Development of Three-Dimensional Hollow Elastic Model for Cerebral Aneurysm Clipping Simulation Enabling Rapid and Low Cost Prototyping

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Key words
- 3D model
- 3D printing
- Cerebral aneurysm
- Clipping
- Rapid prototyping
- Surgical simulation
- Surgical training

Abbreviations and Acronyms
3D: Three-dimensional
3D-CG: Three-dimensional computer graphics
3D-CTA: Three-dimensional computed tomographic angiography
3D-DSA: Three-dimensional digital subtraction angiography
ABS: Acrylonitrile-butadiene-styrene
JPY: Japanese yen
M1: Main trunk of middle cerebral artery
M2: First branch of middle cerebral artery

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OBJECTIVE: **We developed a method for fabricating a three-dimensional hollow and elastic aneurysm model useful for surgical simulation and surgical training. In this article, we explain the hollow elastic model prototyping method and report on the effects of applying it to presurgical simulation and surgical training.**

METHODS: **A three-dimensional printer using acrylonitrile-butadiene-styrene as a modeling material was used to produce a vessel model. The prototype was then coated with liquid silicone. After the silicone had hardened, the acrylonitrile-butadiene-styrene was melted with xylene and removed, leaving an outer layer as a hollow elastic model.**

RESULTS: **Simulations using the hollow elastic model were performed in 12 patients. In all patients, the clipping proceeded as scheduled. The surgeon's postoperative assessment was favorable in all cases. This method enables easy fabrication at low cost.**

CONCLUSION: **Simulation using the hollow elastic model is thought to be useful for understanding of three-dimensional aneurysm structure.**

INTRODUCTION

A prerequisite to cerebral aneurysm surgery is a thorough understanding of both the shape of the aneurysm and the positional relationship of the aneurysm with the parent artery and its branches, bones, brain, cranial nerves, and so on. In the past, cerebral angiography was the only method available for this purpose. The surgeons had to construct mentally a three-dimensional (3D) image in the brain using two-dimensional images from a limited number of angles. The complexity of the vascular network around the aneurysm naturally made 3D visualization of the structure difficult by this method, and the task required extensive training and long experience. With the digitalization of diagnostic radiologic images, it became easy to obtain simulated 3D images at desired angles by, for example, 3D computed tomographic angiography (3D-CTA) or 3D digital subtraction angiography (3D-DSA). In most cases, required views generated from such original data before surgery are used for presurgical assessment and surgical navigation.

Application of virtual reality technology to neurosurgical training has been reported in recent years (7, 13, 14, 19, 21, 26). Although this method is useful, what is seen is a "two-dimensional image that looks like three-dimensional." We believe a "true three-dimensional physical model" is more advantageous for intuitive 3D understanding. We had therefore been using a ZPrinter 450 (3D Systems, Rock Hill, South Carolina, USA; Figure 1A) to fabricate actual size 3D models of cerebral aneurysms using processed 3D-CTA or 3D-DSA. We used the solid models for various purposes such as presurgical assessment, training of junior surgeons, and informed consent process. This patient-specific fabrication method is known as rapid prototyping technology and has been the subject of a number of reports in the cerebral aneurysm field (6, 12, 24, 27, 28). However, it has not been widely adopted as a routine clinical process owing to the considerable labor and time required for the prototyping and the high fabrication cost. We therefore sought to realize inexpensive and rapid prototyping using a small acrylonitrile-butadiene-styrene (ABS) 3D printer and to apply the prototyping clinically. We also developed a method for applying this system for fabrication of hollow and elastic blood vessel and aneurysm models (hollow elastic models).

In the present article, we explain the hollow elastic model prototyping method and report on the effects of applying it to presurgical simulation and training of surgery.

MATERIALS AND METHODS

Twenty patients in which the hollow elastic models were fabricated are grouped into two groups as is shown in Tables 1 and 2.

Clipping was performed in 12 patients (group A; Table 1). In the remaining eight

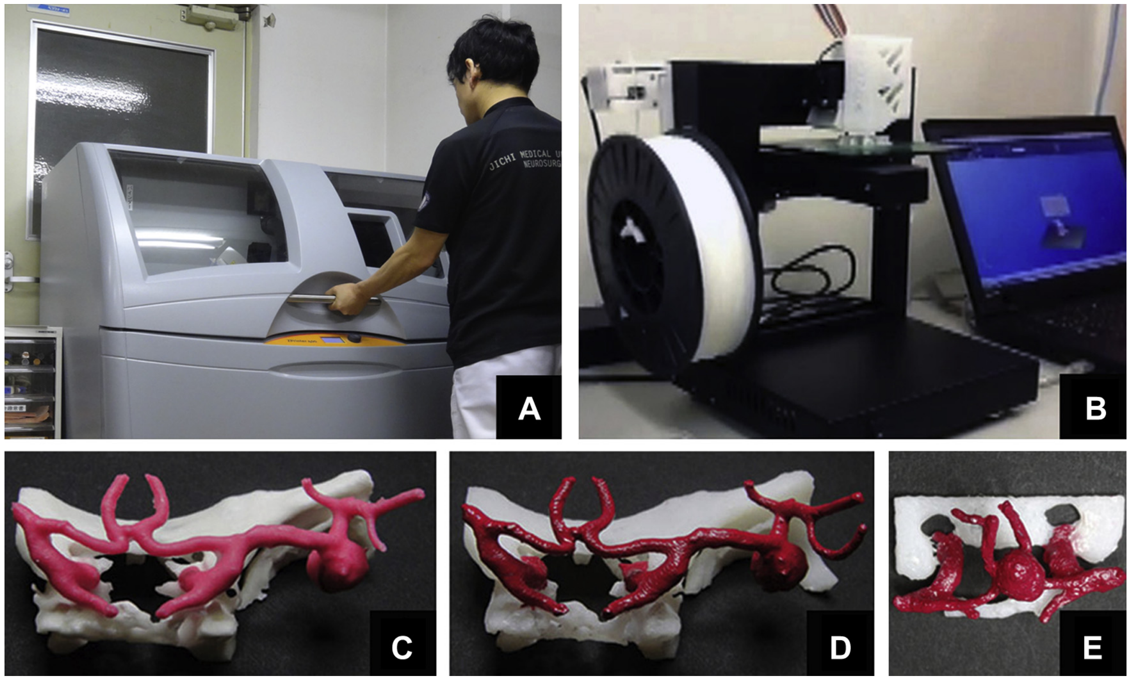

Figure 1. Comparison of ZPrinter and OPT printer. (**A**) Exterior of ZPrinter. Equipment dimensions are 1220 mm × 790 mm × 1400 mm and weight is 193 kg. Three-dimensional models are formed in the left compartment. (**B**) Exterior of the OPT printer. This is small and lightweight, measuring 245 mm × 260 mm × 350 mm and weighing 5 kg. Forming mechanism with this equipment is explained in Figure 2. (**C**) A model of middle cerebral artery aneurysm with part of sphenoid ridge fabricated with ZPrinter. Resolution in this model is 0.1 mm. The equipment produces realistic color models without paint. (**D**) A model of same shape as in **C** formed with the OPT printer tinted with brush after formation. Resolution in this model is 0.15 mm. (**E**) A smaller model of anterior communicating artery aneurysm formed with the OPT printer could be completed in 30 minutes or less.

Table 1. Summary of Group A (Cases Where Clipping Was Performed)

Patient	Age (years)	Sex	Lesion	SAH	Estimated Clip	Actual Clipping	Residual Neck	Unexpected Findings	Cost (JPY)	Time for Fabrication (hours)
1	58	M	L IC-PC	Yes	25-mm straight	25-mm straight + 21-mm straight	Yes	Hard wall	200	18
2	66	F	L IC-PC	Yes	15-mm straight	15-mm straight	Yes		200	14
4	73	F	R IC-PC	No	10-mm straight	10-mm straight	No		150	21
6	75	F	R MCA	No	15-mm straight	15-mm straight	No		230	24
7	67	F	L MCA	No	10-mm straight	10-mm straight	No		160	14
8	70	F	L IC-PC	No	10-mm straight	10-mm straight	No		240	19
9	64	F	L MCA	No	7-mm straight	10-mm straight	No	Adhesion	210	16
11	47	M	R MCA	No	10 mm L	10 mm L + 7.5 mm L	No	Hard wall	90	15
14	65	F	R MCA	No	9 mm J	9 mm J + 6 mm J	No	Hard wall	190	16
15	60	F	R MCA	No	10-mm straight	10-mm straight	No		160	20
16	70	F	L MCA	No	10 mm L	10 mm L	No		170	22
17	60	M	L MCA	No	10-mm straight	10-mm straight	No		160	23

JPY, Japanese yen; IC-PC, internal cerebral artery-posterior communicating artery; MCA, middle cerebral artery; R, right; L, left; F, female; M, male.