Design and Validation of an Open-Source, Partial Task Trainer for Endonasal Neuro-Endoscopic Skills Development: Indian Experience

Ramandeep Singh[1], Britty Baby[2], Natesan Damodaran[2], Vinkle Srivastav[2], Ashish Suri[2], Subhashis Banerjee[3], Subodh Kumar[3], Prem Kalra[3], Sanjiva Prasad[3], Kolin Paul[3], Sneh Anand[1], Sanjeev Kumar[4], Varun Dhiman[4], David Ben-Israel[2], Kulwant Singh Kapoor[5]

■ BACKGROUND: **Box trainers are ideal simulators, given they are inexpensive, accessible, and use appropriate fidelity.**

■ OBJECTIVE: **The development and validation of an open-source, partial task simulator that teaches the fundamental skills necessary for endonasal skull-base neuro-endoscopic surgery.**

■ METHODS: **We defined the Neuro-Endo-Trainer (NET) SkullBase-Task-GraspPickPlace with an activity area by analyzing the computed tomography scans of 15 adult patients with sellar suprasellar parasellar tumors. Four groups of participants (Group E, n = 4: expert neuroendoscopists; Group N, n =19: novice neurosurgeons; Group R, n = 11: neurosurgery residents with multiple iterations; and Group T, n = 27: neurosurgery residents with single iteration) performed grasp, pick, and place tasks using NET and were graded on task completion time and skills assessment scale score.**

■ RESULTS: **Group E had lower task completion times and greater skills assessment scale scores than both Group N and R ($P \leq 0.03$, 0.001). The performance of Groups N and R was found to be equivalent; in self-assessing neuroendoscopic skill, the participants in these groups were found to have equally low pretraining scores (4/10) with significant improvement shown after NET simulation (6, 7 respectively). Angled scopes resulted in decreased scores with tilted plates compared with straight plates (30° $P \leq 0.04$, 45° $P \leq 0.001$). With tilted plates, decreased scores were observed when we compared the 0° with 45° endoscope (right, $P \leq 0.008$; left, $P \leq 0.002$).**

■ CONCLUSIONS: **The NET, a face and construct valid open-source partial task neuroendoscopic trainer, was designed. Presimulation novice neurosurgeons and neurosurgical residents were described as having insufficient skills and preparation to practice neuro-endoscopy. Plate tilt and endoscope angle were shown to be important factors in participant performance. The NET was found to be a useful partial-task trainer for skill building in neuroendoscopy.**

INTRODUCTION

Since its introduction to neurosurgery in 1910, endoscopy has revolutionized the approach to skull base and intraventricular surgery, providing patients with safer, minimally invasive alternatives to previously morbid procedures and considerably faster recovery.[1] The neuro-endoscopic technique, however, demands a unique skill-set whose mastery presents a steep learning curve.[2] Historically, learners have struggled with manipulating long instruments, complicated by fulcrum effect, as well as navigating within a distorted, panoramic, nonstereoscopic, and physically constrained operative field.[3,4]

Key words
- Endonasal
- Neuro-endoscopy
- Open source
- Partial task trainer
- Physical simulator
- Simulation
- Skills training
- Skull base

Abbreviations and Acronyms
NET: Neuro-endo-trainer

From the [1]Centre for Biomedical Engineering, Indian Institute of Technology Delhi, New Delhi; [2]Department of Neurosurgery, All India Institute of Medical Sciences, New Delhi; [3]Department of Computer Science and Engineering, Indian Institute of Technology Delhi, Hauz Khas, New Delhi; [4]Central Scientific Instruments Organization (CSIR-CSIO) Sector 30-C, Chandigarh; and [5]Department of Biostatistics, All India Institute of Medical Sciences, New Delhi, India

To whom correspondence should be addressed: Dr. Ashish Suri, M.B.B.S., M.Ch., D.N.B. (N.S.) [E-mail: surineuro@gmail.com]

Ramandeep Singh and Britty Baby are co-first authors.

Supplementary digital content available online.

Citation: World Neurosurg. (2016) 86:259-269.
http://dx.doi.org/10.1016/j.wneu.2015.09.045

Journal homepage: www.WORLDNEUROSURGERY.org

Available online: www.sciencedirect.com

Despite these competency challenges, no literature exists on an evidence-based curriculum for endoscopic training within neurosurgical residency.[5]

The use of simulation in endoscopic surgical skills training was pioneered by work in laparoscopy, which began only in the last 25 years.[6] A breadth of research now exists showing that laparoscopic simulation develops fundamental skills, such as hand-eye coordination, improves performance in the operating room, is cost effective, and leads to rapid acquisition of competence in advanced surgical training.[7–13] In neurosurgical education specifically, simulation has overcome several constraints imposed by the traditional apprenticeship model, including the availability of residents and educators, case exposure, and uncompromised ethical patient care.[14–20] Yet the adoption of simulation in neurosurgical training has been slow. Early work has focused on cadaveric and virtual simulation, which prove to be resource intensive, difficult to distribute widely, and require advanced technology, which has yet to be realized.[21–28] Synthetic physical models, however, have the potential to impart to the learner a fundamental skill-set at low cost, which learners can refine before and alongside exposure to surgical cases.[23,29,30] These fundamentals, including psychomotor skills, acquaintance with non-stereoscopic visual feedback, and proficiency within limited operative space, are prerequisites for realistic success during clinical cases.[31] Synthetic physical models also are advantageous in that they are inexpensive, accessible at all times of day, and use the appropriate level of fidelity to present an applied task, helping the learner to focus on developing the surgically relevant skills needed for neuro-endoscopy. No synthetic physical model, objectively validated as an effective neuro-endoscopic simulator, currently exists.[3,32,33]

The main objective of this study was to develop and validate an open-source synthetic physical partial task simulator, which successfully trains the fundamental skills useful in neuro-endoscopic surgery, with an emphasis on endonasal approaches. An attempt also was made to establish baseline competency of neurosurgeons and neurosurgery residents at various stages of training.

MATERIALS AND METHODS

Development of the Neuro-Endo-Trainer (NET) SkullBase-Task-GraspPickPlace

We began the development of the synthetic physical model by replicating the dimensions of the surgical field in endonasal endoscopic skull base surgery. A total of 15 consecutive patients between the ages of 18 and 60 years who underwent sellar-suprasellar-parasellar endoscopic endonasal surgery between May and June of 2013 were analyzed. All measurements, either taken directly through physical examination or from preoperative computed tomography imaging studies, were averaged over all 15 patients. Preoperatively, the largest cross-sectional dimension between the nares was measured. On computed tomography in the sagittal plane, distances were defined between the (a) nasal vestibule, (b) anterior aspect of the cribriform plate, (c) tuberculum sellae, and (d) inferior border of the clivus (Figure 1A). In the coronal plane, the (e–f) intercarotid and (g–h) interlateral opticocarotid recess distances were measured (Figure 1B).

Using these data, we constructed a rectangular 110 × 80-mm activity plate with orthogonally oriented pegs situated in a light-proof box with an entry port for endoscopic instrumentation (Table 1; Figure 2). Then, 1.5-mm thick, 12-mm diameter rings were fashioned and placed on the pegs to be used during endoscopic training. The plate was positioned 90 mm from the entry port on a motorized base at a fixed angle of 45° from the horizontal and was rotatable about the vertical axis by 50° both in the clockwise and counterclockwise directions. Two versions of the activity plate were designed, one flat and one with a trough to replicate increased depth after access into the sphenoid sinus.

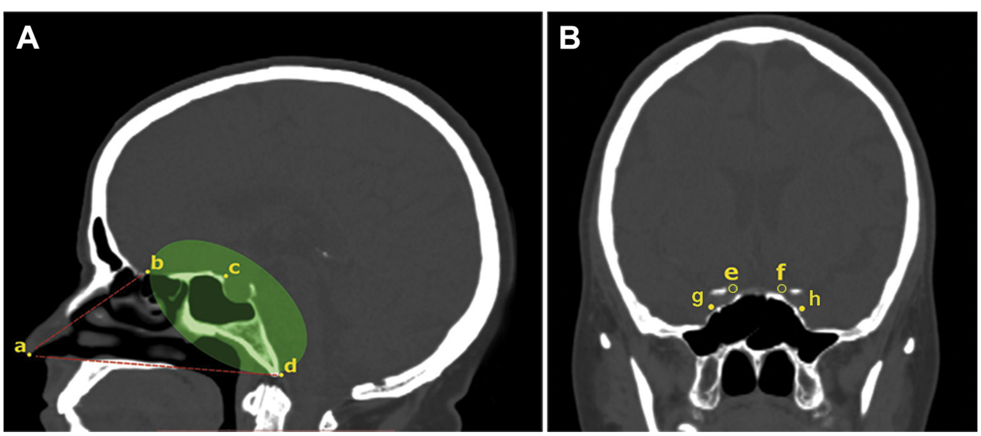

Figure 1. Endoscopic endo-nasal skull base approach operating area: a, nasal vestibule; b, cribriform plate; c, tuberculum sellae; c′, floor of sella; d, inferior margin of clivus; e, right internal carotid artery; f, left internal carotid artery; g, right lateral opticocarotid recess; h, left lateral opticocarotid recess. (**A**) Sagittal view. Line "ab" corresponds to the anterior most trajectory of the endoscope; line "ad" to posterior inferior trajectory of the endoscope; line "bcd" denotes the operative field in the midline. The green eclipse denotes the operative reach of Endoscopic Endo-nasal Skull Base approach. (**B**) Line "ef" denotes intercarotid distance; line "gh" denotes distance between lateral opticocarotid recesses.

Table 1. Summary of Surgical Dimension Constraints with Corresponding NET Activity Zone Parameters

Endonasal Endoscopic Skull Base Surgery Constraint	Dimensions of Surgical Constraints, mm (range)	Corresponding Dimensions of NET Activity Zone*, mm
On physical examination		
Internaris distance	18–20	20
CT studies		
Instrument path length range or depth of operative field	90 (ab) to 100 (ad)	80–100
Tuberculum sellae to inferior margin of clivus	33.42 (cd) (27.9 to 39.6)	40 (max. VIPD)
Inter LOCR distance	30.49 (gh) (24.5 to 38.1)	40 (trough width - Plate B)
Intercarotid distance	20.23 (ef) (17.1 to 24.3)	20 (IPD)
Cribriform plate to inferior margin of clivus	83.56 (bd) (75.7 to 92.4)	110 (Plate length)
Area depth variation	10-20 (c′c)	10 (trough depth - Plate B)
Empirical		
Size of object to grasp	2–5	1.5
Angle of activity area	45°	45°
Angular lateral reach	−45 to 45°	−50 to 50°

Line "ab" corresponds to the anterior most trajectory of the endoscope ie distance between naris to cribriform plate.
Line "ad" corresponds to posterior inferior trajectory of the endoscope ie distance between naris to inferior margin of clivus.
Line "bcd" denotes the operative field in the midline. Line "ef" denotes inter-carotid distance.
Line "gh" denotes distance between the LOCR.
(A) activity plate- Flat; (B) activity plate with mid-trough.
a, nasal vestibule; b, cribriform plate; c, tuberculum sellae; c′, floor of sella; d, inferior margin of clivus; e, right internal carotid artery; f, left internal carotid artery; g, right lateral optico-carotid recess; h, left lateral optico-carotid recess.
NET, Neuro-Endo-Trainer; CT, computed tomography; VIPD, vertical interpeg distance; LOCR, lateral optico-carotid recess; IPD, interpeg distance.
*NET Activity Zone represents the area covered by the pegs.

The ab and ad planes, respectively, were used to define the anterosuperior and inferior limits of the surgical field trajectory. Distances "ab" and "ad" also were used to define the length between the entry port and the plate, which signifies the depth of the operative field. The entry port diameter was correlated with the recorded internaris distance. bd was used to define the plate length (l), ef was used to define the interpeg distance (i), cd was used to define the distance between the outer peg rows (Max. vertical interpeg distance) (v) and by corollary the plate height (h), gh was used to define the trough width (Plate B) (w), and c′c was used to define the trough depth (Plate B) (t) (Figure 2).

The box trainer and plate were modeled initially with the Unigraphics NX 6 CAD (Unigraphic Solutions Inc, Plano, Texas, USA) and printed using a Dimension Elite and Connex 3D Printer (Stratasys, Rehovot, Israel) with fused deposition modeling used for the hard components and Polyjet prototyping used for the rubber components. A membrane keypad and graphic LCD display were custom made to fit in the front face of the box and were programmed by the use of a microcontroller (Arduino Hungary Kft, Budapest, Hungary) to adjust the vertical angle of the activity plate and display the task time.[34]

Study Participants

A total of 61 participants consented to participate in the study, and all successfully completed the training program. They were divided into 4 groups on the basis of their previous level of training: Group E ($n = 4$) comprised expert faculty neurosurgeons with at least 5 years of neuroendoscopic experience, Group N ($n = 19$) comprised novice neurosurgeons with minimal (not within their scope of practice) neuro-endoscopic experience, and Group R and T (11 and 27, respectively) comprised residents within their final 2 years of training. Group R residents were entered into the repetitive assessment stream and underwent 2 iterations of the training program 24–48 hours apart, whereas Group T as well as Groups E and N were entered into the spot assessment stream and performed the training program once.

Group N participants were assessed while they were attending simulation-based skills training workshop our institute. The Group T residents were recruited during their participation in the conjoint Neurological Society of India-Congress of Neurological Surgeons simulation workshop.

Video

Video available at WORLDNEUROSURGERY.org

NET Training Protocol

Before beginning, participants received a video training module describing how to perform the tasks and the proper endoscopic technique (Supplementary Video 1). Participants used the NET with a flat plate (Figure 2A), 4-mm × 18-cm neuro-endoscopes (Karl Storz Inc, Tuttlingen, Germany), and endoscopic

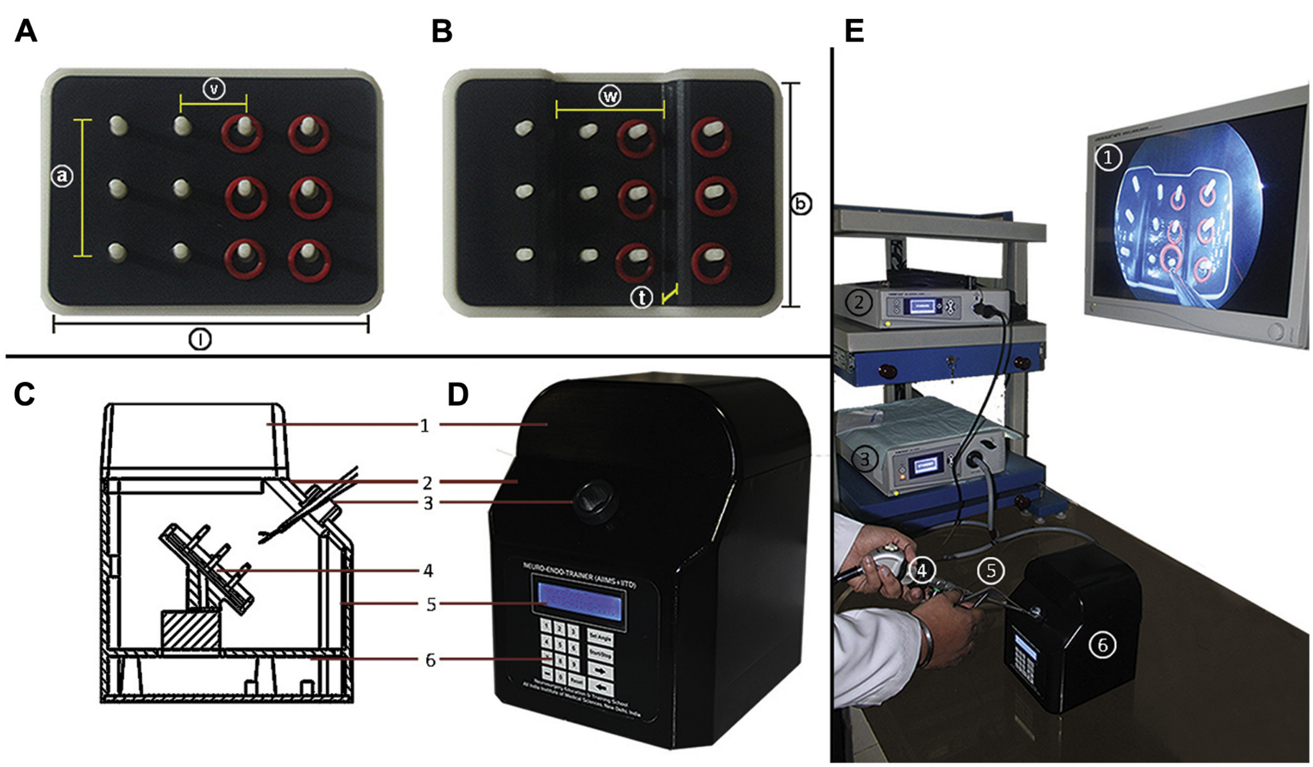

Figure 2. (**A**) Flat Activity plate, a, maximum vertical inter-peg distance; l, plate length; v, inter-peg distance. (**B**) Activity plate with mid-trough b, breath of the plate; t, depth of trough; w, width of the trough. (**C**) Cross-section line diagram of Neuro-Endo-Trainer: 1, cover; 2, angled front plate; 3, rubberized entry port; 4, Activity plate; 5, digital display; 6, membrane input board (**D**) Neuro-Endo-Trainer: 1, cover; 2, angled front plate; 3, rubberized entry port; 5, digital display; 6, membrane input board. (**E**) Complete setup for training: 1, 2D display screen; 2, camera system; 3, lighting for endoscope; 4, endoscope; 5, forceps; 6, Neuro-Endo-trainer.

forceps to maneuver the rubber rings between the pegs according to the schemes outlined in Figure 3. Each task involved moving the rings according to Figure 3A, followed immediately by Figure 3B. The grasp, pick, and place task was performed initially with the 0° endoscope first in the straight position (Figure 3D), followed by the right tilt position (Figure 3C), and finally in the left tilt position (Figure 3E). This series of tasks was then repeated with the 30° endoscope, and once again with the 45° endoscope.

Assessments

Objective Performance Assessment. While Groups E, N, and R participants performed the tasks, the endoscopic video feed was recorded, and later task completion times were recorded and their performance was evaluated, using the Skills Assessment Scale score, by a neurosurgeon who was blinded to the groups (Table 2). The Skills Assessment Scale score uses a 4-point ordinal scale to grade participants on 5 criteria: (1) Hand-eye coordination was assessed by looking for tugging of the rings or hitting of the peg and overshooting or undershooting the activity area. (2) Instrument-tissue manipulation was assessed by critiquing the number of attempts at picking up each ring, the appropriate pressure used to grasp a ring, and any accidental grasping of the plate. (3) Dexterity was assessed by observing the ease in moving instrument and endoscope in all directions. (4) Contiguity/flow of procedure was assessed by recording unnecessary delays between or within tasks. (5) Effectualness was assessed by recording accidental ring slippage or dropping.

Self-Assessment. Groups N and T were asked to evaluate their proficiency in neuro-endoscopy on a scale from 1 to 10 (10 being expert), both before and after the training program.

Posttraining Questionnaire. Participants in Group N completed a questionnaire after completion of the training program. The questionnaire was composed of the following 3 questions that participants answered using a 5-point Likert-type scale (1 = poor, 5 = excellent): relevance to neuro-endoscopic surgery, usefulness in surgical skill building, and appropriateness for neurosurgical residency program.

Statistical Analysis

Statistical analysis was performed using SPSS Ver. 21 (IBM, Inc, Armonk, New York, USA). A value of $P < 0.05$ was considered statistically significant. Differences in task completion times and Skills Assessment Scale scores among Groups E, N, and R were assessed with the Mann-Whitney U test. The changes in score and

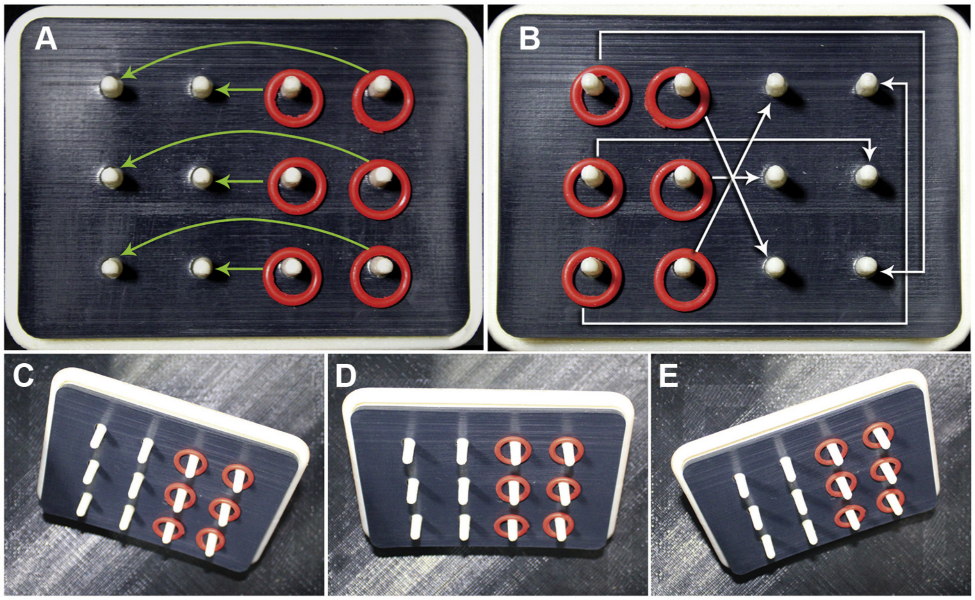

Figure 3. Training pattern on activity plate of the endo-trainer. (**A**) The rings are on the right side. They are placed on the left as shown by the green arrows. This is to train with horizontal movements. (**B**) The rings are placed on the diagonally opposite pegs as indicated by the white arrows. This helps in training for diagonal movements. (**C**) The activity plate has been rotated to right side. (**D**) The plate is in median position. (**E**) The plate has been rotated to left side. This rotation is for training to lateral access.

timing between consecutive sessions in Group R, as well as pre- and posttraining self-evaluation scores within Groups N and T, were assessed by the Wilcoxon test. The effects of plate rotation and endoscope angle were assessed by comparing task completion times and Skills Assessment Scale scores using the Student paired t-test.

RESULTS

Task Completion Time and Skills Assessment Scale Score Performance

Intergroup. The performance of participants in Groups E, N, and R using the 0° scope and the straight plate are summarized and compared in Table 3 (note only first iteration Group R data were used for comparison). Group E participants were found to have statistically significant greater scores than both Groups N and R participants on hand-eye coordination (4 vs. 2, 2), Dexterity (4 vs. 2, 2), and Total Score (18 vs. 13, 12). The task completion time for Group E participants also was lower than Groups N and R, but this finding was not statistically significant (191.5 vs. 212.0, 214.0). There was no statistically significant difference between Group N and Group R participants.

Plate Position. The performance averaged over both iterations of Group R participants by comparing different plate positions is summarized in Table 4A. There were no statistically significant differences in Skills Assessment Scale total score seen with different plate positions when the 0° endoscope was used. When an angled scope was used, however, statistically significant worsening in total scores were observed with tilted plates compared with straight plates (30°: 12.50 vs. 11.77, 11.86; 45°: 12.09 vs. 11.00, 11.45). There was no statistically significant difference observed between the time or total score between right tilt and left tilt. With respect to task completion time, when the 0° scope was used, the straight position took statistically significantly more time to complete than the tilted positions (233.36 vs. 197.77, 209.68). There was no statistically significant difference observed in completion time with different plate positions when angled scopes were used.

Endoscope Angle. The performance averaged over both iterations of Group R participants by comparing different endoscope angles is summarized in Table 4B. With a tilted plate, a statistically significant decrease in Skills Assessment Scale total score was observed when we compared the 0° with the 45° endoscope (right: 12.32 vs. 11.00, left: 13.00 vs. 11.45). When we compared the 0° and 30° endoscopes, a drop in total score was only statistically significant during left tilted tasks (13.00 vs. 11.77). The task completion time took statistically significantly longer with the 0° endoscope compared with the 45° endoscope when participants performed the task with the straight plate (233.36 seconds vs. 180.95 seconds). Neither completion nor total score at any plate orientation was statistically significantly different when we compared the 30° and 45° endoscopes.

Table 2. Skills Assessment Scale

	1	2	3	4
Hand-eye coordination				
Handling of instruments (forceps, drill, endoscope, grasper); depth perception	Continuous struggle throughout the activity	Frequent loss of coordination Able to use endoscope well but poor instrument manipulation	Grossly smooth coordination using low magnification	Perfect coordination under high magnification
Instrument tissue manipulation				
Tissue handling under magnification with various instruments; appropriate pressure and force; Confrontation with neighboring objects (repeated attempt to grasping)	Grossly unacceptable Irregularity/striking objects in trajectory	Frequent difficulty Occasional irregularity of instrument manipulation	Instrument manipulation smooth but slow and not confident	Perfect manipulation Clean focal and surrounding tissues and smooth manipulation
Dexterity				
Lack of tremors/ jitteriness; therblig (intraoperative elemental motion)	Irregular therblig/ tremors/jitteriness throughout the activity and frequent unnecessary movements	Well versed with instruments but unsteady in its handling	Well versed with instruments and steady handling but unable to perform examiner directed procedures with it	Good dexterity and completely at ease to perform examiner directed procedures
Flow of procedure				
Time management during activity; total duration in task completion	Unable to complete tasks and its stages	Considerable delay in completing the stages of the tasks assigned but is able to complete the task in a reasonably delayed time	Completing the tasks in assigned time	Completing the task well before the assigned time
Effectualness				
Final result achieved during activity	$\geq$3 rings slipped	2 rings slipped	1 rings slipped	No rings slipped

Table 3. Comparison of Skills Assessment Scale Score and Task Completion Time Using a 0° Scope and Straight Plate Among Groups E, N, and R*

	Median			Wilcoxon Signed-Rank Test		
Criteria	**Expert (Group E) (n = 4)**	**Novice (Group N) (n = 19)**	**Resident (Group R) (n = 11)**	**E-N *P* Value**	**E-R *P* Value**	**N-R *P* Value**
Hand-eye coordination	4	2	2	0.016	0.001	NS
Instrument tissue manipulation	3	2	2	NS	NS	NS
Dexterity	4	2	2	0.012	0.001	NS
Flow of Procedure	3	3	2	NS	NS	NS
Effectualness	4	4	4	NS	NS	NS
Total score	18	13	12	0.035	0.001	NS
Time, seconds	191.5	212	214	NS	NS	NS

NS, not significant.
*Group R data taken from the first iteration only.

Repetitive Assessment Stream. The first and second training iteration Skills Assessment Scale total scores and task completion times of Group R participants were compared (Figure 4A and 4B). Although improvements were observed, none were statistically significant. Improvement in total score was observed with all endoscopes but most pronounced with the 45° angled scope (straight: 12.00 vs. 12.18, right: 10.91 vs. 11.09, left: 11.18 vs. 11.73). A decrease in completion time was observed with all angled endoscopes but most notably with the 45° angled scope in straight plate position (182.36 vs. 179.55) and left plate position (222.55 vs. 188.64).

Self-Assessment

The median self-assessment scores for Groups N and T before and after completion of the training program are summarized in Table 5A. When we compared Group N and T, their median pretraining score[8] was equivalent. Both groups were observed to have statistically significantly greater self-assessment scores after the completion of one iteration of the training program (N: 4 vs. 6, T: 4 vs. 7).

Posttraining Questionnaire

Numerical responses by Group N participants to the posttraining questionnaire are summarized in Table 5B. The vast majority of participants felt very strongly (5/5) that the NET training program was relevant to neuro-endoscopy, useful for surgical skill building, and would be appropriate for incorporation into neurosurgery residency program (15/19, 15/19, 14/19). Of the participants who rated questions below 5/5, common responses included feelings of boredom during the task and requests for variations in plate design and task protocol.

Table 4A. Impact of Plate Orientation on Mean Skills Assessment Scale Score and Task Completion Time Among Group R over Both Iterations

				P Value		
	Straight ST	**Right RT**	**Left LT**	**ST-RT**	**ST-LT**	**LT-RT**
0°						
TS	12.23	12.32	13.00	NS	NS	NS
Time, seconds	233.36	197.77	209.68	0.003	0.063	NS
30°						
TS	12.50	11.86	11.77	0.040	0.035	NS
Time, seconds	177.09	191.09	198.32	NS	NS	NS
45°						
TS	12.09	11.00	11.45	.000	NS	NS
Time, seconds	180.95	192.05	205.59	NS	NS	NS

Table 4B. Impact of endoscope angle on Mean Skills Assessment Scale Score and Task Completion Time Among Group R over Both Iterations

				P Value		
	0°	**30°**	**45°**	**0°-30°**	**0°-45°**	**30°-45°**
Straight ST						
TS	12.23	12.50	12.09	NS	NS	NS
Time, seconds	233.36	177.09	180.95	NS	.003	NS
Right RT						
TS	12.32	11.86	11.00	NS	.008	NS
Time, seconds	197.77	191.09	192.05	NS	NS	NS
Left LT						
TS	13.00	11.77	11.45	.020	.002	NS
Time, seconds	209.68	198.32	205.59	NS	NS	NS

ST, straight; RT, right tilt; LT, left tilt; NS, not significant; TS, Skills Assessment Scale total score; Time, task completion time.

DISCUSSION

NET Design

After the success of simulation in laparoscopy, work by Haji et al.[35] supported the need for simulation-based training in neuroendoscopy. Importantly, Munz et al.[30,36] determined that the potential for surgical error and need for specialized training were greatest during the initial stages of a trainee's learning curve. Furthermore, it is found that dexterity in neuro-

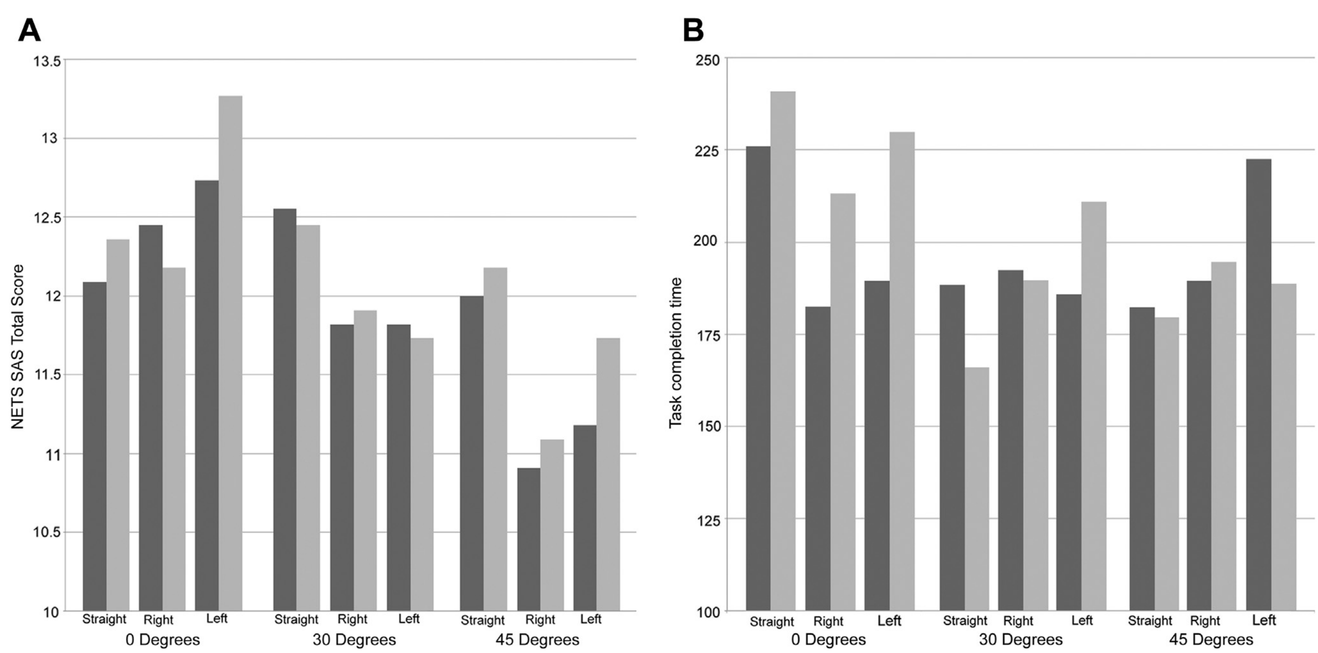

Figure 4. (**A**) The residents (Group R) were rated using Skills Assessment Scale score during their first and second iterations. Their scores were plotted as a graph with dark gray bar denoting first iteration score and light gray bar denoting second iteration score. There was improvement in total scores with 0° and 45° scopes, but these were not statistically significant. (**B**) The task completion time of residents (Group R) during their first and second iterations was plotted as a graph with dark gray bar denoting first iteration score and light gray bar denoting second iteration score. The residents did faster with angled endoscopes during the second iteration.

Table 5A. Groups N and T Self-Assessment of Neuroendoscopic Skills Pre- and Posttraining Program

Group Assessed	Pretraining Median Score	Posttraining Median Score	*P* value
Residents (Group T) No. = 27	4	7	0.000
Novice neurosurgeons (Group N) No. = 19	4	6	0.002

endoscopy was the biggest barrier to surgical proficiency. Approaches in surgical simulation have included synthetic physical models (such as bench models, box-trainers, natural substance simulators), organic physical models (such as cadaveric simulators, animal models—living and nonliving), and virtual reality.[25,26,37] Lately, virtual reality–based simulators are being used in endoscopic training for surgical procedures like endoscopic third ventriculostomy. They have shown promising results in procedural skills acquisition; task-skills training with virtual reality simulators may not be optimal due the information overload. Their large installation cost makes their use in training programs in developing nations difficult.

In designing the NET, the goal of simulation was to impart to the learner the fundamental skills needed for the use of endoscopic equipment and not to provide guidance on the anatomy or stages of a surgical procedure. To this end, the NET was designed to match the constraints of a typical endonasal skull base neuroendoscopic surgery without distracting the learner with superfluous information. A synthetic physical model was therefore chosen as the modality that could produce the optimal level of surgical fidelity. Every parameter within the NET, from the angle of the entry port to the thickness of the rubber rings, was chosen deliberately to force the learner to mimic physical manipulations found in operative cases. Additionally, the entry port was designed without dedicated instruments, such that the learner can use the NET with the endoscopic equipment native to his or her center and gain familiarity with its particular functionality. In this way, the learner can focus on completing the tasks, thereby improving instrument maneuverability and proficiency, without needing to concentrate on simulator-imposed barriers not translatable to the operative environment.

Synthetic physical intermediate fidelity simulators have been shown to be effective at improving psychomotor skills through the work by Hirayama et al.[29] With the use of just an acrylic board with pins and a webcam, their neuro-endoscopic simulator-training program was shown to improve the movement speed and efficiency of their novice participants. This model, however, is limited in that it does not obstruct the activity field from view, does not accurately depict typical anatomic physical constraints, and does not require the learner to operate an endoscope, decreasing the simulators applicability to surgery and the transferable skills gained by the learner.

The S.I.M.O.N.T. simulator designed by Filho et al. is a more anatomically accurate model depicting a ventricular tumor resection. This model was also shown to improve psychomotor skills and increased proficiency on repeated iterations.[23] The greater anatomical fidelity simulators are built to reproduce surgical environment to develop certain specific skills. The use of the NET is therefore advantageous in that it offers accurate physical constraints and instrument performance during surgery but is not restricted by detailed anatomy; the trainer is designed to train dexterity in space dimensionally similar to operative space. These advantages of NET do limit its task-based training of grasp, pick, place skills beyond endoscope and pituitary forceps. But this was overcome by making the training plate removable, wherein different plates for drilling and cutting practice can be placed.

NET Validation

Within this study, the NET's validation was examined.[38] Construct validation describes how well the simulator discriminates between different levels of surgical proficiency. When we compared the performance of the Group E participants who were experts in the field of neuro-endoscopy with Group N (novice neurosurgeons) and Group R (resident neurosurgeons) participants, the experts performed better at eye hand coordination, dexterity, and total score, showing that the NET has construct validity. The remaining parameters, instrument tissue manipulation, flow of procedure, effectualness and completion time, also were likely better in the expert group, but the power of the statistical analysis was limited because of the small sample size of Group E. Interestingly, the performance of Group N and Group R participants was equivalent, implying that the current structure of residency training does not afford novice neurosurgeons the technical skills necessary to practice neuro-endoscopy. This was again noted when Group N and R participants rated their pretraining neuroendoscopic skills equally low with a median value of 4/10 (Table 5A). These results highlight a need for neuro-endoscopic simulation within neurosurgical residency training.

The content validity, which describes how precisely the simulator imitates a real surgical case, was not assessed formally but is not expected to be high, given its inherent design. Indeed, the intention of the design was to limit content to maximize applicability to surgical practice. Rather the focus of design was on face

Table 5B. Numerical Response Summary of Group N Participants to Posttraining Questionnaire

Questionnaire	Minimal (1/5)	Low (2/5)	Neutral (3/5)	Good (4/5)	Excellent (5/5)
Relevance to neuroendoscopic surgery	—	—	2	2	15
Usefulness in surgical skill building	—	—	1	3	15
Appropriateness for neurosurgical residency curriculum	—	—	2	3	14

validity, or how well the simulator replicates the skills needed in surgical practice. In the posttraining questionnaire, an overwhelming majority of participants described the relevance of the NET to neuro-endoscopic surgery (17/19, 89.5%) and usefulness in surgical skill building (18/19, 94.7%) as either good or excellent. The criticism surrounding the face validity of the NET focused on a desire for more plate and task variation. For even greater face validity, the design of the NET allows for use of an unlimited number of plates and tasks, the troughed plate (Figure 2B) being just one, which are inexpensive to produce and distribute, and can be designed to target general or specific surgical approaches. The experts opined for more plate and task variation, that is, expanding the task-based training into cutting, dilating, and drilling activities and creating a bi-nostril entry port.

The predictive validity, which describes how well the simulator predicts the learner's performance during an actual surgery, was outside the scope of this study; however, it is a key area of future research. Some progress has been made in predictive validity within the area of laparoscopic surgery, however, given the small margin of error inherent within neuro-endoscopic procedures leading to legal and ethical concerns, realistic predictive validity remains a challenge.[2,6,39] Finally, concurrent validity, which describes how well the simulator performs against the gold standard, was not assessable because of the current lack of a gold-standard neuro-endoscopic simulator.

Training Program

Resident performance was assessed with recorded endoscopic footage and graded by the use of task completion time and the Skills Assessment Scale score. Video recording, which was previously shown by Eubanks et al.[40] to be an effective means of simulation assessment, allowed the participants the use the NET without interruption and within their own schedules. Group R participants' first iteration trials were analyzed to assess the influence of plate orientation and scope angle on performance (Table 4A and 4B). Interestingly, performance was only negatively affected when both the plate was tilted and the scope was angled; however, a tilted plate with a 0° endoscope, or a straight plate with an angled endoscope did result in a change in performance.

Additionally, the right tilt and left tilt plate positions were found to be equivalent, and similarly the 30° and 45° endoscopes also were found to be equivalent in their effect on participant performance. These results illustrate the need for plate tilting to appropriately challenge the learner in navigating the use of angled endoscopes. Plate tilting also acts to better approximate the normal surgical anatomy and therefore increases the translatability of skills acquired on the NET in real surgery. Comparisons of the performance of Group R participants between training program iterations were analyzed for performance improvement (Figure 4A and 4B). Unfortunately, within the limits of the current study, the Group R sample size was not large enough to provide sufficient power to give these results statistical significance. Nevertheless, Figure 4A and 4B illustrates that after only a single iteration, objective improvements are evident in both task completion times and Skills Assessment Scale scores across all plate positions and endoscope variants. Additionally, pre- and posttraining self-assessment scores of Groups N and T participants show marked statistically significant improvements in their perceived neuro-endoscopic skills, implying that participants found the simulation training practically relevant and are expected to continue to improve with subsequent iterations. The usefulness of the NET to build surgical skills was also stressed in the posttraining questionnaire, which showed that 17 of 19 (89.5%) Group N participants thought the NET would be either good or excellent for neurosurgical residency program (Table 5B).

The comparison of scores within and between iterations was not free of confounding factors for interpretations because of sequential training through various plate positions and endoscopic angles. With plate in median position, group R participants took shorter time to complete with 30° and 45° scopes than with 0° scope; this might be attributable to the fact that the first attempt in the simulator was with the plate in the straight position with 0°scope.

The training was limited to move the rings within the working space of the training plate. Additional training of bringing the ring out of the entry port and placing it back on intended space would provide training for going in and out of the nose smoothly with the right hand especially for right handed surgeon.

Cost of NET

NET is an open-source physical simulator prototype developed by the use of 3-dimensional printing additive manufacturing technology for neurosurgery skills training program in Indian neurosurgery training institution. The manufacturing cost of the electromechanical device is approximately $US 100—150, making it affordable for developing countries.[29]

CONCLUSION

This study describes the rational design as well as the face and construct validity of the NET, an open-source, synthetic physical partial-task simulator for endonasal skull base neuroendoscopy. Before participation, novice neurosurgeons and neurosurgical residents were found to express feelings of insufficient skill and deficient preparation in residency to practice neuro-endoscopy. Plate tilt and endoscope angle were shown to be important factors in participant performance. Improvement in their performance between 2 iterations of the training program showed promising results. Participants overwhelmingly agreed that the NET was a useful simulator for partial-task based skill building in neuro-endoscopy and supported its incorporation into residency program. Future research focusing on the effect of multiple iterations on NET performance and predictive validity will be instrumental in illustrating the full benefits of the NET.

ACKNOWLEDGMENTS

We acknowledge the efforts of technical and application specialists from the Neurosurgery Skills Training Facility, Neurosurgery Education and Training School, All India Institute of Medical Sciences, New Delhi, India. We thank Mr. Subhas Bora, Mr. Ajab Singh, Mr. Ram Niwas, Mr. Shashi Shekhar, Mr. Trivendra Yadav, Mr. Gaurav Bhardwaj, Mr. Suresh Kothari, Mr. Vikram Singh, and Mr. Satish Kumar for their untiring valuable support.

REFERENCES

1. Abbott R. History of neuroendoscopy. *Neurosurg Clin N Am*. 2004;15:1-7.

2. Figert PL, Park AE, Witzke DB, Schwartz RW. Transfer of training in acquiring laparoscopic skills. *J Am Coll Surg*. 2001;193:533-537.

3. Gallagher AG, McClure N, McGuigan J, Crothers I, Browning J. Virtual reality training in laparoscopic surgery: a preliminary assessment of minimally invasive surgical trainer virtual reality (MIST VR). *Endoscopy*. 1999;31:310-313.

4. Perkins N, Starkes JL, Lee TD, Hutchison C. Learning to use minimal access surgical instruments and 2-dimensional remote visual feedback: how difficult is the task for novices? *Adv Health Sci Educ Theory Pract*. 2002;7:117-131.

5. Stefanidis D, Korndorffer JR, Markley S, Sierra R, Scott DJ. Proficiency maintenance: Impact of ongoing simulator training on laparoscopic skill retention. *J Am Coll Surg*. 2006;202:599-603.

6. Bailey RW, Imbembo AL, Zucker KA. Establishment of a laparoscopic cholecystectomy training program. *Am Surg*. 1991;57:231-236.

7. Aggarwal R, Grantcharov TP, Eriksen JR, Blirup D, Kristiansen VB, Funch-Jensen P, et al. An evidence-based virtual reality training program for novice laparoscopic surgeons. *Ann Surg*. 2006; 244:310-314.

8. Aggarwal R, Balasundaram I, Darzi A. Training opportunities and the role of virtual reality simulation in acquisition of basic laparoscopic skills. *J Surg Res*. 2008;145:80-86.

9. Dubrowski A, Park J, Moulton C, Larmer J, MacRae H. A comparison of single- and multiple-stage approaches to teaching laparoscopic suturing. *Am J Surg*. 2007;193:269-273.

10. Hasson HM. Core competency in laparoendoscopic surgery. *JSLS*. 2006;10:16-20.

11. Korndorffer JR, Bellows CF, Tekian A, Harris IB, Downing SM. Effective home laparoscopic simulation training: a preliminary evaluation of an improved training paradigm. *Am J Surg*. 2012;203:1-7.

12. Scott DJ, Bergen PC, Rege RV, Laycock R, Tesfay ST, Valentine RJ, et al. Laparoscopic training on bench models: better and more cost effective than operating room experience? *J Am Coll Surg*. 2000;191:272-283.

13. Snyderman C, Kassam A, Carrau R, Mintz A, Gardner P, Prevedello DM. Acquisition of surgical skills for endonasal skull base surgery: a training program. *Laryngoscope*. 2007;117:699-705.

14. Aboud E, Al-Mefty O, Yaşargil MG. New laboratory model for neurosurgical training that simulates live surgery. *J Neurosurg*. 2002;97:1367-1372.

15. Gasco J, Holbrook TJ, Patel A, Smith A, Paulson D, Muns A, et al. Neurosurgery simulation in residency training: feasibility, cost, and educational benefit. *Neurosurgery*. 2013;73 (Suppl 1):39-45.

16. Ghobrial GM, Anderson PA, Chitale R, Campbell PG, Lobel DA, Harrop J. Simulated spinal cerebrospinal fluid leak repair: an educational model with didactic and technical components. *Neurosurgery*. 2013;73 (Suppl 1):111-115.

17. Gragnaniello C, Nader R, van Doormaal T, Kamel M, Voormolen EHJ, Lasio G, et al. Skull base tumor model. *J Neurosurg*. 2010;113:1106-1111.

18. Krishnan KG, Dramm P, Schackert G. Simple and viable in vitro perfusion model for training microvascular anastomoses. *Microsurgery*. 2004;24:335-338.

19. Lobel DA, Elder JB, Schirmer CM, Bowyer MW, Rezai AR. A novel craniotomy simulator provides a validated method to enhance education in management of traumatic brain injury. *Neurosurgery*. 2013;73:S57-S65.

20. Selden NR, Origitano TC, Hadjipanayis C, Byrne R. Model-based simulation for early neurosurgical learners. *Neurosurgery*. 2013;73 (Suppl 1):15-24.

21. Choudhury N, Gélinas-Phaneuf N, Delorme S, Del Maestro R. Fundamentals of neurosurgery: virtual reality tasks for training and evaluation of technical skills. *World Neurosurg*. 2013;80:e9-e19.

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;79:337-340.

23. Filho FVG, Coelho G, Cavalheiro S, Lyra M, Zymberg ST. Quality assessment of a new surgical simulator for neuroendoscopic training. *Neurosurg Focus*. 2011;30:E17.

24. Neubauer A, Wolfsberger S. Virtual endoscopy in neurosurgery: a review. *Neurosurgery*. 2013;72 (Suppl 1):97-106.

25. Suri A, Roy TS, Lalwani S, Deo RC, Tripathi M, Dhingra R, et al. Practical guidelines for setting up neurosurgery skills training cadaver laboratory in India. *Neurol India*. 2014;62:249-256.

26. Suri A, Tripathi M, Baby B, Banerji S. Beyond the Lenses. Development of hands-on and virtual neuroendoscopy skills training. In: Venkataramanaa NK, Suri A, Deopujari C, eds. *Clinical Neuroendoscopy. Current Status—by Neuroendoscopy Study Group of India*. 1st ed; Vol. 1. New Delhi: Thieme Publishers; 2013:139-149.

27. Tubbs RS, Loukas M, Shoja MM, Wellons JC, Cohen-Gadol A. Feasibility of ventricular expansion postmortem: a novel laboratory model for neurosurgical training that simulates intraventricular endoscopic surgery. *J Neurosurg*. 2009;111: 1165-1167.

28. Wolfsberger S, Forster MT, Donat M, Neubauer A, Bühler K, Wegenkittl R, et al. Virtual endoscopy is a useful device for training and preoperative planning of transsphenoidal endoscopic pituitary surgery. *Minim Invasive Neurosurg*. 2004;47:214-220.

29. Hirayama R, Fujimoto Y, Umegaki M, Kagawa N, Kinoshita M, Hashimoto N, Yoshimine T. Training to acquire psychomotor skills for endoscopic endonasal surgery using a personal webcam trainer. *J Neurosurg*. 2013;118:1120-1126.

30. Munz Y, Kumar BD, Moorthy K, Bann S, Darzi A. Laparoscopic virtual reality and box trainers: is one superior to the other? *Surg Endosc Other Interv Tech*. 2004;18:485-494.

31. Darzi A, Smith S, Taffinder N. Assessing operative skill. Needs to become more objective. *BMJ*. 1999; 318:887-888.

32. Buckley CE, Kavanagh DO, Traynor O, Neary PC. Is the skillset obtained in surgical simulation transferable to the operating theatre? *Am J Surg*. 2014;207:146-157.

33. Champion HR, Gallagher AG. Surgical simulation—A "good idea whose time has come." *Br J Surg*. 2003;90:767-768.

34. Singh R, Baby B, Srivastav VK, Damodaran N, Suri A. A novel electro-mechanical neuro-endoscopic box trainer. Paper presented at: the Proceedings of the International Conference on Industrial Instrumentation and Control (ICIC 2015), IEEE proceedings. May 28-30 2015; Pune, India.

35. Haji FA, Dubrowski A, Drake J, de Ribaupierre S. Needs assessment for simulation training in neuroendoscopy: a Canadian national survey. *J Neurosurg*. 2013;118:250-257.

36. Munz Y, Moorthy K, Bann S, Shah J, Ivanova S, Darzi SA. Ceiling effect in technical skills of surgical residents. *Am J Surg*. 2004;188:294-300.

37. Suri A, Bettag M, Tripathi M, Deo RC, Roy TS, Lalwani S, et al. Simulation in Neurosurgery in India- NETS. *CNS Q*. 2014;3:23-26.

38. Moorthy K, Munz Y. Objective assessment of technical skills in surgery. *Br Med J*. 2003;327:1032-1037.

39. Aggarwal R, Ward J, Balasundaram I, Sains P, Athanasiou T, Darzi A. Proving the effectiveness of virtual reality simulation for training in laparoscopic surgery. *Ann Surg*. 2007;46:771-779.

40. Eubanks TR, Clements RH, Pohl D, Williams N, Schaad DC, Horgan S, Pellegrini C. An objective scoring system for laparoscopic cholecystectomy. *J Am Coll Surg*. 1999;189:566-574.

Conflict of interest statement: We thank the funding agencies for extramural grants: Department of Health Research (DHR)-Project Number- DHR/Plan Scheme/GIA/5/2012, Indian Council of Medical Research (ICMR)-Project Number-No.5/4-5/70/Neuro/TF/2011-NCD-I, Ministry of Health and Family Welfare, Govt. of India - Project Number: GIA/3/2014-DHR; Department of Science and Technology (DST), Ministry of Science and Technology, Govt. of India - Project Number: SR/FST/LSII-029/2012 and IDP/MED/18/2011.

Received 7 July 2015; accepted 8 September 2015

Citation: World Neurosurg. (2016) 86:259-269.
http://dx.doi.org/10.1016/j.wneu.2015.09.045

Journal homepage: **www.WORLDNEUROSURGERY.org**

Available online: **www.sciencedirect.com**

1878-8750/$ - see front matter