CASE REPORT

Embolization using patient-specific vascular models created by a 3D printer for difficult cases: a report of two cases

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ABSTRACT

With the widespread use of three-dimensional printers, organ models created by these printers are now being used in the medical field for preoperative planning of surgeries. In this article, we report two cases in which embolization was expected to be difficult, and the three-dimensional printer-based vascular modeling was helpful in planning the surgery. The first case involved an aneurysm of the splenic artery. We attempted to embolize the aneurysm but were unable to advance the catheter into the distal artery and discontinued the procedure. The second case was a perianal varicose vein, which was initially treated with percutaneous transhepatic obliteration but was recanalized and required embolization. However, we expected difficulty in selecting the inferior mesenteric vein. In both cases, the vascular models were created using a 3D printer from the patients' computed tomography images. Preoperative planning, including treatment simulation, was based on these models. The time required to print a three-dimensional vascular model was approximately 12 hours at a cost of less than $10 each. Patient-specific vascular models using a three-dimensional printer can be a simple and inexpensive tool that can increase the success of embolization in difficult cases.

Keywords: 3D printer, interventional radiology, embolization, vascular model

Abbreviations:
IR: interventional radiology
CT: computed tomography
IMV: inferior mesenteric vein
3D: three-dimensional

INTRODUCTION

Vascular embolization is a widely performed procedure for aneurysms and vascular malformations. During these procedures, it is necessary to advance the catheter to the target vessel to perform an embolization; however, this might be difficult depending on the branching of the

vessel. A three-dimensional (3D) model of a patient's anatomy allows the interventional radiologist to visualize potential problem areas. The advent of 3D printers has facilitated the creation of patient-specific full-scale organ models, which can be used for preoperative planning and education in interventional radiology.[1,2] Using vascular models created by 3D printers enables accurate visualization of the branching angles and distances of vessels, making them a useful aid for difficult vascular embolization cases. We report two cases for which vascular models were created using a 3D printer from the computed tomography (CT) images of the patients.

CASE REPORT

The models were used for preoperative planning of embolization.

3D model creation

Dynamic contrast-enhanced CT was performed using a 320-detector CT scanner (Aquilion ONE; Canon medical systems corporation, Tochigi, Japan). The scanning parameters were as follows: tube voltage, 120 kV; tube current 111–222 mAs; pixel size 0.625 × 0.625 mm; slice interval 0.8 mm; and slice thickness 1 mm. Iopamidol (Iopamiron 370; Bayer, Leverkusen, Germany) was injected at a rate of 3.5 mL/s. The volume of the contrast medium was based on the patients' weight. The images obtained from the dynamic contrast-enhanced CT were manipulated using DICOM Workstation (Ziostaions2: Ziosoft, Inc., Tokyo, Japan), specially designed for navigating and visualizing multimodality and multidimensional images. After automatic vessel segmentation was performed from the CT images, we used the surface rendering function to extract the data of the region of the splenic artery and aneurysm and convert it to stereolithographic data. Digital preparation of the stereolithographic files was accomplished using 3D mesh software (Meshmixer: Autodesk, California, US). The final stereolithographic files generated via digital preparation were imported into Preform (Formlabs, MA, US) for preprocessing for a 3D printer. We then created a 3D model using a Form 3 3D printer (Formlabs, MA, US).

Case 1

Case 1 involved a woman in her 70s with a 3 cm splenic artery aneurysm (Fig. 1A). During the initial procedure, the catheter and the wire were rotating in the aneurysm and could not be inserted into the outflow artery once embolization was attempted (Fig. 1B, 1C). Therefore, we used a 3D printer to create the patient's vascular model and re-design the treatment plan. The vascular model was created using the arterial phase of the dynamic CT imaging. The process required approximately 7 hours for the 3D printer to create the model and around 1 hour for post-processing. The model reproduced the splenic artery, splenic artery aneurysm, and part of the aorta of our patient (Fig. 1D). The only consumable material required was 48 mL of resin (Formlabs Resins Clear: Formlabs) at the cost of US $7.20.

The simulation showed that it was impossible to select the outflow artery by merely bending the wire. We decided to use a steering system,[3] in which the 1.9-Fr no-taper microcatheter can be inserted into a 2.7-Fr steerable microcatheter. The simulation showed that the catheter tip could be directed towards the outflow artery when the steering catheter was bent to the maximum extent (Fig. 1E).

A 4-Fr guiding sheath was inserted from the left upper arm and advanced to the celiac artery. A 2.9-Fr steerable microcatheter (LEONIS Mova: Sumitomo Bakelite Co. Ltd., Tokyo, Japan) was inserted from the 4-Fr catheter and advanced into the splenic artery aneurysm. The tip of the catheter was oriented in the direction of the outflow artery by bending the steerable

catheter within the aneurysm, as planned in the vascular model. By inserting a 1.9-Fr no-taper microcatheter (Carnelian MRAVEL: Tokai Medical Products Inc., Aichi, Japan) into the 2.7-Fr steerable microcatheter and using a 0.014-inch wire, the wire and the 1.9-Fr microcatheter could advance into the outflow artery (Fig. 1F). Coil implantation was performed first in the outflow artery and then in the inflow artery, thereby blocking the blood flow into the aneurysm.
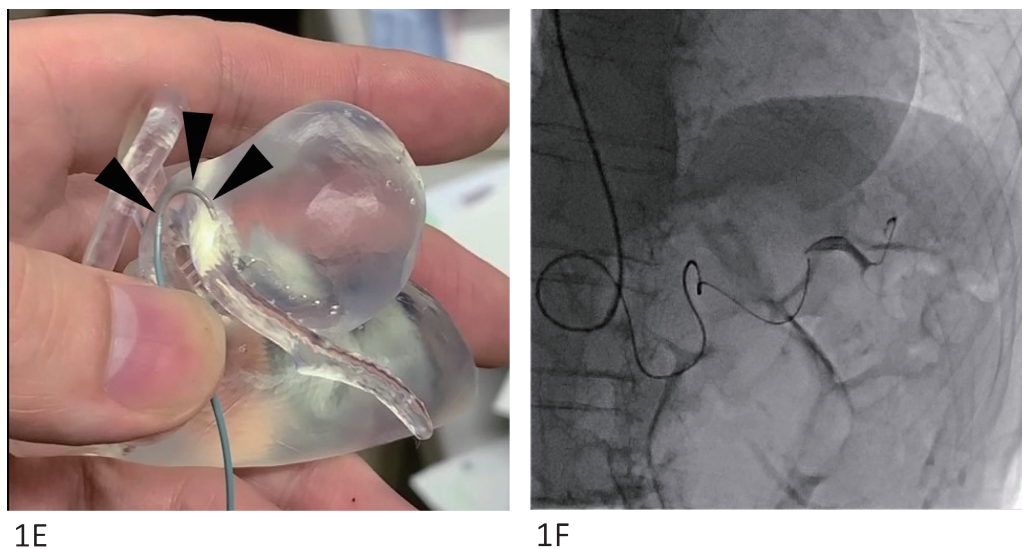

1A

1B

the outflow artery

the inflow artery

1C

1D

1E   1F
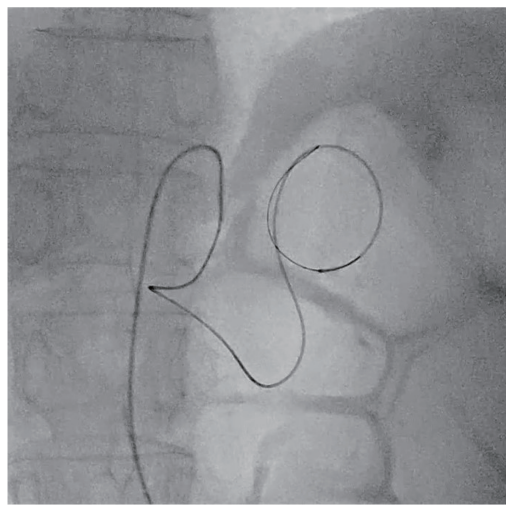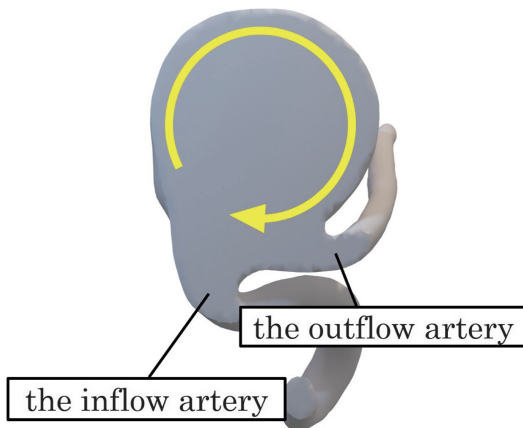
Fig. 1 Splenic artery aneurysm in a 70-year-old woman
Fig. 1A: The 3D-CT shows a 3 cm large aneurysm (arrow) in the splenic artery.
Fig. 1B: Fluoroscopic image shows the wire inside the aneurysm.
Fig. 1C: The cross-sectional view of the splenic artery aneurysm created from the CT image shows that the wire entering from the inflow artery spirals into the aneurysm, and the angle of the outflow artery makes it difficult to access.
Fig. 1D: The image shows that the size of the produced model is consistent with the measurements.
Fig. 1E: A simulation of the use of a steerable catheter (arrowhead) in a vascular model.
Fig. 1F: Fluoroscopic images show that the microcatheter has been inserted into the outflow artery, and angiography is being performed.
CT: computed tomography
3D: three-dimensional

Case 2

The patient was a man in his 70's who had been recently operated for rectal cancer; he had a history of liver cirrhosis and portal hypertension. He had a colostomy in the left lower abdomen with varicose veins. The patient underwent percutaneous transhepatic obliteration for the treatment of bleeding from the varicose veins around the colostomy. The bleeding resolved but recurred 6 months later. A CT scan showed recanalization of the varicose veins; therefore, a second percutaneous transhepatic obliteration was necessary.

During the first percutaneous transhepatic obliteration, a catheter had been inserted through the portal vein into the inferior mesenteric vein (IMV), which was challenging because the transition between the splenic and portal veins was bent (Fig. 2A). The CT image taken before the second percutaneous transhepatic obliteration showed that the IMV was thinner due to the previous embolization (Fig. 2B); therefore, we expected the procedure to be more difficult. The vascular model was created using the portal venous phase of the dynamic CT imaging. The output time for this model on the 3D printer was 9.5 hours using 63 mL of resin (US $8.50).

The vascular model reproduced the splenic vein and the IMV from the main trunk of the portal vein. We calculated the angle and distance from the mainstem of the portal vein to the IMV. With the model as a reference, a steam formation of the 4-Fr catheter was performed so that the tip of the catheter through the sheath inserted through the percutaneous transhepatic route would face the opening of the IMV (Fig. 2C). Though several attempts with the wire were

required during the first time to select the IMV, the steam-formed 4-Fr catheter tip was hooked directly to the origin of the IMV, and we advanced the microcatheter into the varicose vein (Fig. 2D). The varicose vein was embolized with a metal coil after injecting 5% ethanolamine oleate iopamidol. The patient has since not required treatment for the recurrence of melena.
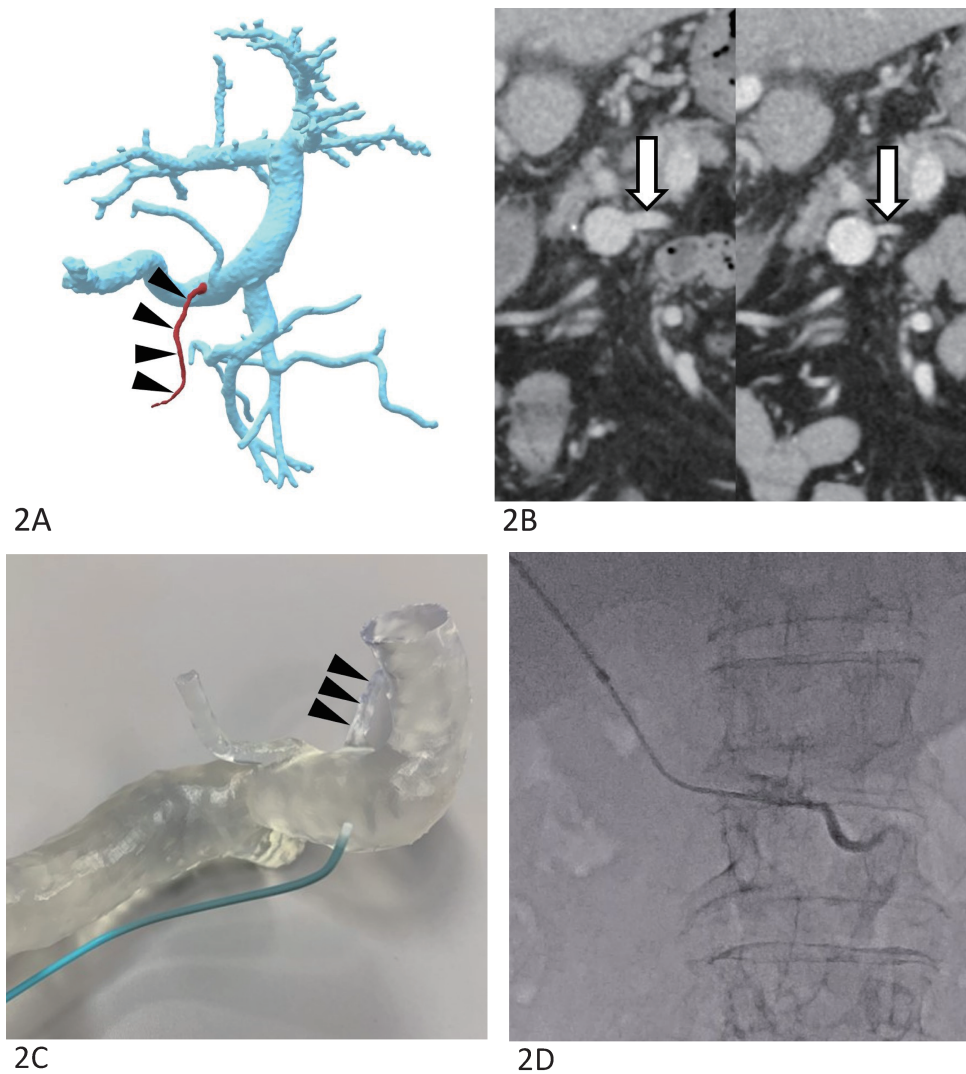

2A

2B

2C

2D

Fig. 2 Stoma varicose veins in a 70-year-old man

Fig. 2A: Dorsal view of a three-dimensional portal vein image created from the CT images. The inferior mesenteric vein (arrowhead) joins the splenic vein.

Fig. 2B: CT image of the coronal section shows the confluence of the inferior mesenteric vein (arrow) and splenic vein. The inferior mesenteric vein is thinner in the CT image after the first treatment (left image) than in the CT image before the first treatment (right image).

Fig. 2C: The image shows a 4-Fr catheter steam-formed based on a vascular model and oriented to the opening of the inferior mesenteric vein.

Fig. 2D: Fluoroscopic images show a steam-formed 4-Fr catheter inserted through a percutaneous transhepatic sheath directly into the origin of the inferior mesenteric vein.

CT: computed tomography

DISCUSSION

Vascular models created by 3D printers have been useful for preoperative planning in interventional radiology, such as embolization of aneurysms[4] and stent-graft implantation.[5,6] When performing interventional radiology, treatment is planned by looking at the CT images on a monitor before the procedure. Medical imaging workstations can perform volume rendering processing to make it easier to visually see the blood vessels and measure the distance and bifurcation angle of blood vessels. However, there is a limitation in recognizing the shape of the blood vessels by viewing them only in 2D on a monitor. By creating a patient-specific vascular model, the distance and angle of vascular branches can be confirmed in 3D by touching it with the hand. By confirming the shape of the blood vessel through the sense of touch rather than visually on a monitor, it is easier to provide feedback for catheter and wire manipulation, making interventional radiology smoother, especially for cases with complex vascular branches. Modern 3D printers are easy to operate, and models can be easily created without engineering knowledge. Novice physicians are likely to benefit the most from 3D models since they are still unfamiliar with interpreting vascular information from the images.[7]

The widespread use of 3D printers has reduced costs, making it easier for hospitals to create such vascular models. The vascular model we created was inexpensive at less than US $10. Much of the process was automated and required several hours for completion. The splenic artery aneurysm in Case 1 could have been treated by implanting coils in the aneurysm but would have required a large number of coils at an increased cost. By embolizing the coils distally and proximally, the savings on coils would exceed the cost of the vascular model. These cases demonstrate a real-world application of 3D printing supporting the embolization procedures. Vascular models might not be necessary for each case but could be useful for cases expected to be difficult to treat.

Our vascular models were not hollow structures as the models reproduced only the morphology of the blood vessels. There have been reports of preoperative simulations in which a hollow-structure vascular model was created and a device, such as a catheter, was inserted.[8,9] To create a hollow-structure vascular model, it is necessary to further process the surface-rendered data from CT images. This process requires a special application and is more complicated to transfer to a 3D printer. Even if a hollow vascular model is created, it will differ from the actual case because of the different friction with the catheters and wires and the stiffness of the vessel wall. A vascular model that reproduces only the vascular structure is easy to create and facilitates understanding of the three-dimensional vascular anatomy, which is useful for preoperative simulation.

CONCLUSION

Vascular models created using a 3D printer before embolization allowed for detailed treatment planning. By referring to the vascular model, we performed catheter steam formation, which facilitated vessel selection. Our cases demonstrate the feasibility of 3D printer-generated vascular models in real-world clinical procedures of embolization.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest.

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