Surgical Simulation of Cerebral Revascularization
Via Skull Base Approaches in the Posterior Circulation
Using Three-Dimensional Skull Model With
Artificial Brain and Blood Vessels

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Abstract

Posterior circulation revascularization is a challenging technique because microanastomosis must be performed in deep locations. A reproducible simulation model is proposed for training. The prototype three-dimensional skull model with artificial brain was used. The mesencephalic segment of superior cerebellar artery (SCA) and the caudal loop of the posterior inferior cerebellar artery (PICA) were made from artificial blood vessels and glued on the brain. The skull model was drilled to perform the presigmoid transpetrosal approach and then superficial temporal artery-SCA anastomosis was performed under the operating microscope. The skull model was also drilled to perform the far lateral approach and then occipital artery-PICA anastomosis was performed. The skull model with artificial brain and arteries allows simulation and training in the surgical techniques of posterior circulation revascularization with skull base approaches.

Key words: far lateral approach, occipital artery-posterior inferior cerebellar artery anastomosis, presigmoid transpetrosal approach, superficial temporal artery-superior cerebellar artery anastomosis, training model

Introduction

Cerebral revascularization techniques include superficial temporal artery to superior cerebellar artery (STA-SCA) anastomosis and occipital artery to posterior inferior cerebellar artery (OA-PICA) anastomosis,1,2,9) and have become essential neurosurgical methods not only for posterior circulation revascularization to treat vertebro-basilar insufficiency but also for flow isolation or alteration strategies to treat unclippable dissecting or giant aneurysms in the posterior circulation.5,10) However, STA-SCA anastomosis and OA-PICA anastomosis are both deep cerebral revascularization procedures which require microsurgical anatomical expertise in the posterior fossa structures and micro-anastomosis technique in deep locations.8) Such expertise requires training with cadaveric dissection and further experience to develop micro-anastomosis technique in deep locations. Therefore, adequate cadaveric training may not be available, and a reproducible training model is necessary to simulate posterior circulation revascularization procedures in the laboratory.

We previously described our surgically dissectable three-dimensional (3D) skull base model for simulating skull base surgical techniques.11,12) Recently, a 3D model was developed consisting of artificial skull and brain for training of deep microvascular anastomosis.6) Here we discuss the simulation of STA-SCA anastomosis and OA-PICA anastomosis with skull base techniques using this 3D skull model. The temporobasal approach is the main technique for STA-SCA anastomosis. However, STA-SCA anastomosis combined with the presigmoid transpetrosal approach is also advocated to improve the surgical working space and reduce damage to the temporal lobe.3,7) The OA-PICA anastomosis originally requires suboccipital craniotomy with or without removal of the posterior arch of the atlas. To obtain enough working space, the addition of the far lateral approach may be beneficial.4) We also demonstrate the differences between the original and combined methods of skull base approaches using the 3D model.
Fig. 1 Prototype three-dimensional half skull model (OMeR-KEZLEX® A36; Ono & Co., Ltd., Tokyo) and artificial brain (A). Prototype artificial blood vessels (upper: 3-mm diameter, lower: 2-mm diameter; KEZLEX® B61-ABV-30, B61-ABV-20; Ono & Co., Ltd.) for training in microanastomosis (B).

Materials and Methods

The 3D half skull bone model with artificial brain (OMeR-KEZLEX® A36; Ono & Co., Ltd., Tokyo) reproduces the surface and inner bony details and is dissectable with the surgical drill (Fig. 1A). Fronto-temporal craniotomy and suboccipital craniotomy are already simulated for training in deep cerebral revascularization technique.6) The silicone-made artificial brain is soft and retractable using the surgical spatula.6) The polyvinyl alcohol-made artificial blood vessels (2- and 3-mm diameters; KEZLEX® B61-ABV-20 and B61-ABV-30; Ono & Co., Ltd.) are produced for training in micro-anastomosis technique (Fig. 1B). The lateral pontomesencephalic segment of the artificial SCA (2 mm diameter) is glued on the pontomesencephalic sulcus. The caudal loop of the artificial PICA (2 mm diameter) is also glued on the medulla oblongata under the tonsil and biventral lobule. The transverse and sigmoid sinuses are reconstructed using blue silicone. The V2 and V3 segments of the vertebral artery are reconstructed using red wire. The modified model is fixed with Mayfield’s tri-pins, dissected using the surgical drill, and microanastomosis procedures are performed under the operating microscope.

Results

I. Surgical simulation of STA-SCA anastomosis via the posterior petrosal approach

The modified skull model was positioned in the lateral position. Sugita tapered spatulas were used to retract the temporal base. The temporo-basal approach was performed (Fig. 2A). The artificial SCA was observed at the ambient cistern under the operating microscope. Two micro-forceps were introduced into the space around the lateral pontomesencephalic segment of the artificial SCA, but the working space was inadequate for micro-anastomosis, especially in the posterior area, because the working angle was limited by the pyramid bone (Fig. 2B). Therefore, posterior mastoidectomy was added using a high speed drill. The transverse-sigmoid sinus was exposed, and the presigmoid bone and petrous ridge were drilled away, preserving the semicircular canals, fallopian canal, and digastric ridge (Fig. 2C). After the addition of posterior mastoidectomy, adequate working space was obtained around the SCA for the micro-anastomosis (Fig. 2D). The rubber sheet was placed under the SCA and temporary clips were applied to both ends of the lateral pontomesencephalic segment of the SCA. Arteriotomy was performed on the SCA and the cut edge was stained with methyl violet B (pyoktanin blue) (Fig. 3A). The end of the artificial STA was cut into the fish-mouth shape and stained with pyoktanin blue. The artificial STA was introduced into the ambient cistern (Fig. 3A). Side-to-end anastomosis was performed between the STA and SCA using 9-0 nylon (Fig. 3B, C). The working space was adequate...
Fig. 3 Simulated procedures of superficial temporal artery (STA)-superior cerebellar artery (SCA) anastomosis. A: Arteriotomy was performed in the SCA and the STA was introduced into the ambient cistern. The cut ends of the SCA and STA were stained with pyoktanin blue. Temporary clips were placed on both sides of the lateral pontomesencephalic segment of the SCA. B: Microanastomosis between the STA and SCA was performed in the side-to-end fashion using 9–0 nylon. C: After the anastomosis. D: Complete anastomosis was confirmed by injection of normal saline via the STA.

Fig. 4 Simulated procedures of occipital artery (OA)-posterior inferior cerebellar artery (PICA) anastomosis. A: Suboccipital craniotomy was extended to the occipital condyle to perform the far lateral approach using a high speed drill. B: Microanastomosis between the OA and caudal loop of the PICA was performed in the side to end fashion using 9–0 nylon. C: After the anastomosis. D: Complete anastomosis was confirmed by injection of normal saline via the OA. BL: biventral lobule, C1: posterior arch of the atlas, CH: cerebellar hemisphere, CT: cerebellar tonsil, MO: medulla oblongata, OC: occipital condyle, V3: V3 portion of the vertebral artery.

II. Surgical simulation of OA-PICA anastomosis via the far lateral approach

The modified model was positioned in the park bench position. The suboccipital craniotomy was extended to the occipital condyle to perform the far lateral approach using a high speed drill (Fig. 4A). Addition of the far lateral approach provided adequate working space for microanastomosis in the proximal part of caudal loop of the PICA. The artificial cerebellar tonsil and biventral lobule were retracted superiorly using a Sugita tapered spatula. The rubber sheet was placed under the PICA. Temporary clips were placed on the proximal and distal sides of the caudal loop. Arteriotomy was performed on the recipient caudal loop and the cut edge was stained with pyoktanin blue. The artificial OA was introduced into the cisterna magna space. Side-to-end anastomosis was performed between the OA and caudal loop of PICA using 9–0 nylon (Fig. 4B, C). Complete anastomosis was confirmed by injecting normal saline via the OA (Fig. 4D).

Discussion

The skull model with artificial brain used in this study was first developed for education and training in microvascular anastomosis of the posterior circulation and the inside of the sylvian fissure. The 3D skull models are manufactured by rapid prototyping methods using selective laser sintering technology based on 3D computed tomographic data of the human skull and completely reproduce both the surface details and inner bony structures of the human skull. The artificial bone is made from polyamide nylon and glass beads, and is dissectable using the surgical drill. The artificial blood vessels used in this study are produced for training in microvascular anastomosis instead of cadaver or animal blood vessels. The texture of the vessel wall is similar to the real arterial wall and can be sutured using the surgical needle. The cut end of the artifi-
cical vessels can be stained with pyoktanin blue similarly to the real arterial wall.

In this study, the commercially available skull model and blood vessels were combined and modified for training in STA-SCA and OA-PICA anastomoses via skull base approaches. We found that the original method via the temporobasal approach did not provide adequate working space to anastomose the vessels in the ambient portion. However, addition of the posterior petrosal approach to the original method did provide enough space for use of the microforceps. STA-SCA anastomosis via the posterior petrosal approach has advantages such as the recipient SCA running perpendicularly in the operative field, which is easier for microsuturing, and reduced risk of temporal lobe contusion due to excessive retraction. However, this modified method has disadvantages such as requiring extra time to perform the skull base procedure and increased risk of postoperative cerebrospinal fluid leakage. We found that the far lateral approach provided adequate working space for the OA-PICA anastomosis.

Development of the surgical skills for microanastomosis in deep locations and skull base techniques requires repeated training under similar conditions to real surgery. Our present model for education and training in posterior circulation revascularization provides a reproducible system that can be performed in the laboratory. Furthermore, the size and location of the SCA and PICA can be tailored according to individual angiographic findings, so the preoperative simulation surgery can be customized.

References


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