Novel Brain Model for Training of Deep Microvascular Anastomosis

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Abstract
Models of the brain and skull were developed using a selective laser sintering method for training in the procedures of deep microvascular anastomosis. Model A has an artificial skull with two craniotomies, providing fronto-temporal-subtemporal and suboccipital windows. The brain in Model A is soft and elastic, and consists of the brainstem and a hemispheric part with a detailed surface. Rehearsals or training for anastomosis to the insular part of the middle cerebral artery, superior cerebellar artery, posterior cerebral artery, and posterior inferior cerebellar artery can be performed through the craniotomies. Model B has an artificial skull with a bifrontal craniotomy and an artificial brain consisting of the bilateral frontal lobes with an interhemispheric fissure and corpus callosum. Rehearsals or training for anastomosis of the callosal segment of the anterior cerebral artery can be practiced through this craniotomy. These realistic models will help to develop skills for deep vascular anastomosis, which remains a challenging neurosurgical procedure, even for experienced neurosurgeons.

Key words: deep microvascular anastomosis, training, model

Introduction
Complex cerebral aneurysms require vascular reconstruction as a tactic to avoid ischemic complications.5) Bypasses are sometimes required, not only for arteries of the anterior circulation such as the insular segment (M2) of the middle cerebral artery (MCA) and callosal segment (A2/3) of the anterior cerebral artery (ACA), but also for arteries of the posterior circulation such as the superior cerebellar artery (SCA), posterior cerebral artery (PCA), and posterior inferior cerebellar artery (PICA).5) Specific bypasses are performed using particular operative fields, and require specialized surgical equipment and skills. Neurosurgeons performing such bypasses need to obtain experience in deep microvascular anastomosis. For expert neurosurgeons, rehearsal under realistic conditions is ideal to ensure confidence before performing the procedures on actual patients. However, opportunities to learn how to perform and practice deep vascular anastomosis are very limited.

With advances in technology, particularly three-dimensional (3D) computed tomography (CT), precise replicas of the brain and skull have become commercially available. A 3D skull base model with artificial dura mater, cranial nerves, and venous sinus has recently been developed for training in skull base surgery.7) Likewise, we have developed a realistic model consisting of artificial skull and brain with surface details. Using this model, deep anastomoses can be taught and practiced under close-to-real circumstances.

Models
We have made two different models (Models A and B; Ono & Co., Tokyo) for various locations of the recipient artery. These models consist of two parts: the skull and the brain. The skull is made from resin and inorganic substance, using a selective laser sintering method based on CT data, and is suitable for surgical drilling. The elastic brain is made from super soft resin, using reversal pattern technology and a molding method. This brain model can be retracted with a brain spatula as in real surgery. The artificial brain is detachable from behind, by removing a panel supported with screws. Sponge-like filling is placed between the brain and the panel, and the amount of filling can be selected to adjust the depth of the brain. Substitute vessels (either artificial tubing or animal artery) can be pinned directly to the artificial brain, and the skull has three reinforced
Fig. 1 Photographs showing the Model A artificial skull, fixed with a Mayfield head holder to the operating table (left). The brain spatula retracts the temporal lobe of the artificial brain through the fronto-temporal-subtemporal craniotomy in training for superficial temporal artery to superior cerebellar artery bypass (left, and lower right). With some rotation of Model A, anastomosis of the posterior inferior cerebellar artery (PICA) of the caudal loop (occipital artery to PICA bypass) can be practiced (upper right). A swine artery is fixed to the artificial brain with pins, a silicone sheet is inserted under the vessel, and the artificial brain is retracted by brain spatula as in real surgery.

Fig. 2 Photographs showing the Model B artificial skull, fixed to the table using a Mayfield head holder (left). The brain spatula retracts the frontal lobe of the artificial brain through the bifrontal craniotomy for training of side-to-side anastomosis for callosal segment of the anterior cerebral artery (upper and lower right). A swine artery is placed onto the corpus callosum with pins, a silicone sheet is inserted under the vessel, the segment for arteriotomy is colored blue with methylrosaniline (pyocyaninum blue) to allow clear visualization, and the artificial brain mold is retracted using the brain spatula.

areas allowing fixation to the table with a Mayfield head holder.

**Model A:** This model has two craniotomy windows. One window is used for the trans-sylvian and subtemporal approaches, and is used for training anastomosis procedures to the M2, SCA, and PCA. The other window is used for suboccipital craniotomy for anastomosis to the PICA. The artificial brain mold consists of two parts: the hemisphere with sylvian fissure and insular cortex; and the brainstem and cerebellum. For modeling anastomosis to M2, the substitute vessel is placed directly within the insular cortex. For modeling SCA, PCA, and PICA anastomoses, the substitute vessel is fixed to the brainstem and then assembled into the skull with the hemispheric part (Fig. 1).

**Model B:** This model has a midline cranial window and the bilateral frontal brain including the interhemispheric fissure and corpus callosum. This model allows training for bypass procedures using the callosal segment of the ACA as a recipient (as in A2-A3 side-to-side anastomosis). The substitute vessel can be fixed to the corpus callosum (Fig. 2).

These models are suitable for training and for demonstration purposes under the operating microscope in a real operating room. The models are ready-made and usable repeatedly for practicing standard deep bypass techniques rather than simulating a particular surgery on a single patient, although any individual modifications can be requested. Type A (OMeR-KEZLEX-A36) model can be purchased from Ono & Co. Ltd. (http://ono-and.com/index.html) for 170,000 yen and Type B (OMeR-KEZLEX-A37) for 160,000 yen. Any vascular substitutes must be prepared separately.

**Discussion**

Training of surgical skills is extremely important for mastering the techniques of microvascular anastomosis. Two different issues have been discussed in microsurgical training. The first issue involves the types of vascular substitutes appropriate for training. Gauze fibers, silicone tubes, cadaveric materials, animal vessels, and perfused animal vessels have all been used in training. Artificially pulsatile or perfused arteries in models can create a relatively realistic situation.

The second issue is how to reproduce situations of similar technical difficulty as real vascular anastomosis. To date, training methods for techniques of microvascular anastomosis have mainly been for resident neurosurgeons who have recently started...
microvascular surgery. Deep microvascular anastomosis is a far more difficult technique than standard superficial temporal artery-cortical MCA anastomosis, and few practical tools have been available for training. Even for neurosurgeons who feel no difficulty in superficial microvascular anastomosis, training or rehearsal is still required for deep microvascular anastomosis prior to operating on actual patients. Training using instruments that produce a deep corridor at a realistic depth of the interhemispheric fissure has been reported for A1-A3 anastomosis.3) Very recently, a unique training method for deep anastomosis was described using a mannequin head.8) This model provides a similar depth for M2 and PCA, but not realistic conditions.

The present models provide variable depths of microvascular anastomosis for practice under close-to-real situations. Deep anastomosis has different levels of difficulty to depending on depth. Using our model, neurosurgeons can practice under an operative field with both realistic depth and realistic width for manipulation of operative instruments. Although we are trying to modify the feel of the materials used for the artificial brain to provide a more similar experience to the real brain, the present model provides practice on how to place brain retractors and how to manipulate the forceps or needle-holder for microvascular anastomosis.

The models are quite expensive for individual use, so should be purchased by educational facilities or training hospitals for the use of trainees. Demonstration of surgical techniques by an expert neurosurgeon is also possible even if no real patient is available. Moreover, we can try different variations to choose which the most appropriate type of apparatus. The models may also help us in producing and evaluating novel devices for microvascular anastomosis.

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References


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Commentary

The authors provide an innovative resin-inorganic model, derived directly from the CT of a specific patient, that can simulate a realistic microneurosurgical procedure. Therefore, it is particularly useful for training, both in skull base and in neurovascular procedures. The utility of this model, in its various forms, are well described in the paper. Another major advantage is, in my opinion, that a surgeon can train in the usual operating room, using the instruments and the microscope he is used to. This would not be possible with an animal model or a cadaver specimen, that up to now have been the only realistic alternatives to the true surgery for training. The authors should be congratulated for their work: we all hope that, with increasing number of the requests, the price of the resin model will significantly decrease.

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