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Tailor-made shaping of microcatheters using three-dimensional printed vessel models for endovascular coil embolization

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ABSTRACT

Background: Stabilization of microcatheters during coiling after their optimal shaping are key factors for successful endovascular coil embolization of cerebral aneurysms. However, stabilization and optimal shaping of microcatheters are sometimes difficult. Our aim was to introduce “tailor-made” microcatheter shapes for coil embolization using three-dimensional (3D) printed vessel models.
Method: Since August 2014, we have been investigating the use of 3D printed models of intracranial arterial aneurysms to produce optimally shaped microcatheters for endovascular coil embolization. Using Digital Imaging and Communication in Medicine data obtained from preoperative cerebral angiography, a vessel model was produced with a 3D printer using acrylic resin. Preoperative planning of microcatheter navigation and shaping were performed using the 3D vessel models. Before the procedure, microcatheter mandrels were bent manually to the intended angle, referring to the vessel model, and then sterilized. The 3D vessel models were also sterilized with plasma and used during the procedure.
Results: Twenty-six patients (27 aneurysms) were treated using a total of 48 microcatheters shaped while referring to the 3D printed vessel model. Of the 48 catheters, only 9 (19%) required modification of the initial shape due to inappropriate positioning of the catheter. Only 29% of the catheter placements required repositioning due to catheter kick back. There were no procedure-related complications, including aneurysm rupture. The responses from assistants to a questionnaire administered after the embolizations on the usefulness of the technique were favorable.
Conclusions: Tailor-made shaping of microcatheters may facilitate easier and safer procedures in coil embolization of intracranial aneurysm.

1. Introduction

While endovascular coil embolization is a common technique for treatment of intracranial cerebral aneurysms, the learning curve for this technique is typically steeper than that for microsurgical clipping. One of the key factors for successful coil embolization is safe microcatheter navigation within the aneurismal sac, which requires appropriate shaping of the microcatheter. Although advanced neuroradiological techniques, particularly three-dimensional (3D) image reconstruction, are widely applied, there is a discrepancy between the actual vessel and 3D images displayed on a monitor. It was necessary to produce a mandrel and catheter shapes in real proportion to the dimensions and shapes of the parent vessel and aneurysm. Different solutions have been attempted in recent years [1], however none of them provided a simple, presurgical creation and use of a model within 2–3 h. Therefore, we developed a technique for shaping “tailor-made” microcatheters using 3D printed models, which allows for optimal microcatheter navigation into cerebral aneurysms.

2. Materials and methods

2.1. Patient selection

The study protocol was approved by our institutional review board. All aneurysms treated using this technique were

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unruptured. Twenty-six patients (27 aneurysms) were treated with microcatheters shaped using 3D printed models. According to locations, the aneurysms were as follows: 23 internal carotid artery (ICA) aneurysms (8 paraclinoid, 4 ophthalmic, 5 posterior communicating, 1 cavernous portion, 3 anterior choroidal, 2 ICA terminal), 2 anterior communicating aneurysms, 1 middle cerebral artery aneurysm and 1 basilar top aneurysm. The average size of the aneurysms was 6.2 ± 3.6 mm. Average dome neck ratio was 1.3 ± 0.6 mm. Nineteen aneurysms were embolized using a double microcatheter technique, and the remaining – using a balloon-assisted technique. Coil embolization was performed successfully in all patients.

2.2. Production of 3D printed vessel model using Digital Imaging and Communication in Medicine (DICOM) data (Fig. 1)

Three-dimensional digital subtraction angiographic (3D-DSA) images from diagnostic cerebral angiography were obtained at least one day prior to embolization in all patients. The raw data of 3D-DSA in a DICOM file were used for creating a 3D model of the target vessel segment. These data were converted to standard triangulation language (STL) surface data as an aggregation of fine triangular meshes using 3D visualization and measurement software (Amira version X, FEI, Burlington, MA, USA). An unstructured computational volumetric mesh was constructed from the triangulated surface. Smoothing and remeshing followed as next steps. The STL file was then transferred to a 3D printer (OBJET30 Pro; Stratasys Ltd., Eden Prairie, MN, USA). The resolution of the build layer was 0.028 mm, and the 3D printed vessel model was produced using acrylic resin (Vero). Following immersion in water for a few hours, the surface of the 3D printed model was smoothed by manually removing spicule.

2.3. Shaping of mandrel before the procedure (Video)

Prior to embolization, the mandrel was bent manually to the intended shape while referring closely to the vessel model. The shaped mandrel was then sterilized. During the procedure, the mandrel was used for steam shaping of the microcatheter. The 3D vessel models were also sterilized with plasma and used during the procedure. To avoid the potential risk of contamination with microparticles from the models, the 3D vessel models used for adjusting microcatheter shapes were placed in small, sterilized plastic bags. We were able to obtain the appropriate shape of the microcatheter using the 3D vessel models in all cases.

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2.4. Assessment of usefulness of the technique (Table 1)

The assisting to the procedure surgeons assessed the usefulness of the technique based on four criteria (Accessibility, Positioning, Stability, and Shape modifications). Using the same criteria for all operations, the assistants evaluated each procedure as “Good” or “Poor” for Accessibility, Positioning and Stability, and recorded whether any Shape modifications were necessary. Assistants were

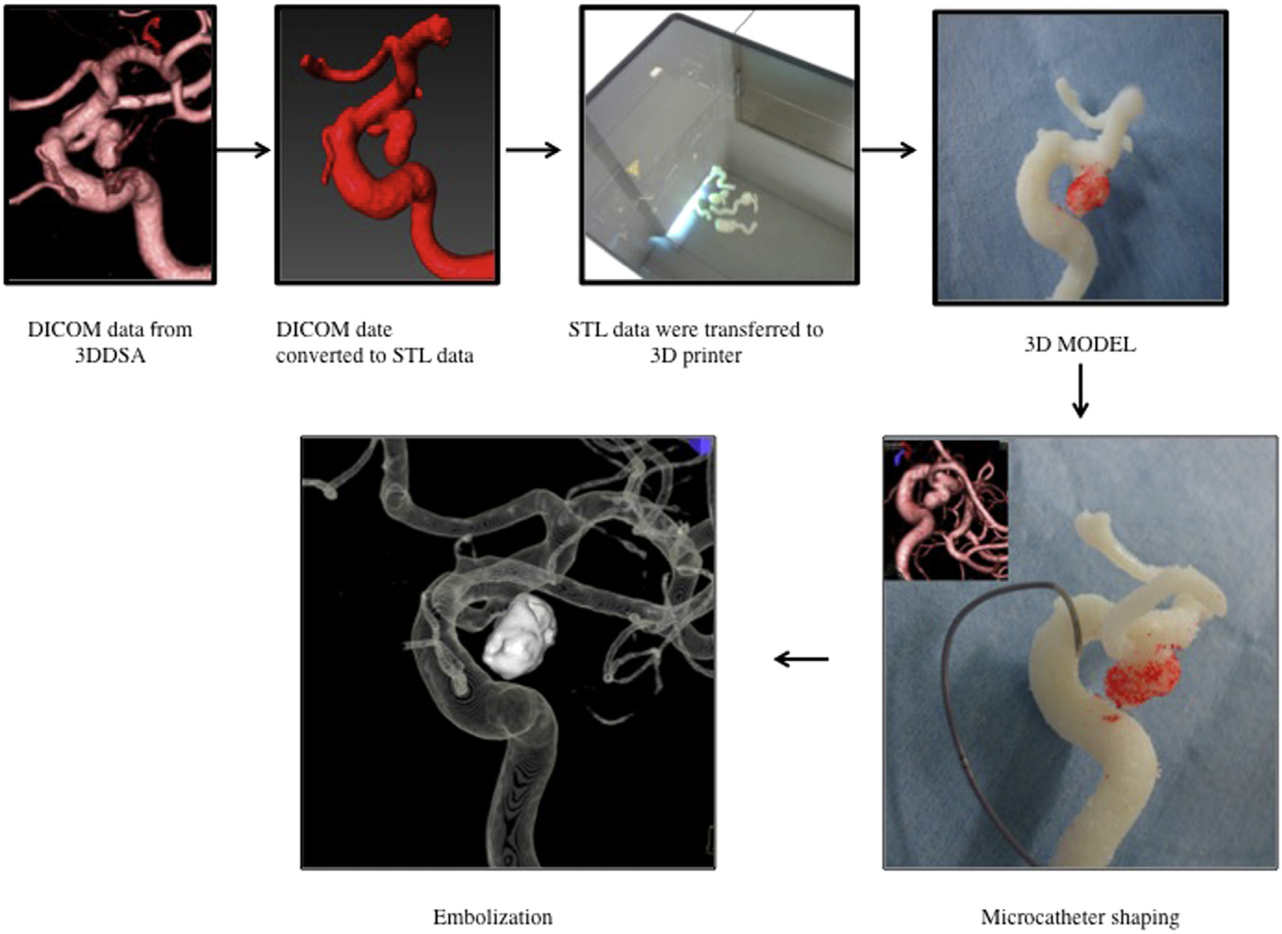

Fig. 1. Workflow to produce 3D vessel models used to shape microcatheters for endovascular coil embolization. 1. Data were obtained from 3D-DSA images. 2. DICOM data were converted to STL format. 3. STL data were transferred to a 3D printer. 4. A vessel model was printed using acrylic resin (Vero). 5. The microcatheter was shaped. 6. Embolization was performed using the inserted microcatheter.

blinded to the surgeon's opinion when performing the procedure. *Accessibility* refers to how easy it was to access the aneurysm (either ≤ 2 or more attempts). An attempt was considered the microcatheter maneuvering in the vascular segment of interest, before its significant withdrawal or re-insertion after re-shaping. *Positioning* refers to evaluation of the microcatheter tip position inside the aneurysms (achieving optimal or sub-optimal position of the catheter tip). *Stability* was rated based on the presence of unintended kickback during the procedure. Any factors leading to *Shape modifications* were noted. After the completion of each procedure, the operative assistants entered all relevant data on a special form.

Table 1
Assessment of microcatheter shaping.

Accessibility	Good	98%	Poor	2% (1cath)
Positioning	Good	96%	Poor	4% (2cath)
Stability	Good	96%	Poor	4% (2cath)

3. Results

A total of 48 microcatheters were shaped while referencing a corresponding 3D printed model. It took approximately 2–3 h to make the 3D printed vessel model from the 3D image processing. The microcatheters included Excelsior SL10® (Stryker, Kalamazoo, MI, USA) in 41 instances, Headway 17® (Microvention/Terumo, Tustin, CA, USA) in 4, Echelon 10® (Covidien, Irvine, CA, USA) in 2 and Excelsior 1018® (Stryker) in 1. Of the 48 catheters, only 9 (19%) required modification of their initial shape due to

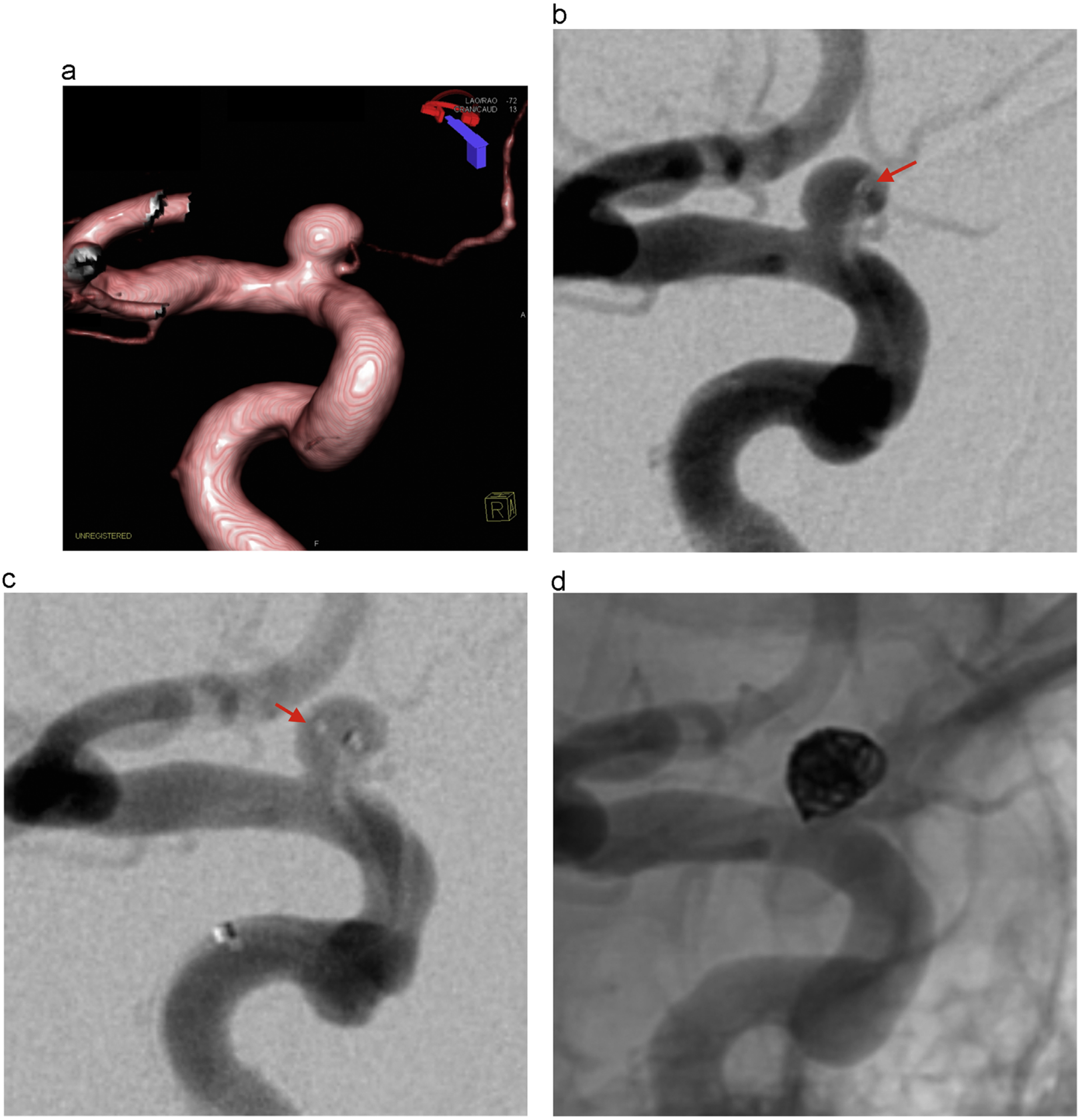

Fig. 2. Case presentation. An unruptured intracranial aneurysm was located at the right internal carotid artery-ophthalamic artery segment (a). After shaping microcatheters according to the model, they were easily navigated into the aneurysm, and positioning of the tips was appropriate for embolization. One microcatheter was navigated into the aneurysm (b), followed by a second (c). Coil embolization was successfully achieved with small neck remnant (d).

inappropriate positioning for coil deployment, re-shapings occasionally were done on more than one occasion for the same catheter particularly in “double catheter” technique. They were used for coiling of 7 aneurysms in 6 patients. There were no procedure-related complications, including aneurysm ruptures. The responses of assistants to the procedures on the questionnaire administered after the embolization were favorable (Table 1).

3.1. *Case presentation (Fig. 2)*

An unruptured intracranial aneurysm was detected in a patient during evaluation for headache. The 3.8-mm aneurysm, projecting superiorly, was located at the right ICA–ophthalamic artery segment (Fig. 2A). Although the aneurysm was small, it was a source of constant anxiety for the patient, who insisted on being treated. Microcatheter navigation is usually difficult in these types of aneurysms. A double microcatheter technique (Headway 17 and SL10) was employed. After shaping the microcatheters according to the model, they were easy to navigate into the aneurysm, and positioning of the tips was appropriate for embolization (Fig. 2B, C). There was no need for re-shaping. A total of five coils were deployed into the aneurysm, and coil embolization was successfully achieved with small neck remnant (Fig. 2D).

4. Discussion

Microcatheter shaping is a key factor for successful coil embolization of aneurysms. Most surgeons usually make the shape using 3D-DSA imaging on a computer screen. However, preparing precise microcatheter shaping is difficult because of the following two reasons.

The first one is the lack of information on depth on the two-dimensional computer screen, so surgeons cannot be able to imagine three dimensional structure of the vessel and the position of the microcatheter along that third dimension. The second one is that the surgeon may have difficulties in imagining the real route of the microcatheter into the parent artery. Because of that, microcatheter shaping usually depends on surgeon's experience. Therefore, a more appropriate shape can be achieved by using the precise measures and proportions of the parent vessel and aneurysm morphology on 3D printed vessel models.

4.1. *Technique and preparation time*

Using currently available 3D printers, the preparation time ranged between 1 h 30 min and 2 h 45 min based on the size and complexity of the aneurysm morphology. The technique is simple once the method for inputting data into the 3D printer is learned. However, while the technique can be applied to all unruptured intracranial aneurysms, it is still too time-consuming to be compatible with the urgent management required for ruptured aneurysms.

Recently Mashiko et al. [2] presented the usefulness of a 3D model for a cerebral aneurysm clipping simulation, and Kono et al. [3] reported preoperative simulations of endovascular treatment for cerebral aneurysms using a silicone model. Other researchers have also actively explored the use of simulations and 3D models for treatment of aneurysms [1,4]. While it previously took up to two weeks to create a silicone model, recent techniques [1] have reduced the time for model creation to two days (starting the day before surgery). If the 3D-DSA information is available, our method makes it possible to create a model inexpensively in just a few hours.

4.2. *Imagination*

Shaping of catheters is largely based on imagining the catheter floating in the vascular and aneurismal lumen under specific blood flow conditions in the vascular segment of interest. Often used for coil embolization, 3D-DSA images are useful for understanding aneurysm shape, neck and projection. Steam shaping of the microcatheter usually relies on the shaper’s ability to imagine the vascular segment of interest from the 3D-DSA image on the 2D screen. However, steam-shaped microcatheters are often not well adapted to the aneurysm and require re-shaping. Using a 3D vessel model, the surgeon can easily imagine the route of the microcatheter in the parent artery and the aneurismal cavity, which can make deployment easier.

4.3. *Value of the preoperative simulation of coil embolization*

Preoperative simulation with a model is useful, especially for large ICA aneurysms, where the proximal portion of the aneurysm neck has the tendency to become remnant since the microcatheter is difficult to navigate into that portion. In such situations, microcatheter shaping is a key factor for proper navigation.

4.4. *Sense of distance*

Proper estimation of distances is a merit of the 3D model. In shaping a catheter, the distance from the tip to the first bend is important. Measurements of this distance on 3D-DSA images often yields discrepancies compared with the actual vessel, and such discrepancies can lead to inaccurate shaping.

4.5. *Angle*

For the first five cases, a shaping mandrel was bent the day before the procedure and then sterilized and used during the procedure. However, at times the twisted mandrel could not be inserted easily into the microcatheter. Consequently, the 3D printed model was sterilized and used during the procedure for subsequent cases. Plasma sterilization was practical under these conditions.

4.6. *Limitations and future applications*

We shaped a microcatheter mandrel manually according to a solid 3D cast model. The shape of the microcatheter depends on the access route imagined by the endovascular surgeons. However, it is unclear whether the selected route is the most appropriate. Future computational simulations may yield optimal access routes. Another limitation of this technique is the time required for manually generating the STL file from DICOM data, which prevents the method from being used for coil embolization of ruptured aneurysms. Automating the data conversion process will greatly expedite creation of 3D vessel models. The proposed shaping method can be of great help to those learning neuroendovascular intervention. In the future, 3D printing of the mandrel will eliminate the need to manually shape the microcatheter, and skilled endovascular surgeons will be able to perform safer aneurysm coil embolizations.

Conflict of interest statement

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The other authors have no conflicts of interest to disclose.

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