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Technical Note

Usefulness of Preoperative Simulation Using a Stereolithographic 3D Printer in Cerebral Aneurysm Coil Embolization

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Objective: We present a preoperative simulation of cerebral aneurysm coil embolization using a hollow model of cerebral blood vessels created by a stereolithography (SLA) 3D printer.

Case Presentation: The patient was a 66-year-old woman. During follow-up, coil embolization was planned for an expanding paraclinoid aneurysm. A hollow cerebral vascular model was created preoperatively using an SLA 3D printer. The catheter was malleable and inserted into the hollow model, which enabled the surgeons to confirm its movement, stability, and ease of insertion. In the surgical procedure, the catheter was easily inserted into the aneurysm without reshaping. The procedure was completed without stability problems.

Conclusion: The use of a hollow model of cerebral blood vessels was useful as a preoperative simulation and improved the safety of the procedure.

Keywords ▶ 3D printing, unruptured aneurysm, preoperative simulation, catheter shaping

Introduction

In cerebral aneurysm coil embolization, the stability of the catheter and ease of its insertion are elements that directly affect the difficulty and safety of the procedure.[1–3] For cerebral aneurysm embolization, the catheter is shaped using steam or a hot gun after determining the positions of the aneurysm and parent artery by 3D imaging techniques such as 3D DSA. However, the images are different from the anatomical structures in scale and experience is needed to imagine the route of catheter passage in the body. This method is largely dependent on the surgeon's experience and causes variability in the procedure. The catheter is occasionally unstable and reshaping is often necessary.

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Recently, a method using a 3D printer was reported as a solution for this problem. A life-size cerebrovascular model was created by bending the catheter using a mandrel into a shape that fits the blood vessel by direct observation.[4] This method improved the precision, but how the catheter runs when inserted is unclear and shaping may not fit depending on the route of insertion. It is more reliable to prepare a hollow cerebral vessel model, shape the catheter into a configuration that exactly fits the model, and confirm its fit by inserting it into the model.

We report a case in which the catheter was successfully shaped using a hollow model of the cerebral vasculature prepared by a 3D printer.

Case Presentation

The patient was a 66-year-old woman with an unruptured cerebral aneurysm. Although she was periodically followed up by intracranial MRA, the aneurysm increased in size. As the patient requested coil embolization of the aneurysm, treatment was planned. The lesion was a left paraclinoid aneurysm with a maximum diameter of 3.9 mm and a dome/neck ratio of 1.39 (**Fig. 1**).

The patient had no notable clinical or familial history.

Before using the 3D printer, digital imaging and communications in medicine (DICOM) images of 3D DSA

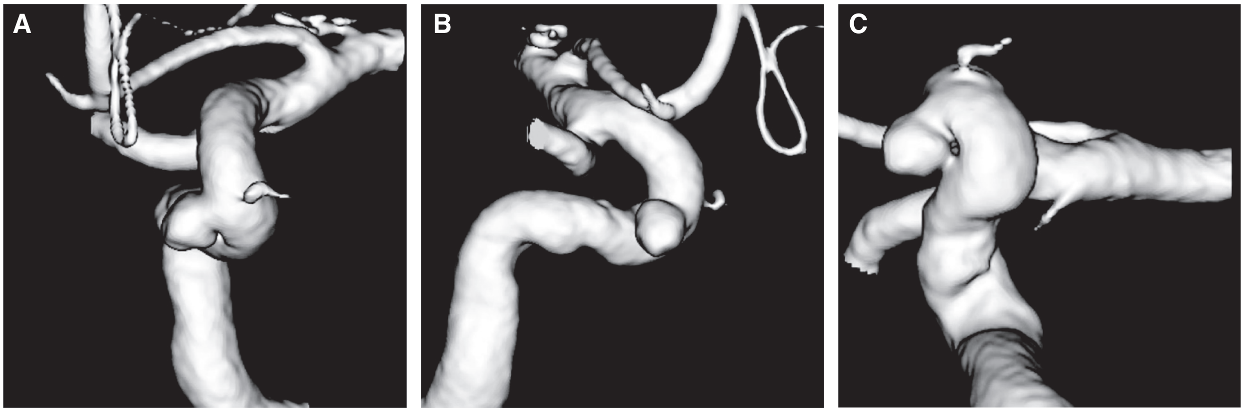

Fig. 1 Preoperative 3D DSA images: (**A**) frontal view, (**B**) lateral view (right side), and (**C**) caudal view.

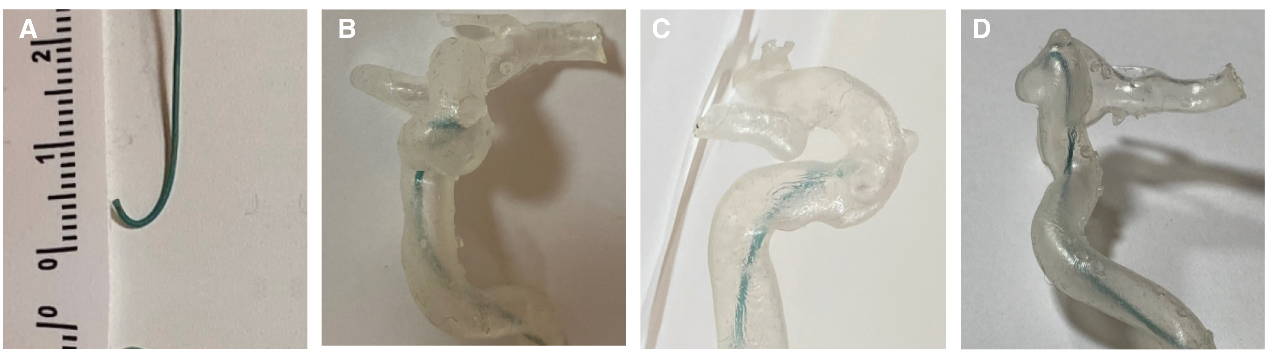

Fig. 2 (**A**) The microcatheter was shaped into a J-shape. The catheter was not inserted into the aneurysm. Movement was observed through the aneurysm along the internal carotid artery, (**B**) frontal view, (**C**) lateral view (right side), and (**D**) caudal view

were converted to files using ZAIO STATION 2 (Ziosoft, Tokyo, Japan). The model was made hollow using a meshmixer (Autodesk, San Rafael, CA, USA) and the wall thickness was set at 0.25 mm. Then, data corruption was assessed and support was provided by PreForm (Formlabs, Somerville, MA, USA). A hollow cerebral vessel model was prepared using a Form 3 3D printer (Formlabs).

The microcatheter was shaped using a heat gun in advance and simulation was performed by inserting it into the hollow cerebrovascular model. First, the hollow cerebrovascular model was grossly observed from outside and shaping into a J shape was assumed. When the microcatheter was inserted into the model, it passed the opposite side of the aneurysm and its tip headed for the distal area of the internal carotid artery, passing by the aneurysm (**Fig. 2**). Other shapes, including a tornado, were tested, but they made insertion difficult. The microcatheter was able to be inserted when it was shaped into a J shape with an extended tip, but it was unstable and further evaluation was required for more stable shapes. The microcatheter was later shaped into a 1-cm-long crank with only the tip bent at 90 (**Fig. 3**). By this shaping, the microcatheter was able to be inserted into the aneurysm directly without using a microwire because it was stabilized on the vascular wall firmly at 2 points (**Fig. 4**). The prepared mandrel was sterilized in preparation for prompt shaping of the catheter during surgery.

Treatment

Surgery was performed under general anesthesia. After a 6-Fr Axcelguide (Medikit, Tokyo, Japan) was placed in the left internal carotid artery via the femoral artery, a 6-Fr Cerulean DD6 catheter (Medikit) was placed as an intermediate catheter. The microcatheter used was a Headway 17 (Terumo, Tokyo, Japan).

The mandrel prepared before surgery was brought into the surgical field, and the Headway 17 was shaped into a 1-cm-long crank with only the tip bent at 90°. The catheter was able to be inserted into the aneurysm easily using a Radifocus guidewire M 0.012 double angle (Terumo). As the dome/neck ratio was low,

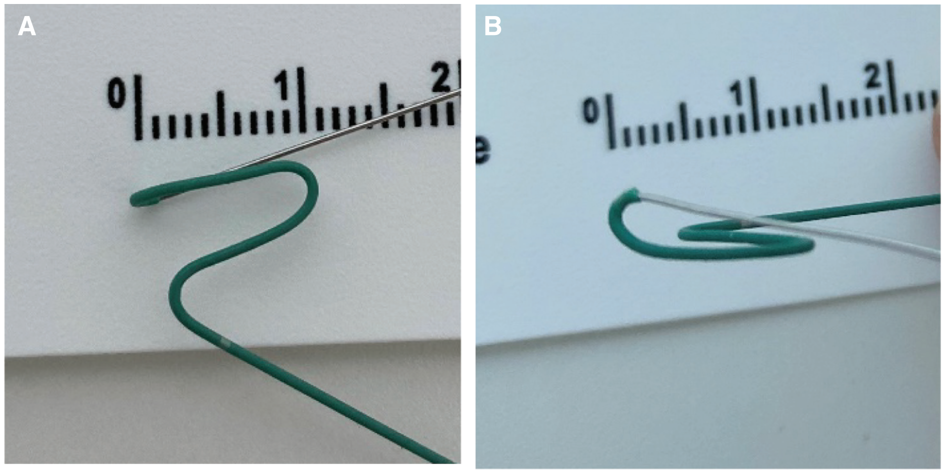

Fig. 3 The catheter was shaped into a 1-cm-long crank with the tip bent at 90 degrees (**A** and **B**)

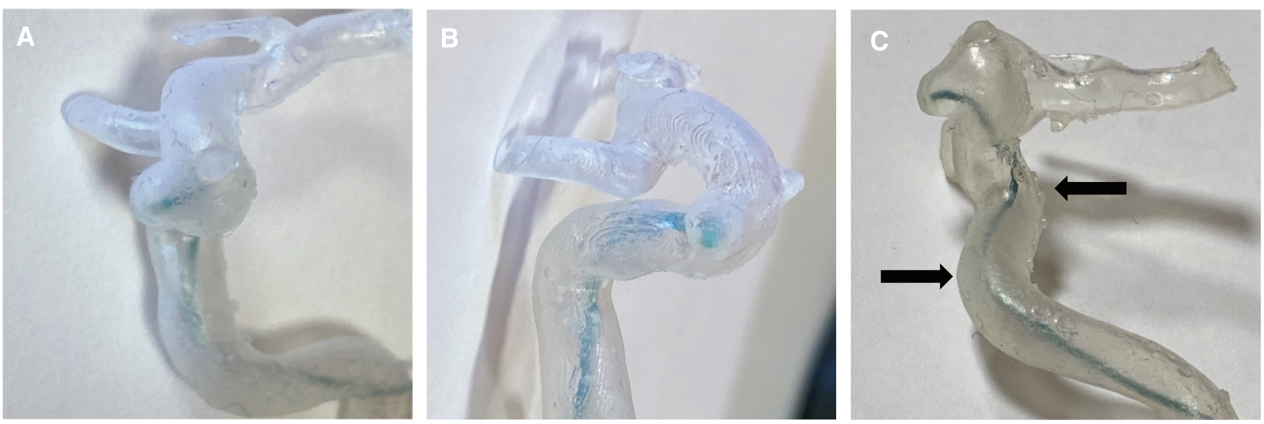

Fig. 4 (**A**) Frontal view, (**B**) lateral view (right side), and (**C**) caudal view. The crank-shaped catheter was easily inserted into the aneurysm. The catheter was supported and stabilized at two points (arrows) in the wall of the internal carotid artery

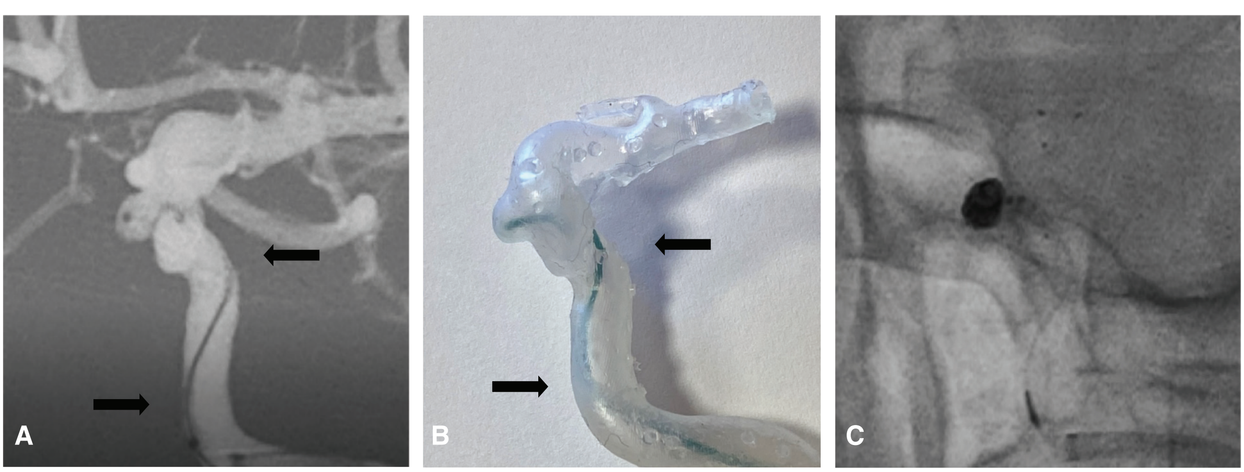

Fig. 5 The catheter was stabilized at two points (arrows) on intraoperative angiography (**A**). The catheter in the hollow cerebral blood vessel model was also stabilized at 2 points (arrows) (**B**). The aneurysm was occluded by the coils without repositioning (**C**)

stent-assisted coil embolization was performed. A Neuroform Atlas 4.0 × 21 (Stryker, Kalamazoo, MI, USA) was deployed using an Excelsior SL-10 (Stryker). Coils were inserted via the jailed Headway 17. The catheter was markedly stable. The procedure was ended when the catheter was pushed out (**Fig. 5**).

After surgery, no complications were noted and complete occlusion was confirmed by imaging examination. No high-intensity area or hemorrhage was found on MRI-DWI performed the next day.

Discussion

The morbidity, mortality, and recanalization rates associated with coil embolization of cerebral aneurysms remain constant despite technical improvements.[5–8] It is important to determine the anatomical configurations of the blood vessels and aneurysms to safely perform coil embolization of cerebral aneurysms. However, the complexity of the morphology of blood vessels often causes difficulty in treatment using conventional modalities such as MRA, CTA, and 3D DSA. Simulation using hollow cerebrovascular models prepared by a 3D printer is expected to optimize treatment by facilitating determination of the anatomical configuration of cerebral vessels, and the direction and location of the catheter.

There are many types of 3D printers, and the materials used, price, precision, shaping speed, and size depend on the shaping method and printer model.

Among 3D printers for personal use, fused deposition modeling types are most accessible. As this type is inexpensive, it has gained wide acceptance and has been applied to catheter shaping. A method of preparing a 3D model and catheter shaping under gross observation was previously reported to improve precision.[4] However, if hollow models are prepared using an inexpensive 3D printer, the wall is thickened in small structures, such as cerebral vessels, causing difficulty in insertion of devices or observation of the catheter from outside is difficult because of the low transparency of the material. Therefore, it is necessary to prepare hollow models by applying silicone over 3D models and removing the hollow parts by dissolving them, which is time-consuming and labor-intensive.[9,10]

The price of stereolithographic (SLA) 3D printers is decreasing. As liquid resin is hardened by ultraviolet rays, small and complicated structures, such as cerebral vessels, can be shaped with high precision, and as highly transparent materials can be used, hollow models can be prepared directly. An advantage of hollow models is that the suitability of catheter shaping can be tested by inserting the catheter to directly check its position, direction of insertion, and stability. In treatments using therapeutic devices, such as coils and stents, their suitability can be evaluated by inserting them into the model before surgery.[11,12]

In the present case, the initial shape was deemed inappropriate by preoperative simulation and the design was markedly altered. In treatment, the catheter was able to be inserted into the aneurysm by shaping it only once and treatment was completed in a short time. Without preoperative simulation, the risk of complications, such as intraoperative hemorrhage and vascular dissection, is higher. In addition, as prolonged catheterization increases the risk of embolic complications,[13] preoperative simulation is considered to increase the safety of the entire procedure.

However, there are problems in such preoperative simulation using a 3D printer. First, the cost must not be disregarded. In addition to the price of the printer itself (approximately ¥600000 for the printer used for this patient), the running costs, including the cost of the resin (¥100–200 for our patient), cannot be ignored. Moreover, preparation of hollow models is often difficult using the software attached to the printer and appropriate software must be obtained separately, but multifunctional software that supports DICOM processing, hollow designing, and 3D printing is often expensive.

Other problems to note include the limitation of the size of printable structures. In general, the price is lower for smaller ranges of modeling, but in catheter shaping, the structures around the aneurysm and passage of the catheter are important factors. In particular, parts that are markedly curved, such as the carotid siphon, are important. As these factors cannot be disregarded, a printer with a size sufficient to output a model that covers the area from the site of guiding catheter placement to the aneurysm is optimal.

If catheter shaping is performed using a 3D printer, exact reproduction of the designed shape is another requirement. If the shape is not complicated, it is possible to reproduce the shape based on measured values. If the shape is complicated, however, shaping and sterilizing the mandrel in advance and using it for direct shaping at the time of treatment is a useful approach. It makes copying of complicated shapes possible and shortens the time of surgery. In addition to these methods, a method using a catheter that was inserted was previously reported. Xu et al.[14] reported that they inserted a catheter into a sterilized hollow model of an aneurysm, shaped the catheter by heating it with the model in a water bath at 50°C for 5 minutes, and used the shaped catheter directly for treatment.

Cerebrovascular models prepared by a 3D printer have been used not only for preoperative catheter shaping but also for more precise evaluation of lesions with complex morphology, such as arteriovenous malformation (AVM),[15] and are considered to improve the safety. Hollow cerebrovascular models were also suggested to be useful for preoperative simulation of intracranial endovascular treatment. They may also be applied to preoperative training in manipulation of novel devices and determination of the site of deployment of a flow diverter.[16] In the future, they may be employed for training of more practical endovascular treatments.[12,17]

Conclusion

By preoperatively shaping the catheter for endovascular treatment of cerebral aneurysms, assessment of the guideability and stability of the catheter has become possible, thereby improving the safety of the procedure. Hollow cerebrovascular models prepared by a 3D printer are useful for preoperative simulation of surgery.

Disclosure statement

The authors declare no conflicts of interest.

References

1) Kwon BJ, Im SH, Park JC, et al: Shaping and navigating methods of microcatheters for endovascular treatment of paraclinoid aneurysms. *Neurosurgery* 2010; 67: 34–40; discussion 40.

2) Jia ZY, Song YS, Sheen JJ, et al: Loop microcatheter technique for coil embolization of paraclinoid aneurysms. *Acta Neurochir (Wien)* 2018; 160: 1755–1760.

3) Cho YD, Rhim JK, Park JJ, et al: Microcatheter looping to facilitate aneurysm selection in coil embolization of paraclinoid aneurysms. *Korean J Radiol* 2015; 16: 899–905.

4) Ishibashi T, Takao H, Suzuki T, et al: Tailor-made shaping of microcatheters using three-dimensional printed vessel models for endovascular coil embolization. *Comput Biol Med* 2016; 77: 59–63.

5) Molyneux AJ, Kerr RSC, Yu LM, et al: International subarachnoid aneurysm trial (ISAT) of neurosurgical clipping versus endovascular coiling in 2143 patients with ruptured intracranial aneurysms: a randomised comparison of effects on survival, dependency, seizures, rebleeding, subgroups, and aneurysm occlusion. *Lancet* 2005; 366: 809–817.

6) Crobeddu E, Lanzino G, Kallmes DF, et al: Review of 2 decades of aneurysm-recurrence literature, part 1: reducing recurrence after endovascular coiling. *AJNR Am J Neuroradiol* 2013; 34: 266–270.

7) Ringer AJ, Rodriguez-Mercado R, Veznedaroglu E, et al: Defining the risk of retreatment for aneurysm recurrence or residual after initial treatment by endovascular coiling: a multicenter study. *Neurosurgery* 2009; 65: 311–315; discussion 315.

8) Pierot L, Wakhloo AK: Endovascular treatment of intracranial aneurysms: current status. *Stroke* 2013; 44: 2046–2054.

9) Namba K, Higaki A, Kaneko N, et al: Microcatheter shaping for intracranial aneurysm coiling using the 3-dimensional printing rapid prototyping technology: preliminary result in the first 10 consecutive cases. *World Neurosurg* 2015; 84: 178–186.

10) Kaneko N, Mashiko T, Ohnishi T, et al: Manufacture of patient-specific vascular replicas for endovascular simulation using fast, low-cost method. *Sci Rep* 2016; 6: 39168.

11) Kaneko N, Minhas A, Tateshima S, et al: Pre-procedural simulation for precision stent-assisted coiling of cerebral aneurysm. *Interv Neuroradial* 2019; 25: 419–422.

12) Kono K, Shintani A, Okada H, et al: Preoperative simulations of endovascular treatment for a cerebral aneurysm using a patient-specific vascular silicone model. *Neurol Med Chir (Tokyo)* 2013; 53: 347–351.

13) Tokunaga K, Hatano T, Nakahara I, et al: Factors associated with postprocedural diffusion-weighted imaging-positive lesions in endovascular treatment for unruptured cerebral aneurysms. *World Neurosurg* 2019; 130: e457–e462.

14) Xu Y, Tian W, Wei Z, et al: Microcatheter shaping using three-dimensional printed models for intracranial aneurysm coiling. *J Neurointervent Surg* 2020; 12: 308–310.

15) Dong M, Chen G, Li J, et al: Three-dimensional brain arteriovenous malformation models for clinical use and resident training. *Medicine* (Baltimore) 2018; 97: e9516.

16) Scavarda D, Cavalcante T, Trébuchon A, et al: Tailored suprainsular partial hemispherotomy: a new functional disconnection technique for stroke-induced refractory epilepsy. *J Neurosurg Pediatr* 2018; 22: 601–609.

17) Wang JL, Yuan ZG, Qian GL, et al: 3D printing of intracranial aneurysm based on intracranial digital subtraction angiography and its clinical application. *Medicine* (Baltimore) 2018; 97: e11103.