ORIGINAL ARTICLE

Training in Cerebral Aneurysm Clipping Using Self-Made 3-Dimensional Models

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INTRODUCTION: Recently, there have been increasingly fewer opportunities for junior surgeons to receive on-the-job training. Therefore, we created custom-built three-dimensional (3D) surgical simulators for training in connection with cerebral aneurysm clipping.

METHODS: Three patient-specific models were composed of a trimmed skull, retractable brain, and a hollow elastic aneurysm with its parent artery. The brain models were created using 3D printers via a casting technique. The artery models were made by 3D printing and a lost-wax technique. Four residents and 2 junior neurosurgeons attended the training courses. The trainees retracted the brain, observed the parent arteries and aneurysmal neck, selected the clip(s), and clipped the neck of an aneurysm. The duration of simulation was recorded. A senior neurosurgeon then assessed the trainee's technical skill and explained how to improve his/her performance for the procedure using a video of the actual surgery. Subsequently, the trainee attempted the clipping simulation again, using the same model. After the course, the senior neurosurgeon assessed each trainee's technical skill. The trainee critiqued the usefulness of the model and the effectiveness of the training course.

RESULTS: Trainees succeeded in performing the simulation in line with an actual surgery. Their skills tended to improve upon completion of the training.

CONCLUSION: These simulation models are easy to create, and we believe that they are very useful for training junior neurosurgeons in the surgical techniques needed for cerebral aneurysm clipping. (J Surg Ed ■:■■■-■■■. © 2016 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

KEY WORDS: 3D model, 3D printing, cerebral aneurysm, aneurysm clipping, simulator training, simulator

COMPETENCIES: Practice-Based Learning, Systems-Based Practice, Medical Knowledge

INTRODUCTION

The performance of cerebral aneurysm surgery is dependent on a thorough understanding of the positional relationship of an aneurysm to the parent artery and its branches, bones, and the brain. In the past, these skills were acquired through practical experience gained during actual operations. Recently, however, there have been increasingly less opportunities for junior surgeons to receive on-the-job training owing to restrictions imposed by society and the extensive use of endovascular techniques.[1,2] Therefore, surgical simulation must be widely used for training purposes.[3-6] Although computer graphics have become extremely lifelike, a simulation of the surgical procedure remains difficult and far from being put into practical use even when advanced technologies (e.g., the haptic system) are adopted. To overcome these problems, we adopted a three-dimensional (3D) printing technique for creating actual 3D models for use in presurgical simulation, intraoperative navigation, education, and informed consent.

These models are very useful for gaining an understanding of the intracranial structures, and we have been attempting to develop more effective simulation models by making use of them. For example, we created hollow, elastic cerebral aneurysm models using a 3D printer, which can be used for the simulation of clipping with an actual clip.[11] We also created simulation models for microvascular decompression surgery required for a hemifacial spasm[12] and succeeded in simulating brain retraction and neurovascular decompression. These models have proven to be effective for the training of junior surgeons.

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Such experiences led us to postulate that a combined model composed of the skull, dura mater, arachnoid membrane, as well as a soft retractable brain and blood vessels with an aneurysm might be useful for simulating surgical clipping. Thus, we created new models for the simulation of a dural incision, brain retraction, the opening of the sylvian fissure, and clipping the neck of an aneurysm. In this study, we describe how this simulation model can be created and its effectiveness for surgical training.

METHODS

Creating Simulation Models

Three patient models with unruptured middle cerebral artery (MCA) (M1-M2) aneurysms were fabricated using the method described as follows (Fig. 1).

Preparation of CT Data for 3D Printing

Contrast-enhanced computed tomography (CT) images of a patient with MCA aneurysm were obtained. The protocol for CT was a Definition FLASH CT (Siemens, Munich, Germany, base matrix: 512 × 512 × 512, and slice thickness: 0.8 mm). The Digital Imaging and Communication in Medicine data were visualized in 3 dimensions using the 3D visualization application Amira5.4.1. or Amira 5.4.2., (VSG, Burlington, MA). The skull, brain, vein, and artery required for surgical simulation were extracted from this image. The results were converted to a standard triangulated language or stereolithography file, and a 3D solid model was fabricated using 3D printers.

3D Printing

We used the following two 3D printers:

1. ZPrinter450 (3D Systems, Rock Hill, SC)
   This printer works with full-color ink-jet printing on thin layers of plaster powder.
   After printing 1 layer, the next layer is printed on top and reprinted; thus, a 3D model was created through a repeated process of sequentially printed layers. The speed of fabrication was 23 mm in thickness per hour.
2. UP! Plus 3D Printer (Beijing Tiertime Technology, Beijing)

This printer creates 3D models by injecting an acrylonitrile-butadiene-styrene (ABS) resin from the nozzle, melted by heating to 260°C with a spatial resolution of 0.15 mm. The model is formed together with an automatically generated base and supports.

Fabricating the Parts of the Model

1. *Skull model*: Trimmed skulls with a craniotomy were 3-dimensionally printed using the ZPrinter (Fig. 1P).
2. *Retractable brain model*: Soft, retractable brain models were created as described later. First, prototypes were produced using the ZPrinter (Fig. 1G) as a positive cast.
   Negative casts were then made with silicone ("M8012," Asahi Kasei-Wacker Silicone, Tokyo, Japan). Soft polyurethane ("Hitohada Gel, zero hardness," Exseal Corporation, Gifu, Japan) was poured into the negative casts and solidified (Fig. 1H). The casted models were incubated at 80°C to decrease the time for solidification.
3. *Soft vein model*: Prototypes were created as positive casts using the UP! Printer (Fig. 1J). Negative casts of silicone ("X-32-2100 T," Shin-Etsu Chemical Corporation, Tokyo, Japan) were then created. Colored silicone (the same product as mentioned earlier) was injected into the negative casts (Fig. 1L and R).
4. *Soft artery model*: We created soft and hollow artery models. The details of this method have been reported previously,[11] and the main points are summarized later. The artery model was made with ABS created by the UP! Printer (Fig. 1M). A compound liquid comprising liquid silicon and hardener was then applied (Fig. 1N). Once it had hardened, the inside of the ABS model was melted for approximately 4 hours and removed using xylene, after which the hollow silicone model was complete (Fig. 1O and S).
5. *Dura mater and arachnoid membrane models*: Dura mater was made with tissue paper (KimWipes; Kimberly-Clark, Irving, TX) coated with silicone. The arachnoid membrane coating the brain surface was made with X-32-2100 T silicone and plastic film (Parafilm; Bemis Flexible Packaging, Neenah, WI). The arachnoid trabecula in the sylvian fissure was made with ABS as follows: ABS was liquefied with xylene and manually stretched and weaved like a spider web. This structure was occasionally omitted as it is highly inconvenient.
6. *Assembly*: Those mentioned earlier (1-5) were assembled (Fig. 1T) in the correct position. The skull and the brain were easily connected because they had the same cutting plane. The soft artery model was connected with the stump of the internal carotid artery of the skull model. As the vein corresponds to the brain surface in its shape, it was set into the appropriate position.