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ARTICLE *in* JOURNAL OF SURGICAL EDUCATION · JANUARY 2013

Impact Factor: 1.38 · DOI: 10.1016/j.jsurg.2013.08.010

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# Injecting Realism in Surgical Training—Initial Simulation Experience With Custom 3D Models

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The traditionally accepted form of training is direct supervision by an expert; however, modern trends in medicine have made this progressively more difficult to achieve. A 3-dimensional printer makes it possible to convert patients imaging data into accurate models, thus allowing the possibility to reproduce models with pathology. This enables a large number of trainees to be trained simultaneously using realistic models simulating actual neurosurgical procedures. The aim of this study was to assess the usefulness of these models in training surgeons to perform standard procedures that require complex techniques and equipment.

**METHODS:** Multiple models of the head of a patient with a deep-seated small thalamic lesion were created based on his computed tomography and magnetic resonance imaging data. A workshop was conducted using these models of the head as a teaching tool. The surgical trainees were assessed for successful performance of the procedure as well as the duration of time and number of attempts taken to learn them.

**FINDINGS:** All surgical candidates were able to learn the basics of the surgical procedure taught in the workshop. The number of attempts and time taken reflected the seniority and previous experience of each candidate.

**DISCUSSION:** Surgical trainees need multiple attempts to learn essential procedures. The use of these models for

surgical-training simulation allows trainees to practice these procedures repetitively in a safe environment until they can master it. This would theoretically shorten the learning curve while standardizing teaching and assessment techniques of these trainees. (J Surg ■■■■-■■■. © 2013 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

**KEY WORDS:** neurosurgery, simulation, training, clinical skills, 3D rapid prototyping

**COMPETENCIES:** Practice Based Learning and Improvement

## INTRODUCTION

The trend of shorter working hours, increasing number of trainees, and medicolegal issues has made the training of neurosurgeons progressively more difficult. The traditionally accepted form of training is direct supervision by an experienced person. However, this is not always possible in view of the imbalance between the numbers of trainees and teachers.

The concept of workshops to teach a set group of tasks has become popular among the surgical-teaching community in recent times. These workshops involve groups of trainees who perform tasks either on cadavers, for example, in spine and skull-base surgery, or repetitive tasks on models, for example, suturing and vascular anastomosis.<sup>1-3</sup>

The drawback of cadaveric workshops is the lack of true pathology and its accompanying distortion of anatomy. Consequently, training based on current commercial models lacks realism. Another new method of training is

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virtual-reality surgery, which is conceptually enticing but lacks tactile feedback, as it stands currently.

Recently, a number of researchers have developed a variety of anatomically accurate physical models based on computed tomography (CT) and (magnetic resonance imaging) MRI data, using 3-dimensional (3D) printing technology.<sup>4-7</sup> Models based on patients with pathology have been developed, and using recent printing technology, models that have wide-ranging textures to resemble normal tissue structures have also been created.<sup>7,8</sup>

Based on these models, a workshop was conducted with the aim of training junior neurosurgical trainees in a variety of standard neurosurgical procedures.<sup>1,9</sup> The objective of this workshop was to assess the ease of teaching the utilization of image-guidance equipment, as well as frameless biopsy procedures using an anatomically accurate physical model with a preexisting pathology and to obtain initial data to allow us to introduce this concept as a useful and viable training tool.<sup>10</sup>

Therefore, the exercise mentioned earlier was designed to recreate training in using an expensive and complex surgical tool that requires multiple physical and cognitive skills for the performance of certain standard neurosurgical procedures using real patient data.

## METHOD

CT and MRI data sets were obtained from a patient with a deeply located thalamic lesion (Fig. 1). This particular problem was selected as the lesion was small, deeply located, and required planning that took into consideration a suitable entry point and trajectory to avoid the ventricle. The data were fused and manually segmented, differentiating various tissue structures into skin, bone, dura, tumor, and surrounding the brain. The data were then converted enabling the 3D printer (Object) to print a 3D model.<sup>10</sup> Four exact replicas were created. These models were checked for similarity and accuracy before the workshop to ensure standardization and quality assurance.



**FIGURE 1.** MRI of the deep seated tumor.

A syllabus based on these models was prepared to cover aspects of patient positioning in relation to pathology, setting up, and utilization of navigation systems for cranial surgery, target selection, and planning for surgery. This included placement and creation of a burr hole with a high-speed drill system (Midas Rex) with the purpose of performing a biopsy on the underlying tumor. (Figs. 2 and 3, and Videos 1 and 2)

Navigation-related steps were carried out using both the Medtronic S7 and BrainLAB Kolibri navigation platforms, utilizing various proprietary tools and devices. As the model was constructed using an actual patient's CT and MRI data, it was possible to load all imaging information onto both the platforms and subsequently register the models as if the trainees were operating on a real patient. The ability to register these models to both the navigation systems and the accuracy of registration has been discussed in a previous publication.<sup>10</sup>

Eight candidates and 2 experts performed the registration on both the platforms. The 8 candidates ranged in experience and specialty. There were 2 candidates each from year 1 and year 3 of neurosurgical training, as well as 2 year-3 trainees from the Ear, Nose, Throat specialty. Both the experts were qualified neurosurgeons. All candidates including the neurosurgeons had various levels of exposure to both the image-guidance systems, proportionate to their level of training.

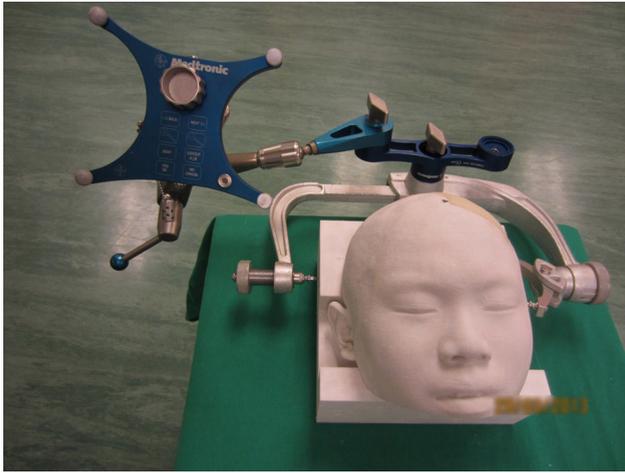
The candidates went through the series of lectures based on the syllabus before the assessment. Each candidate went through both the platforms in sequence and was assessed by a qualified neurosurgeon. The number of attempts taken to achieve a successful and acceptable registration was recorded. The duration of the last successful attempt was also recorded.

Subsequently, 4 of the neurosurgical trainees from year 2 and 3 as well as the 2 surgeons proceeded with the frameless biopsy procedure on the Medtronic platform (Fig. 2). The number of attempts taken for registration, planning, and assembly of the biopsy instruments were recorded separately. The total time taken and success of biopsies were also recorded (Fig. 4) and (Video 3).

## RESULTS

All 8 candidates were able to learn the basics of navigation registration and manipulation on both the platforms quite easily. As expected, both the year-1 candidates with no navigation experience took the most number of attempts as well as the longest time to achieve successful registration. Consequently, the senior year-3 candidates took the least number of attempts and duration to achieve successful registration (Table 1).

The average number of attempts on the BrainLAB platform was 2.5, whereas it was 2.25 attempts on the



**FIGURE 2.** Model with image guidance frame in place.

Medtronic platform. The duration for a successful registration of navigation protocol was  $9.5 \pm 1.5$  minutes on the BrainLAB platform and  $8.5 \pm 1.5$  minutes on the Medtronic platform. Both the qualified surgeons were able to register on the first attempt on both the platforms, averaging 6 minutes on BrainLAB platform and 6.5 minutes on Medtronic platform.

Among the 4 candidates who proceeded with the biopsy procedure, the number of attempts at planning and performing the biopsies were between 2 and 5 attempts, averaging  $22 \pm 3$  minutes on their last successful attempt. Both the surgeons were able to plan and perform the biopsy at the first attempt, averaging  $16.5 \pm 0.5$  minutes (Table 2).

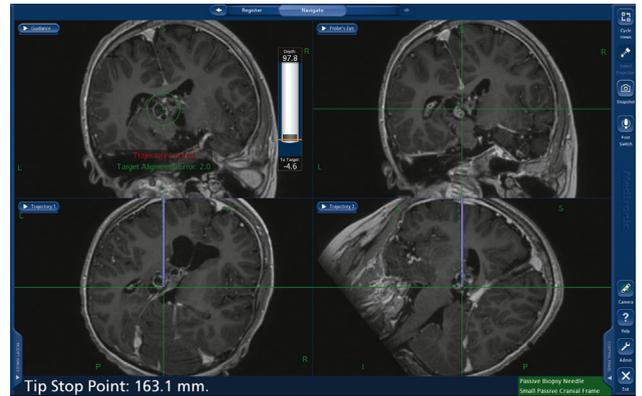
All the candidates were able to successfully obtain the biopsy “specimen” from within the tumor.

## DISCUSSION

Surgical training is often learnt by performing essential steps repeatedly, and this has been demonstrated in numerous



**FIGURE 3.** Biopsy in progress.



**FIGURE 4.** Trajectory locked image.

previous studies.<sup>1-3</sup> This has led to an increased popularity in surgical skills workshops that allow trainees to repeat certain steps until a procedure is mastered.

The training of surgeons in performing procedures is presently conducted by the candidate operating on patients under the supervision of seniors. Based on the results of this study, junior trainees generally require more than 2 attempts to successfully register a patient and more senior trainees require up to 5 attempts to complete a full registration and biopsy procedure. If this was extrapolated into a busy operating room environment, most trainees would require multiple patients before mastering a single basic step. Progress in training can also be expected to occur in burst and spurts based on patient availability, which in turn is pathology dependent. By utilizing models from patient data with pathology embedded, trainees are able to repeat steps until they are mastered. This should shorten the learning curve.

Cadavers, the next preferred method, is constrained by the difficulties in obtaining and preparing them in many parts of the world. Furthermore, owing to rules restricting the sharing of equipment between cadavers and actual patients, this technique in training does not prove to be financially feasible for regular use with relevance to the use of expensive equipment or procedures that require imaging like CT scans or MRI scans. Cadavers also lack pathology that exists in the models, which is created using actual patient data.

The advantages of using 3D models are that the procedures can be standardized and are reproducible. Candidates can also repeat the steps until they feel confident that they are able to carry them out on actual patients, thereby accelerating the training process.

3D-prototyping techniques have been recently used by a number of authors in developing models to allow preoperative surgical planning.<sup>11-17</sup> These models not only allow a sense of realism to the pathology but also are accurate spatially.

Proceeding from our previous work, we were able to reproduce multiple exact models based on imaging data

**TABLE 1.** Number of Attempts and Time Taken for Successful Registration of Navigation

Trainee (Level)	BrainLAB		Medtronic	
	Successful Registration (No. of Attempts)	Duration (min)	Successful Registration (No. of Attempts)	Duration (min)
1 (y 1)	4	9	3	10
2 (y 1)	4	10	4	9
3 (y 2)	3	8	2	8
4 (y 2)	2	8	2	7
5 (ENT)	2	9	2	8
6 (ENT)	2	11	2	9
7 (y 3)	2	8	1	7
8 (y 3)	1	8	2	8
Surgeon 1	1	6	1	6
Surgeon 2	1	6	1	7

from 1 patient.<sup>7</sup> We were then able to standardize a training format enabling the participants to be trained in using an expensive, complex computer-based navigation system and carry out some basic standard neurosurgical steps.

The candidates were able to carry out various processes involved in navigation surgery repeatedly, without the pressure of time. They were also able to link surgical planning to perform the surgery during the same simulation. Quite often during the training process in live surgery, trainees only get to do part of the job (whether it is the surgical planning or a part of the surgery). This takes place for a long period before they are able to combine both steps together. With this method, they get to link the 2 parts, and therefore their knowledge of a surgical process is hastened. Based on these techniques, a variety of models representing various common pathologies can be created and multiple candidates can be trained in a standardized fashion before they are required to perform similar maneuvers on actual patients.

We were only able to perform a qualitative assessment as the sample size was too small to presently perform meaningful quantitative assessment. However, the qualitative analysis supports the immense usability of these models in carrying out group training. There was also a trend that supported the premise that seniority and familiarity with an operation improved time taken for training.

These models with pathology can be used to train surgeons in the basics of pituitary surgery, stereotactic

biopsies (both frame and frameless), degenerative spine surgery, and endoscopic ventricular surgery.<sup>11-17</sup> The accuracy of these models and the fact that they are spatially an exact replica of actual patients make them especially useful in the training of surgeons in (procedures that require) navigation-required procedures.

Although this article is focused in the area of neurosurgery, these models can also be extended into other disciplines in surgery or indeed medicine as a whole.

The disadvantage of these models at present is the lack of blood as well as the texture of material currently available that do not exactly match actual human tissue. Also, the present cost to make these models is between USD 2000 and USD 3000. With the rapid development of the 3D printing industry, we expect improvisation on these issues in the near future.

## CONCLUSION

The use of 3D printers in creating models based on imaging data from patients with pathology allows the possibility of standardized training of certain complex operations to be carried out on them.

## AUTHORS' CONTRIBUTION

V Waran—Original concept and primary author; V Narayanan—Primary author and trial implementation; K Rav-

**TABLE 2.** Successful Registration and Biopsy Arm Assembly on the Medtronic Platform

Trainee	Attempts at Registration	Attempts at Performing		Total Successful Duration	Successful Biopsy
		Brain Biopsy			
1 (y 2)	2	5		25	+ve
2 (y 2)	2	3		20	+ve
3 (y 3)	1	3		21	+ve
4 (y 3)	2	2		19	+ve
Surgeon 1	1	1		16	+ve
Surgeon 2	1	1		15	+ve

indran, P Devaraj, and H Chandran—Trial implementation and data analysis; R Raman, ZAA Rahman, Owen SLF, and Aziz TZ—Advice of conduct of study, development of idea, and review of manuscript.

## ACKNOWLEDGMENT

We would like to thank University of Malaya for funding support for this research via the High Impact Research Grant (H-50001-00-A000026) granted to Professor Vicknes Waran. The grant committee or University of Malaya had no direct role in the study design; in the collection, analysis, and interpretation of data; in the writing of the report; or in the decision to submit the paper for publication.

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## SUPPLEMENTARY MATERIAL

Supplementary material cited in this article is available online at <http://dx.doi.org/10.1016/j.jsurg.2013.08.010>.