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ORIGINAL ARTICLE

Developing a dynamic simulator for endoscopic intraventricular surgeries

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Abstract

Introduction A novel dynamic simulator brain model with hydrocephalus has been developed for endoscopic intraventricular procedures. Detachable components allow enhancement of the walls of the ventricle by choroid plexus, ependymal veins and the membranous floor of the third ventricle which are derived from cadaveric lab animal tissues to give a lifelike appearance. These can be changed for every exercise. Ventricles are filled with injection of saline to give appropriate transparent medium and connected to a device transmitting pulsations creating conditions similar to live surgeries.

Material and methods Thirty-five participants have used this model over the last 1 year and found it to be useful for conducting third ventriculostomy. Further development of the model for septostomy, aqueductoplasty and tumour biopsy has also been recently tested successfully by 12 participants.

Conclusion It is hoped that this simulator model for intraventricular endoscopy is comprehensive as a learning tool in carrying out most of the the surgical procedures currently practised.

Keywords Brain simulation model · Endoscopic third ventriculostomy · Intraventricular tumors · Septostomy · Tumor biopsy

Introduction

Advances in neuroendoscopic technology have fuelled an interest in endoscopic brain surgeries for ventricular, endonasal skull base and endoscope-assisted procedures. Endoscopic third ventriculostomy (ETV) has been recognised to be as equally effective as ventriculoperitoneal (VP) shunts and has become a valid alternative to shunts for obstructive hydrocephalus [1]. Other ventricular surgeries include procedures for CSF diversion, viz. septostomy and aqueductoplasty, tumour biopsy, tumour excision and evacuation of intraventricular haemorrhage [2].

As with any surgical technique, neuroendoscopy has unique challenges. ETV is the most commonly performed procedure which is relatively technically simple but has potential for disastrous complications. Adaptation to different angled scopes and adjustment to the surgical space or geometric scale is essential, especially in paediatric cases. This makes the learning process more difficult resulting in a steep learning curve.

Simulator training has become the norm in many industries to familiarise personnel with the equipment used and the tasks performed. The clinical fields of anaesthesia, emergency medicine, plastic and laparoscopic surgery have also been using various simulation methods to teach and refine training practices to reduce the learning curve.

Virtual reality simulator offers a distinct advantage for anatomical education [3] but lacks in expertise with relation to surgical skills education. Absence of haptic feedback and inability to simulate real-life scenarios hindered their efficacy in the past [4]. Physical simulation for intraventricular endoscopic procedures is a nascent field, with a limited range of models and exercises available. These vary in their anatomic accuracy and procedure related endpoints.

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We have embarked on a process of developing a physical simulation system for intraventricular procedures like ETV, septostomy, aqueductoplasty and intraventricular tumour biopsy. This is probably the first dynamic model with simulation of pulsations and CSF flow described for intraventricular surgeries and has been developed with active participation of the technical support team at the Center of Excellence for Minimal Access Surgery Training (CEMAST), an educational institute in Mumbai, India. Minimal access neurosurgery discipline has recently been developed here and this model is the first neurosurgical model to be developed and refined at the institute for simulation training.

Materials and methods

This model is made of silicone cast (Fig. 1) derived from anatomical drawings with a dilated ventricular system including the the third ventricle and the aqueduct of Sylvius simulating the ventricular system of a young child. The brain model has two halves corresponding to the cerebral hemispheres (Fig. 2) and a detachable brain stem component (Fig. 3). This is housed inside a plastic skull with a detachable vertex. There are access holes with subsequent prefixed trajectories to reach the ventricular system. These are 6 mm in diameter and are located at the standard entry points. One frontal pre-coronal entry point is taken 2.5 cm off the midline for ETV, second frontal pre-coronal entry point is 4 cm off the midline for septostomy and the third frontal entry point is taken at hairline and 2.5 cm off the midline to simulate third ventricular tumour biopsy (Fig. 4).

Within the lateral ventricle, septum is created in the midline from native animal cadaveric tissue, viz. membranes derived from the omentum of sheep and chicken in two layers which are glued with the help of synthetic cyanoacrylate glue. The septal vein, thalamostriate vein and choroid plexus are recreated similarly from sheep and chicken cadaver used for other training modules in the same institute. The venous angle is simulated at the foramen with the choroid plexus extending up to the foramen of Monro (Fig. 5). The bulge of the caudate nucleus is created at the time of 3D printing.

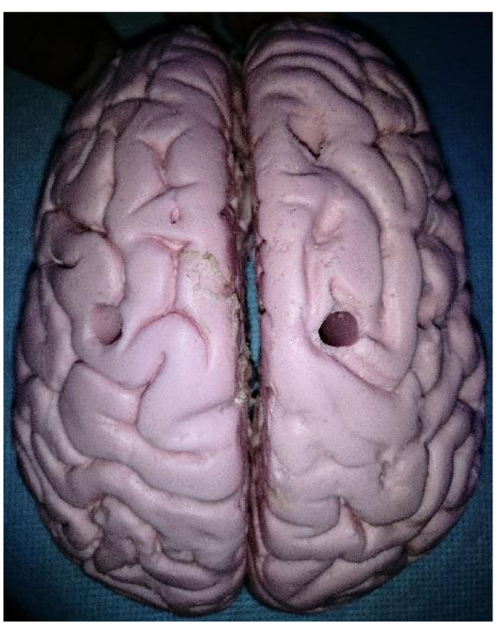

Fig. 1 Model made of silicon cast derived from anatomical drawings

Fig. 2 One-half of the model denoting the cerebral hemisphere

A painted red dimple simulates the infundibular recess of the floor of the third ventricle anteriorly. The floor of the third ventricle is made up of two ‘membranes’ recreated from the omentum of cadaveric animal as described above. These membranes simulate the thinned floor and the membrane of Liliequist, which are encountered and need fenestration, during the actual procedure. Beyond the membranes simulating the floor, the prepontine space has the basilar artery with its bifurcation, made with popliteal arteries from sheep or chicken cadavers. The mammillary bodies are made from silicone mould (Fig. 6). Posteriorly, the aqueduct is fashioned in the brainstem component. Here, a posterior third ventricular tumour (made of crushed chicken muscle) is simulated. This mimics the consistency of soft fleshy tumours that often need biopsy/excision.

Lifelike pulsation is simulated in the model by using an external oscillatory pulse generating pump (organ pulsating device; developed by one of the authors and marketed by Darsh innovation ™, Mumbai) that circulates water in the ventricular

Fig. 3 Detachable brainstem component of the model

Fig. 4 External surface markings of the standard entry points to access the ventricular system

system simulating CSF and by pulsating tissue perfusion trainer (PTPT—developed by one of the authors). The pump action has a frequency set at 50–60 cycles per minute. This is adequate to see the pulsations through the perforated floor membranes in the model. This frequency mimics the resting heart rate. Beyond the membranes, vertebrobasilar complex is also injected with blood

Fig. 5 Foramen of Monro lined by the septal (blue arrow) and thalamostriate vein (black arrow)

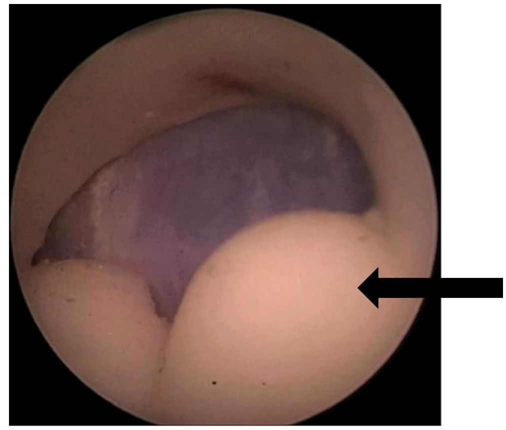

Fig. 6 Floor of the third ventricle showing the mammillary bodies (black arrow)

coloured fluid and pulsates at the same rate. The model has been made watertight by ensuring that the nasal and orbital passages remain closed during the procedures. The floor of the third ventricle has a removable diaphragm which can be reinserted after the procedure which also ensures that the flow remains watertight. Standard instruments used for performing an ETV and biopsy were used. This includes 0° endoscope with a working sheath with two channels (LOTTA Endoscope, Karl Storz SE & Co. KG ™), a ventriculostomy forceps (Karl Storz SE & Co. KG ™) and a 3 or 4 Fr Fogarty's balloon catheter. To create the perforation in the floor, a monopolar cautery probe without application of energy can also be used.

The ETV simulation session begins with a senior faculty demonstrating the procedure on a model described. This is followed by the trainee entering into the ventricle through the frontal pre-coronal point 2.5 cm off the midline. After inspection of the lateral ventricle and inspection of foramen of Monro, the scope is navigated through the foramen into the third ventricle. The floor is inspected and the point of fenestration is decided upon. The floor of the third ventricle is punctured and the opening is dilated. The second membrane is perforated if not adequately done before. The prepontine space is inspected and the adequacy of the opening is assessed prior to gentle withdrawal of the endoscope system out of the head (Fig. 7). For the endoscopic septostomy simulation, the scope is introduced through the frontal pre-coronal entry point 4 cm off the midline. The lateral ventricle is entered and the septum medially is inspected. The septum is punctured and the opening is dilated with Fogarty's catheter. The adequacy of the opening is assessed before gentle withdrawal of the endoscope system out of the head (Fig. 8).

For endoscopic third ventricular tumour biopsy steps, the scope is introduced through the frontal entry at hairline and 2.5 cm off the midline. Through the lateral ventricle and foramen of Monro, the floor of the third ventricle is reached. The 'tumour' is visualised near the aqueduct and the vascularity, consistency of the tumour is assessed. The crushed muscle simulating the tumour can be fixed in place with cyanoacrylate glue

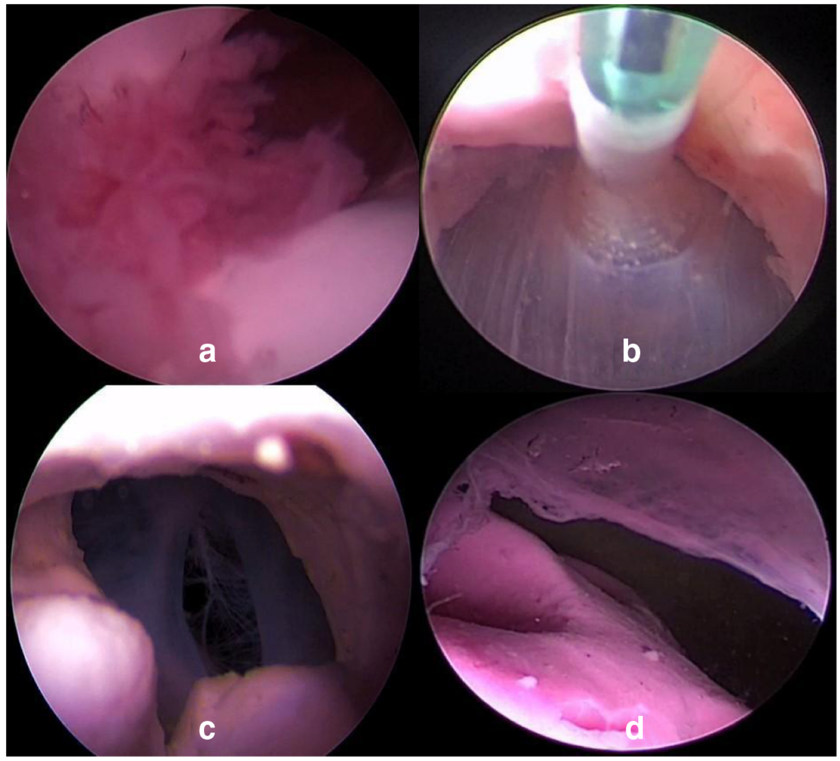

Fig. 7 **a** Choroid plexus lining the foramen of Monro. **b** Dilatation of the perforated third ventricle floor using Fogarty's balloon catheter. **c** Fenestration of both membranes at the floor of the third ventricle after dilatation. **d** Prepontine space showing the basilar vessel

in the pineal region or the tectum or in the ventricular surface of the thalamus. The endoscopic biopsy forceps is introduced and piecemeal bite of the tumour is taken with 180° rotation of the forceps. The biopsy site and ventricular space are assessed followed by gentle withdrawal of the scope (Fig. 9).

Results

A novel, indigenous dynamic model for intraventricular surgeries has been developed by our team for simulation of standard endoscopic procedures. Thirty-five participants which included 28 young neurosurgeons having less than 10 years of experience and 7 trainee neurosurgeons in their final year of residency programme have used this model over the last 1 year and found it to be useful for conducting third ventriculostomy. Further development of the model for septostomy, aqueductoplasty and tumour biopsy has also been recently tested successfully by 12 participants. Thirty participants were requested for feedback for the training, quality of the model and ease of the procedure using a 5-point Likert scale. An open-ended comments section regarding their opinion about the simulator was also provided at the end of the feedback. As can be assessed from the table (Table 1), most participants agreed that it improved their familiarity with instruments and ventricular anatomy along with improvement of their skill set. The dynamic CSF flow model was especially

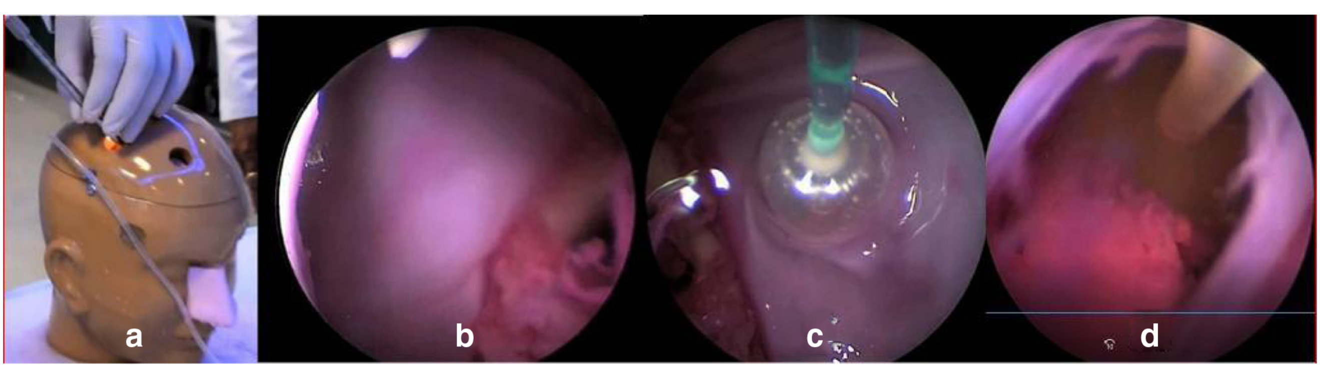

Fig. 8 **a** Frontal pre-coronal entry 4 cm off the midline for septostomy. **b** An animal tissue derived septum pellucidum assembled between the corpus callosum and fornices. **c** Dilatation of the perforated septum using Fogarty's balloon catheter. **d** Final image showing septum pellucidotomy flap and the opposite lateral ventricle

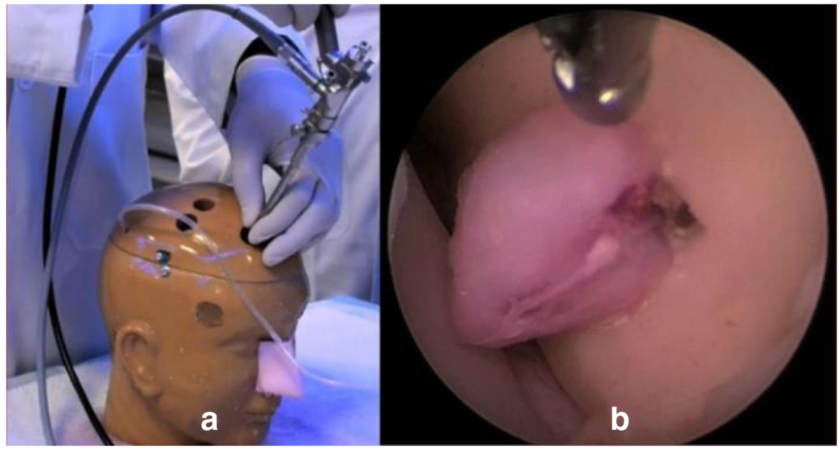

Fig. 9 **a** Frontal entry at hairline and 2.5 cm off the midline to access posterior third ventricle. **b** Posterior third ventricle tumour amenable for biopsy

commended as well as the lifelike haptic feedback from the third ventricular floor. Two main suggestions given by the participants were to develop a model on which ventricular trajectories could be practised and to improve the quality of the tumour material used for biopsy.

Discussion

Endoscopic procedures for hydrocephalus and intraventricular pathologies are well-established techniques and have acquired the stature of a subspecialty. In 2007, a survey on neuroendoscopic surgery training showed that majority of the hospitals borrowed endoscopic instruments from the company and had to rely upon an externally called neuroendoscopist surgeon to perform the procedures [5]. Regular use of the endoscope for most neurosurgeons is soon becoming a necessity with regular use of ETV and endonasal skull base endoscopy as well as endoscope-assisted microsurgery. With changing medico-social circumstances, the necessary skill requirement has to be fulfilled by simulation. This has become a much felt need during the training of residents as well as established neurosurgeons wanting to update their skills.

The aim of training exercises is to acquire skills centred on cognition, integration and automation as proposed by the Fitts and Posner theory on human performance [6]. Training for transnasal procedures and skull base procedures can be done in the cadaveric lab; however, simulation for intraventricular procedures poses unique challenges. The intraventricular endoscopy procedure is usually performed in dilated ventricles which are difficult to find in a cadaver. Preservation of CSF in the cadaveric ventricle is not possible by any methodology. Intraventricular procedures require specific pathology or targets to be visible and 'treatable'. This again is difficult to reproduce in the cadaveric lab.

When the model is designed as a simulation substrate, it is possible to incorporate many or all parameters required for a successful practice, in the exercise. Since the model is designed

Table 1 Table showing feedback given by participants on a 5-point Likert scale

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
The exercise improved my familiarity with endoscopy instruments	24	6			
The exercise improved my hand-eye coordination during handling of endoscopic instruments	18	12			
Anatomy of the model closely resembled the actual anatomy of the ventricle	12	18			
Anatomy of the model closely resembled the actual anatomy of the third ventricular floor	12	18			
The dynamic CSF flow made the exercise more realistic		24	4	2	
The biopsy simulation closely resembled the actual procedure (12 participants)*		8	4		
The septostomy simulation closely resembled actual procedure (12 participants)*		12			
The steps performed in the exercises were similar to the steps performed during actual procedures	6	24			
The workshop experience can be practically applied during the actual procedure	18	12			
I would recommend this model to my other colleagues	30				

*Last 12 participants who have succesfully tested septostomy, aqueductoplasty and tumour biopsy in the the updated model from a cast using 3D printing technology with silastic, a dilated ventricular system can be made. The standard entry points are also cored out for rapid insertion of the endoscope system.

The specific advantages of this model include a realistic choroid plexus, the veins and the third ventricular floor that has the resistance and feel of an actual membrane with a second membrane in the prepontine space. The prepontine space has a pulsatile basilar artery and the flapping of the membrane can be well visualised after a successful puncture as seen in live surgery. The second advantage is that these twin membranes used at the floor are easily replaced after exercise with a turnover time of approximately 10 to 15 min. A changeable set of membranes for ETV as well as septostomy allow the same basic model to be used by many participants on the same day. An animal tissue derived septum pellucidum can be similarly assembled in two layers between the corpus callosum and fornices, which is amenable to practicing a septostomy. The third addition to this model is the design of a third ventricular tumour. This lesion is constructed around the aqueduct and is amenable for a biopsy.

One of the first descriptions of surgical training utilising fruits for simulation and practise was described by Sushruta between 600–1000 BC [7]. Several exercises for endoscopy training have been developed and used around the globe. Suri et al. have described the use of inanimate objects, viz. box trainers which aid in developing good hand-eye coordination and have good reproducibility leading to automation of psychomotor skills [8]. Many objects kept in a restricted space approached through a tiny opening have also been described for learning [9]. Exercise specific to ETV needs honing of skills which can be practised on capsicum, papaya [10] and also on models developed utilising coconuts as patented by Teegala et al. [11].

Coelho et al., in 2011, described three simulators made of a special type of resin simulating enlarged ventricles and intraventricular lesions amenable for biopsy [12]. Filho et al. utilised synthetic thermoretractable rubber to develop a model for neuroendoscopy training in 2011. They used face validation, retest and interrater reliability to conclude that probability of any single error reduced after each training session, with a mean reduction of 41.65% [13]. Breimer et al. described a brain silicone replica in 2015 which mimicked normal mechanical properties of an infant with hydrocephalus [14].

Cadaver and lab animals provide good tactile feedback with a detailed anatomy study. However, neuroendoscopy training exercises on cadaver are associated with inconsistent visualisation. A navigation guided intraventricular injectable cadaveric dissection model has been described by Ashour et al. in 2016 [15].

Simulation models using live Wistar rats as described by Jaimovich et al. [16] reduce the learning curve in neuroendoscopy. Anaesthetized rat models are also used for observing endoscopic anatomy and perforation of the diaphragm as an exercise for ETV at the University of Homburg by Dr. Oertel and his group (personal communication).

Weinstock et al. in 2017 have created a simulator model using 3D printing technology which reproduces the pulsation of basilar artery, ventricles, cerebrospinal fluid and floor of the third ventricle using an electronic pump [17].

The utility of video telescopic operating monitor system for neuroendoscopy has been studied by Yadav et al. using an exoscope giving comparable image quality to that of a microscope or endoscope [18].

Virtual reality simulation training for ETV and a standard ETV module for residents has been recognised as a valuable addition in training for neurosurgeons [19]. Electronic simulations have been devised [8] which are unable to give haptic feedback to the operator for various scenarios. These are extremely useful tools as a primer for developing motor skills and hand-eye coordination. However, there may be some distance to achieve in accuracy and specific scenario management. A comparison between virtual reality models and physical simulation models tells us that procedural content and instrument handling is better in physical simulators while representation of intraventricular foramen of Monro anatomy is better in virtual reality models [20].

The elasticity of the ventricular wall cannot be replicated which can be considered a limitation of our model but tactile feedback from the floor and septum has been made as close to real appearance as possible. As per feedback from some of the participants, the ventricular tap should have been part of the exercise model but it would not be feasible given the consistency of the brain and the necessity to maintain a patent ventricular system. Therefore, preformed trajectories had to be used from the standard entry burr holes.

Our silicone model though expensive to make initially (approximately 3000 US$), does not need many modifications to be used repeatedly (cost per use (< 100 US$)). The use of cadaver animal tissue seems to mimic human tissue to a large extent and can be a cost-effective solution.

Conclusion

The new model developed for third ventriculostomy and other ventricular endoscopic procedures seem to be a viable method for training in endoscopic techniques. This dynamic model closely simulates the live operative procedure. This has so far been tested by 35 young neurosurgeons in the lab with a feedback for simulation. The double membrane floor with pulsatile flow is unique to our new model with excellent haptic feedback as well as visual feedback of flapping membrane. We hope these features will help in more precise learning and will fulfil the need of an inexpensive simulator for intraventricular endoscopy.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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