators for skills training in neuroendoscopy.**

■ RESULTS: **The screening of the articles resulted in classifying the physical training methods developed for neuroendoscopy surgical skills into synthetic simulators and box trainers. The existing simulators were compared based on their design, fidelity, trainee evaluation methods, and validation studies.**

■ CONCLUSIONS: **The state of simulation systems demands collaborative initiatives among translational research institutes. They need improved fidelity and validation studies for inclusion in the surgical educational curriculum. Learning should be imparted in stages with standardization of performance metrics for skills evaluation.**

INTRODUCTION

Neurosurgery is a superspecialty that deals with the diseases of the central nervous system. Minimally invasive surgical techniques in neurosurgery such as neuroendoscopic surgeries are reported to reduce the postoperative recovery time, hospitalization time, morbidity, and cost of patient care.[1-3] The typical neuroendoscopic procedures are endoscopic endonasal transsphenoidal surgery (EETS) and endoscopic third ventriculostomy (ETV) (**Figures 1** and **2**).

Neuroendoscopy demands independent visual, bimanual, and psychomotor skills. The narrow, monocular field of view and video presentation on the two-dimensional (2D) display limit the visual feedback. The monoscopic view leads to missing depth cues, and a narrow field of view leads to difficulty in forming a three-dimensional (3D) mental picture. The endoscope is moved forward and backward to obtain the depth cue. The reflection of the light on different surfaces helps in identifying the distance. Tactile and haptic feedback is limited because of the use of long instruments, the fulcrum effect, and a reduced degree of freedom. The long instruments and endoscope are inserted by creating an opening in the skull or through natural orifices. The endoscope has 4 degrees of freedom constrained by the fulcrum at the entry site, and an additional degree of freedom for the relative rotation of the camera along its axis.[4] The skills required in neuroendoscopy are thus challenging and require dedicated training systems and deliberate practice.[5,6]

The learning and doing concept shows less acceptance when it comes to invasive procedures. An alternate training method is the use of simulators that provide repeated practice environment and provide individual feedback to the trainee. They offer a safe laboratory environment and can mimic operating room practices. There is an opportunity for formative and summative assessment of the trainees by repeated practice under standardized conditions.

Live animals are used across various countries for hands-on skills training of

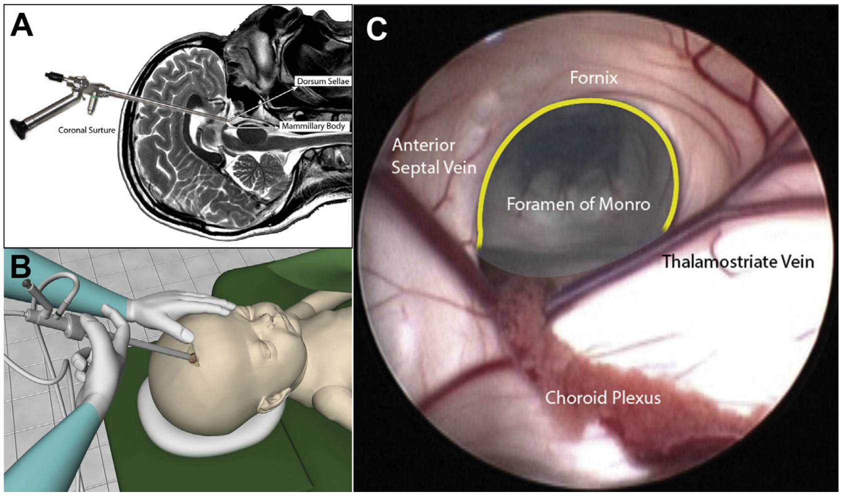

Figure 1. (**A**) Planning on magnetic resonance imaging. (**B**) Burr-hole incision and placement of endoscope. (**C**) Endoscopic view of the third ventriculostomy.

surgeons, but there are some political and social barriers that motivate the development of simulation-based skills training. Automated learning systems, Web-based learning, and virtual reality systems are highly recommended.[7] Another way of simulation is to use mechanical models that include synthetic or inanimate structures for training. These physical simulators provide real-time haptic feedback and are effective for task-based training. They are cost-effective compared with virtual reality simulators and are effective for developing basic psychomotor skills and procedure-based orientation. There is no extensive review of physical simulators for neuroendoscopic techniques and the results of their impact in imparting skills to the neurosurgeons. Our main objective was to review the available neuroendoscopic physical skills training systems or physical simulators based on the design, tasks involved, evaluation methods, and validation studies.

METHODS

The various physical systems available for neuroendoscopy were reviewed. The review articles and related studies were searched online using the search engines Google Scholar, PubMed, Scopus, IEEE Xplore, and dblp. The keywords used were "neuroendoscopy," "training," "simulators," "physical," and "skills evaluation." The PubMed search resulted in 45 articles, Google scholar 255 articles, IEEE Xplore 12 articles, and dblp 39 articles. The articles had to fulfill the following criteria to be eligible for the study:

- Be published in the English language
- Physical simulation or training setup developed for neuroendoscopy
- Relevancy in training of ETV or EETS procedures.

We included review papers, cross-reference reports, and book chapters. We also included articles that describe the design and development criteria even if no validation studies were involved. Also, we included simulation studies that are related to the nonneurosurgical specialties (i.e., ear, nose, and throat—otorhinolaryngology or head and neck surgery).

We performed an initial screening of the title, which was followed by an independent review of abstracts and full articles. The articles with ambiguous titles and contents were reviewed together and all disagreements were resolved by consensus. We concentrated our review on articles about surgical skills training that mentioned words such as endoscopy, neuroendoscopy, and objective skills evaluation and short-listed 28 articles for our review. We divided the short-listed articles into 2 categories: 21 articles for synthetic simulators and 7 articles for box trainers (Figure 3).

RESULTS

The existing physical simulators were compared based on their design of trainer, fidelity, trainee evaluation methods, and validation studies. Fidelity measure can be considered as the level of realism, functional parameters (accountability and responsibility), contextual parameters (environment, situation, resources, and causality), and interfacing (person, data, team members, and communication).

User evaluation is based on the method of recording the task performed, which includes video-based or sensor-based performance metrics. The validity measures can be based on subjective or objective measures. The subjective measures are based on the questionnaire asked from novices and experts after a session on the simulator. They provided face, content, and expert and referent validity of the simulator. The objective measures include construct, concurrent, and discriminative and predictive validity based on the experiments conducted. For any simulator to be a part of the surgical education curriculum, it should be designed based on consideration of the trainee, content, task or procedure, and proper validation.[8]

Synthetic Simulators

The synthetic simulators resemble the anatomic structures to impart the procedure and task-based training. The synthetic simulators provide a mannequin-based intermediate level of fidelity and increased accountability and causality by providing standard learning criteria (Figure 4). They provide options for guidance from the facilitator and incorporate procedure-based and task-based training. The practice of critical thinking is missing, and haptic feedback is limited because of synthetic anatomic structures. The synthetic simulators were available for ETV and EETS.

SIMONT (Sinus Model Oto-Rhino Neuro Trainer) is a neurosurgical trainer developed for neuroendoscopic training of ETV. It resembled the intraventricular structures along with some pathology. Also, it simulated hydrocephalus flow by

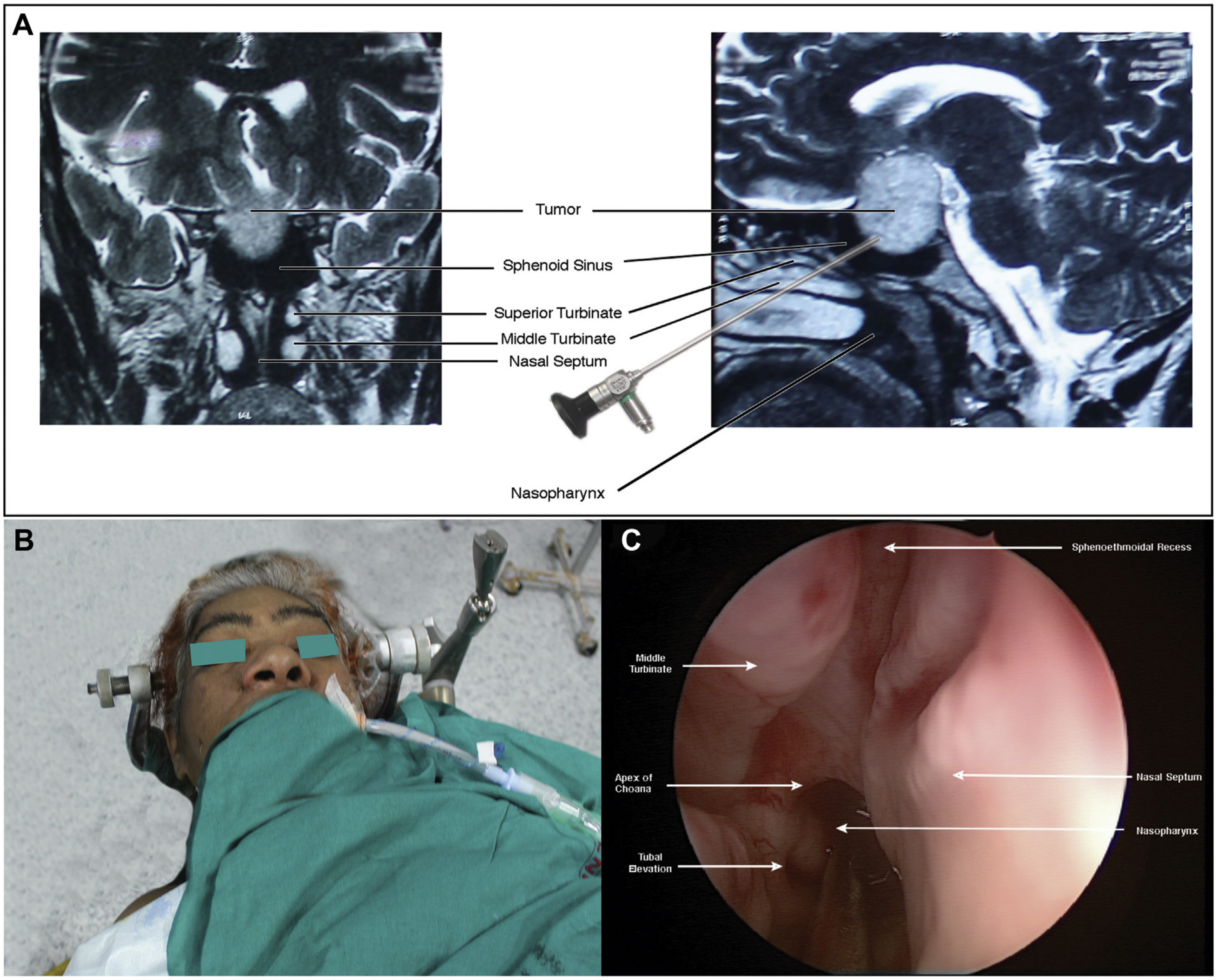

Figure 2. (**A**) Planning on magnetic resonance imaging. (**B**) Patient positioning for endonasal approach. (**C**) Endoscopic view of endonasal transsphenoidal surgery.

using water. The validation studies included the face, retest, and interrater reliability and construct validation. Participants were scored based on the time taken for the procedure and direct observation by 2 experienced neurosurgeons. There was also a study to identify the performance of the real simulator using image guidance for training intraventricular endoscopic procedures (e.g., enlarged ventricles and intraventricular lesions). The model was prepared and a magnetic resonance T1 sequence was obtained and then used for navigation. The error in navigation using the simulator was found to have a median of 4.6 mm.[9-11]

Waran et al.[12-14] developed a 3D-printed third ventriculostomy simulator by maintaining appropriate pressure of the fluid and also used neuronavigation for planning and performing the surgery. These investigators studied the performance of the commercially available neuronavigation systems on their developed model. The surgical training procedure included model registration, skin incision, burr-hole making, dural incision, endoscope introduction, tumor visualization, and biopsy. Three neurosurgeons and 1 expert in surgical simulations were questioned on the ability of the trainer. The study was also performed to identify the ability of the 3D-printed trainer for navigation by printing 3 different pathologic cases: hydrocephalus, right frontal cortical lesion, and midline clival meningioma. The score given by the experts for the trainer was 4.0 on 5.0 and an average of 4.0 and 4.6 on 5.0 by junior trainees for every individual step performed.

Coelho et al.[15] developed ASPEN (Anatomical Simulator for Pediatric Neurosurgery), a pediatric simulator for neuroendoscopic practice. Volumetric magnetic resonance imaging (MRI) of a child with hydrocephalus was used for the estimation of the dimensions of the ventricular cavities of the simulator. The

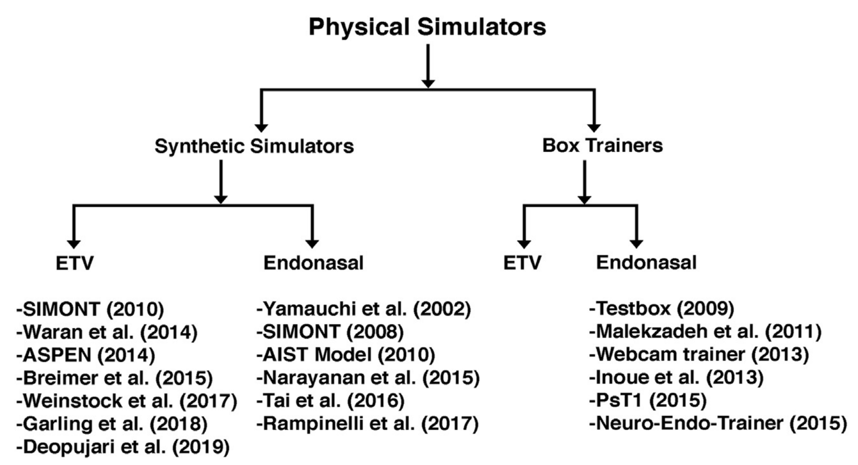

Figure 3. Classification of simulators for neuroendoscopic ventricular and endonasal surgeries. ETV, endoscopic third ventriculostomy.

other anatomic structures included choroid plexus, blood vessels, and intraventricular lesions. The simulator was radiopaque and was compatible with computed tomography (CT) visualization. All 5 evaluators agreed to its use in the training environment. However, 3 (60%) believed that the model shows a distorted view compared with the real endoscopic scenario.

Breimer et al.[16] developed a synthetic simulator using CT and MRI data of 4-month-old child with hydrocephalus. They used patient-specific data and hence, the production cost was fixed for the initial molds, but had recurring synthetic simulator costs. Of the participants, 95% agreed that the simulator anatomic features, tissue properties, and bleeding scenario were on a par with the real surgical scenario. The investigators have addressed the drawbacks of the study, including the lack of objective evaluation, by tracking the instruments or identifying the force at the tip and intend to come up with future iterations. They developed an assessment scale (NEVAT [Neuroendoscopic Ventriculostomy Assessment Tool]) for ETV using the procedure-specific checklist of surgical errors, and a global rating scale.[17]

Weinstock et al.[18] developed a novel ETV simulator. A 14-year-old adolescent patient with hydrocephalus was recreated with external physical details and neuroanatomy. The model contains replaceable components, pulsation of ventricular cavities, basilar artery, and cerebrospinal fluid flow. The validation studies included face validity and content validity using a 14-item Likert-like questionnaire. The construct validity was performed by evaluating the performance of trainees at different levels of experience by blinded observers (2 neurosurgeons) using the OSATS (Objective Structured Assessment of Technical Skills) scale. The model obtained high ratings for face and content validity. For construct validity, blinded observers rated the fellows significantly higher than residents, showing that the model could distinguish between novices and experts.

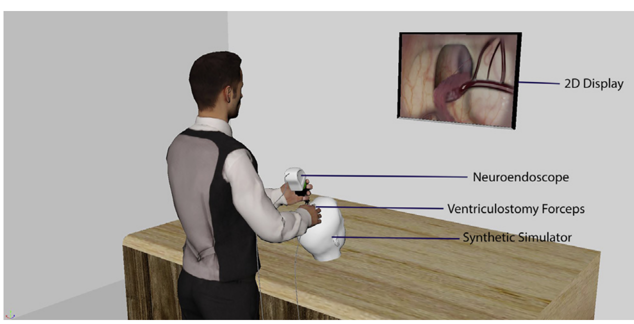

Figure 4. Generalized training setup of synthetic simulators. 2D, two-dimensional.

Garling et al.[19] developed a low-cost third ventriculostomy simulator using open source software by isolating the skin and brain from CT and MRI of a 2-year-old boy with hydrocephalus. They also created a mimetic endoscope along with the simulator. The silicone/slacker ratio of 10:6 and 10:7 was found to have comparable compression and shearing with the brain parenchyma. The face and content validity were obtained using a 5-point Likert scale survey. Eighty-seven percent of the participants agreed on the usefulness of the trainer for resident training, and 93% strongly agreed on the usefulness of the simulator for the orientation with the endoscope.

Deopujari et al.[20] using 3D printing technology and added detachable components that mimic choroid plexus, ependymal veins, and the floor of the third ventricle using cadaveric animal tissues. The cerebrospinal fluid pulsation is simulated using an external oscillatory pulse-generating pump. Thirty-five participants used the model for >1 year and found it useful for third ventriculostomy training. Thirty participants provided feedback for training, quality of the model, and ease of procedure.

The normal commercial simulation models were also used for ETV training around 12 countries of East, Central, and Southern Africa with the help of a mobile endoscope. The training was promoted by a volunteer neurosurgical team from the Neurosurgery Education Development Foundation at hospitals in regional sites in these developing countries.[21] The 2018 CURE Hydrocephalus and Spina Bifida fellowship program in Uganda uses 3D printed cranial model, designed from thin-cut radiographs for the training of surgeons from low- and middle-income countries.[22]

Yamauchi et al.[23] developed an endoscopic sinus surgery simulator

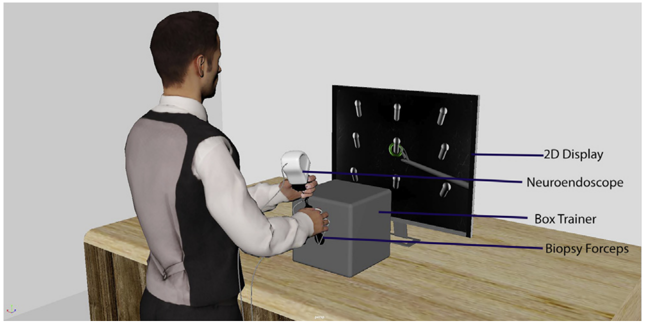

Figure 5. Generalized training setup of box trainers. 2D, two-dimensional.

consisting of a head dummy, force sensors, position sensor, video monitoring system, and computer systems. The force sensors were attached to the right and left of the head dummy. The net value of force was zero in the absence of external force. The left nostril was used for evaluation and the right nostril for training. The target for training was the ostium of the maxillary sinus, whereas the target for evaluation was the ostium of the frontal sinus. The simulator provided a varied surgical environment for training and evaluation. The output of the force sensors and the position sensors was obtained during the evaluation and training tasks. A demonstration video on the procedure by the experienced surgeon was provided at the beginning of the evaluation and training task. The video camcorder recorded the activity and played back these videos for individual feedback. Maximum, average, and integral force were measured. The integral force was found to have decreased significantly by repeated performance. There was also a significant difference in the force applied by the residents and nonmedical participants.

The SIMONT Otorhino and Skull Base Surgery simulator was developed for skull-base surgery simulation. A study was conducted in which a total of 19 residents from 2 separate academic institutions performed 83 simulated endoscopic procedures.[24] The study assessed the initial cost, training cost, and individual rating based on the Physician Performance Diagnostic Inventory Scale (a Likert scale for self-rating). The study showed that the trainees self-perceived to improve ($P < 0.001$) based on training on these simulators. The model was not patient specific and required replacement of brain, ventricular system, and skull base/pituitary after each session, leading to increased cost.

In another study in 2010, commercially available nasal models such as AIST (National Institute of Advanced Industrial Science and Technology) were used to describe endoscopic endonasal procedures.[25] The evidence for validation was missing in this study.

Narayanan et al.[26] used the 3D printed skull-base simulator for training the endoscopic skull-base surgery for ear, nose, and throat surgeons as a part of a training workshop. Fifteen participants evaluated the whole procedure including model registration, the introduction of the endoscope, incision of the mucous membrane, identification of anatomic structures, and drilling and exposing the dura. The average score obtained for the whole procedure was 4.0 on a scale of 5.0. The patient-specific models were created for the study.[27]

Tai et al.[28] developed a physical model for training the drilling during the endoscopic endonasal approach. The model consisted of a skull frame, replaceable drilling part, skin and nasal cavity tissue mask, and internal structures. Eight neurosurgeons from 2 neurosurgery training programs evaluated the content validity of the model. The assessment was based on a 23-item survey using a 4-point rating scale, with 4 being the highest score. The average score obtained by the model was 2.8, suggesting minor adjustments are needed before considering it for the endoscopic endonasal approach curriculum.

Rampinelli et al.[29] used the SIMONT simulator for their study comparing the surgical maneuverability of 2D high-definition versus 3D endoscopy in a preclinical setting for endonasal endoscopic surgery. The participants performed 2 tasks of simulating the grasping and dissection movement on the model. All the participants were asked to provide their subjective evaluation of the setup, and time taken for the tasks was recorded. For 25 participants, Aurora magnetic-based neuronavigator (Northern Digital Inc., Waterloo, Canada) and ApproachViewer software (Gtx-UHN, Toronto, Canada) were used to track the activity on the simulator which had been CT scanned at 1×1 frame with contiguous slices at 0.4 mm. The trajectories of the participants were analyzed to compare the jitter, the sum of squared differences, and funnel index for both 2D and 3D cases. The study showed that the total execution time was significantly lower for 3D endoscopy ($P < 0.05$) in beginners and experts and only 14% of beginners experienced discomfort with 3D endoscopy. There was a trend toward an increase in the effectiveness of surgical maneuvers with 3D on the analysis of jitter. For experts, the sum of the squared difference and funnel index showed better values.

Physical Box Trainers

Box trainers are intermediate fidelity trainers that provide a low level of realism in anatomy but provide task-based hands-on training (Figure 5). The tasks are defined based on actual surgery, and the actual instrumentation is used for training. The task is performed in a standard, repeatable manner to evaluate the trainee. Causality and accountability are high, and the resources provided are cheap and reproducible. Box trainers are widely accepted in the laparoscopic training environment, and there are a few box trainers for neuroendoscopy. The evaluation of box trainers can be based on subjective or objective criteria. In subjective direct observation, the evaluator watches the person performing the task or procedure on the box trainer. There are also options such as recording the endoscopic video for later evaluation. The objective criteria include a Likert-scale–based observation, wearable

Table 1. Detailed Classification of Neuroendoscopic Synthetic Simulators

Synthetic Simulators

Type of Simulator	Simulator Details	Institution	Fabrication	Participants	Evaluation Criteria	Validation
ETV	1) SIMONT; Zymberg et al., 2010[9]; Guimarães Filho et al., 2011[10]	Federal University of Sao Paulo, Brazil	Neoderma rubber	9 experienced and 13 inexperienced neurosurgeons performed the training experiments	Direct observation based on scale	Face Construct Interrater reliability retest
	2) SIMONT simulator for image guidance training; Coelho et al., 2011[11]				Error calculation before and during neuronavigation	—
	4) Waran et al., 2014, 2015[12-14] 3D ETV model	Division of Neurosurgery, Faculty of Medicine, University of Malaya, Kuala Lumpur, Malaysia in 2014	3D printing technology to replicate different tissue types such as skin, dura, bone, and tumor with materials of varying density and consistency	3 experienced neurosurgeons and 12 junior neurosurgeons scored the trainer	Likert scale score	Face
	5) ASPEN; Coelho et al., 2014[15]	Department of Neurology and Neurosurgery, Paulista School of Medicine, Federal University of Sao Paulo, Sao Paulo, Brazil	Synthetic Neoderma rubber was used to simulate the tissues and silicon and fiberglass molds were used to form the shape of cerebral ventricles	5 experienced neurosurgeons were asked to rate the realism of the simulator	Opinion	Face
	6) Breimer et al., 2015[16,17] Synthetic ETV	Center for Image-Guided Innovation and Therapeutic Intervention, The Hospital for Sick Children, Toronto, Ontario, Canada	3D printed molds and synthetic materials (silicone and slacker)	16 neurosurgical trainees (postgraduate years 1—6) and 9 pediatric and adult neurosurgeons They also established the content validity by 17 international experts	Likert scale score Neuroendoscopic Ventriculostomy Assessment Tool (NEVAT) for ETV using the procedure-specific checklist of surgical errors, and a global rating scale	Face Content
	7) Weinstock et al., 2017[18]	Department of Anesthesia, Johns Hopkins Hospital, Baltimore	Fusion of 3D printing and special effects to provide lifelike tactile properties	13 residents and 4 neurosurgery fellows	14-item Likert-like questionnaire for trainer Two neurosurgeons evaluated the performance of the participants using OSATS scale	Face Content Construct
	8) Garling et al., 2018[19]	Department of Neurosurgery, Wayne State University, Michigan	Skull was created by 3D printing and the brain was created from 3D printed mold and silicone	15 neurosurgeons participated in the evaluation of the simulator with the mimetic endoscope	5-point Likert scale	Face Content
	9) Deopujari et al., 2019[20]	Centre of Excellence for Minimal Access Surgery (CEMAST), Mumbai, India developed an endoscopic third ventriculostomy simulator	3D printing	30 participants on 5-point Likert scale, 35 participants including 28 young neurosurgeons, 7 trainee neurosurgeons evaluated usefulness for a year	5-point Likert scale	Face Content

ETV, endoscopic third ventriculostomy; 3D, three-dimensional; ENT, ear, nose, and throat.

Continues

Table 1. Continued

Synthetic Simulators

Type of Simulator	Simulator Details	Institution	Fabrication	Participants	Evaluation Criteria	Validation
Endonasal skull-base model	1) Yamauchi et al., 2002[23] Endoscopic Sinus Surgery Simulator	National Institute of Advanced Industrial Science and Technology, Higashi, Tsukuba, Japan			Force sensors	Construct
	2) SIMONT Otorhino and Skull Base Surgery Simulator; Nogueira et al., 2008[24]	ENT Centre, Sao Paulo, Brazil		19 residents	Likert scale—based self-rating	
	3) AIST model; Ge and Feng, 2010[25]	Xu-anwu Hospital, Capital Medical University, Japan			—	—
	4) Narayanan et al., 2015,[26] Waran et al., 2012[27] Skull-base simulator	Division of Neurosurgery, University Malaya, Kuala Lumpur, Malaysia	3D Printing	15 ENT surgeons	Likert-scale—based rating by	Face
	5) Tai et al., 2015[28] Endoscopic endonasal approach	University of Michigan, Ann Arbor, Michigan	3D Printing, silicon molding	8 neurosurgeons	23-item survey using a 4-point rating scale	Content
	6) Rampinelli et al., 2017[29]	Department of Medical and Surgical Specialities, Radiological Sciences and Public Health, University of Brescia, Brescia, Italy	—	68 volunteers including novices and experienced surgeons	Aurora magnetic-based neuronavigator and ApproachViewer software	Construct

ETV, endoscopic third ventriculostomy; 3D, three-dimensional; ENT, ear, nose, and throat.

electronic sensors, and computed video analysis.

Fraser et al.[30] developed a box trainer specifically to compare the performance of 2D and 3D endoscopes. The task of the trainer was defined as the removal of the simulated tumor. It was used for the testing of hand—eye coordination.

Malekzadeh et al.[31] developed a sinus surgery task trainer using gelatin embedded with readily available recyclable materials. It was used to train junior-level otolaryngology residents. Various tasks were involved in the model, including recess probing, targeted injections, removal of superior suture, extraction of the bead, and antrostomy of the egg. A 5-point Likert-scale—based questionnaire was used to evaluate the fidelity of the model, and 90% reported the model to be useful.

Hirayama et al.[32] developed a webcam-based endoscopic endonasal trainer and studied the effectiveness of training by evaluating the performance before and after the training using LapSim virtual reality simulator (Surgical Science Sweden AB, Göteborg, Sweden). The basic tasks involved were peg transfer and instrument navigation. Nineteen novices and 6 experienced neurosurgeons who participated in the study were objectively evaluated based on 11 variables, including path length, average angular path, instrument time, instrument misses, and tissue damage. The movement, speed, and efficiency of the novices were reported to have significantly improved with training.

Inoue et al.[33] compared the performance of 43 examinees on 3D and 2D endoscope with the help of a task trainer. Three tasks were provided; first for depth perception, second for horizontal motion, and third for anteroposterior motion. The 3 tasks were performed on a 3D-printed skull model. The execution time and path length were measured while the tasks were performed using an optical tracking system. The novices and beginners showed a significant reduction in time for task 3 using 3D endoscopes compared with 2D. For them, the 3D system was better for depth perception than for horizontal motion. No difference was found in the expert group. This study showed a shorter learning curve using 3D endoscopes for novice surgeons.

Espinoza et al.[34] developed a low-cost optical simulator for emulating the neuroendoscopic optics (0° and 30°) by using commercially available USB (Universal Serial Bus) 2.0 camera. These investigators also developed a box trainer to check the realism of the optical simulator using 3 psychomotor evaluation modules (spatial adaptation, depth adaptation, and dissection). Thirty-five experts and nonexpert neurosurgeons performed the evaluation

Table 2. Detailed Classification of Neuroendoscopic Box/Task Trainers

Type of Simulator	Simulator Details	Institution	Participants	Evaluation Criteria	Validation
Box/Task Trainers					
Endoscopic third ventriculostomy	—	—	—	—	—
Endonasal	1) Testbox; Fraser et al., 2009[30]	Weill Medical College of Cornell University, Presbyterian Hospital, New York, USA	—	Testing 2D versus 3D	—
	2) Malekzadeh et al., 2011[31] Sinus surgery task trainer	Head & Neck Surgery, Georgetown University Medical Center, Washington, DC, USA	—	5-point Likert scale questionnaire	Face
	3) Webcam for endonasal transsphenoidal surgery; Hirayama et al., 2013[32]	Department of Neurosurgery, Osaka University Graduate School of Medicine, Suita, Osaka, Japan	19 novices and 6 experienced neurosurgeons	LapSim simulator metrics	Construct
	4) Inoue et al., 2013[33]	Graduate School of Medical Sciences, Kyushu University, Fukuoka, Japan	—	Testing 2D versus 3D: Execution time and total path length	Construct
	5) PsT1 optical simulator; Espinoza et al., 2015[34]	Research and Advanced Studies Center of the National Polytechnic Institute of Mexico	—	Depth adaptation, spatial location, dissection	Face
	6) Neuro-Endo-Trainer for endonasal surgery; Singh et al., 2015[35]; Singh et al., 2016[36]	Centre for Biomedical Engineering, Indian Institute of Technology Delhi, India	4 groups of volunteers including 4 expert neuroendoscopists, 19 novice neurosurgeons, 11 neurosurgery residents performing multiple iterations, and 27 neurosurgery residents with a single iteration	Video-based observation, Neurosurgery Education and Training School Skills Assessment Scale	Face Construct

2D, two-dimensional; 3D, three-dimensional.

of the system, and 81% agreed on the visualization and 90% on the movement and control.

Raman et al. developed Neuro-Endo-Trainer (NET) for endonasal transsphenoidal surgery task training. This model included an activity area derived from the surgical exposure retrospectively obtained from CT images of 15 patients. The training model was a box with a grasp and pick-place activity. The level of difficulty was increased by variations in the activity plate (carrying peg and rings) by introducing tilts. This process provided acquaintance with variable angled scopes and depth perception. A demonstration training video was provided to explain the method of training and evaluation. The training was imparted with real instruments used in the surgery and a standard endoscope system. The investigators performed a validation study for face and construct validity on four groups of volunteers based on subjective questionnaire and objective rating by a neurosurgeon watching the endoscopic video of the task performed. The objective rating scales were developed based on modified OSATS (Objective Structured Assessment of Technical Skills) criteria called Neurosurgery Education and Training School Skills Assessment Scale (NETS-SAS), dedicated to neurosurgery. The experts showed lower task completion times and greater skills assessment scale scores than did novices and residents. The self-rating of novices and residents showed significant improvement after Neuro-Endo-Trainer simulation (6 and 7, respectively). There was a significant difference in the training using the angled scope and tilted plates.[35,36] This model also incorporated an objective evaluation measure for the existing box trainer by introducing an auxiliary camera to record the activity of the trainee. The video recorded from the activity was automatically segmented, and the forceps tooltip was tracked using Gaussian mixture-based background model and tracking-learning-detection algorithms. The authors calculated objective evaluation measures from the video (e.g., the number of times of hitting the board, time taken, and smoothness and arch length of the path traversed). Results were provided as synopsis feedback for the trainee to help them in the improvement of subtasks.[37]

DISCUSSION

The monocular view of the neuroendoscope projected on a 2D screen demands practice for eye—hand coordination, depth perception, bimanual dexterity, fulcrum effects, and constrained movements. Some studies suggest the need for extensive training systems for endoscopic surgery.[38,39] Therefore, the traditional "teach one, see one, do one" concept of apprenticeship is no longer applicable for endoscopic skills training. Snyderman et al. reviewed their experience in endonasal skull-base surgery from 1998 to 2006 and proposed a training plan for the acquisition of surgical skills. These investigators suggested a level-based or incremental modular approach to develop fundamental endoscopic skills on cadavers. However, because of limited availability and legal and ethical issues with cadavers, the reviewed simulation systems are better supplements during the initial stages of learning. The fundamental surgical skills can be practiced on laboratory models that allow supervision, self-instruction, videotape monitoring, and practice.[40,41] The simulation environment is necessary to prepare the residents to treat patients using potentially dangerous instruments.[42] The question arises whether simulations provide the necessary training to improve real-world surgical skills, or are they just making the trainees good simulation users. Deliberate practice on simulation systems has been found to improve skills and to translate into the real patient scenario.[5,6]

Virtual reality simulations and physical simulators are promising simulation methods for training in neuroendoscopy.[43,44] Virtual simulations are considered good for procedure-based skills training, but the reviews of these simulators show that there should be anatomic variations and a range of cases for improved fidelity.[45,46] The synthetic simulators include anatomic variations and different cases and are low-cost replacements for the costly virtual reality simulators. Currently available synthetic simulators are single-use models and lack pathology and haptic feedback similar to real tissues. Box trainers are a better counterpart for the task-based skills training and include objective scoring criteria for evaluation of surgical skills. The major disadvantage of box trainers is that they lack the anatomy and realism of actual surgery.

The current study helped to classify physical training systems based on design, fidelity, and validation studies. One of the limitations of the current review is that it focuses on physical simulators for neuroendoscopy; the physical simulators for microneurosurgery have not been covered. Another limitation is that some of the commercially available physical simulators are not included in this study because of a lack of reported studies. The neuroendoscopic skills training physical simulators were divided into synthetic simulators (Table 1) and box trainers (Table 2). The synthetic simulators for the endonasal transsphenoidal approach and the ETV were separated. Some ETV simulators also included training for neuronavigation systems. Direct observation based on a Likert scale was the common evaluation criterion for most of the synthetic trainers. Validation results were available for face validity, content validity, and construct validity. Box trainers were available for endonasal transsphenoidal surgery training. A variety of objective measures were used, including evaluation metrics from simulators, video-based observation using neurosurgery specific scale, and the Likert scale questionnaire. The validity studies reported include face validity and construct validity.

The objective measures for the skills evaluation can be broadly divided into objective-scale—based direct observation, psychomotor testing, a sensor-based evaluation such as the Imperial College Surgical Assessment Device, inertial measurement unit, magnetic, optical, TrEndo, and video-based evaluation.[47-51] The evaluation systems using objective measures are not as popular in neuroendoscopy as in laparoscopy. This situation may be because neuroendoscopy is a relatively new technology adaptation and the neurosurgical area of exposure and maneuverability is narrow and in miniature.

CONCLUSIONS

ETV and the endonasal transsphenoidal approach are the standard neuroendoscopic procedures. Various physical training systems have been developed, including synthetic simulators and box trainers. Validation studies of the simulators show that they are suitable for inclusion in a surgical curriculum. The commercially available training systems are limited. The physical simulations have great potential but require more realism and objective evaluation measures.

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