Microcatheter Shaping for Intracranial Aneurysm Coiling Using the 3-Dimensional Printing Rapid Prototyping Technology: Preliminary Result in the First 10 Consecutive Cases

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■ OBJECTIVE: **An optimal microcatheter is necessary for successful coiling of an intracranial aneurysm. The optimal shape may be predetermined before the endovascular surgery via the use of a 3-dimensional (3D) printing rapid prototyping technology. We report a preliminary series of intracranial aneurysms treated with a microcatheter shape determined by the patient's anatomy and configuration of the aneurysm, which was fabricated with a 3D printer aneurysm model.**

■ METHODS: **A solid aneurysm model was fabricated with a 3D printer based on the data acquired from the 3D rotational angiogram. A hollow aneurysm model with an identical vessel and aneurysm lumen to the actual anatomy was constructed with use of the solid model as a mold. With use of the solid model, a microcatheter shaping mandrel was formed to identically line the 3D curvature of the parent vessel and the long axis of the aneurysm. With use of the mandrel, a test microcatheter was shaped and validated for the accuracy with the hollow model. All the planning processes were undertaken at least 1 day before treatment. The preshaped mandrel was then applied in the endovascular procedure. Ten consecutive intracranial aneurysms were coiled with the pre-planned shape of the microcatheter and evaluated for the clinical and anatomical outcomes and microcatheter accuracy and stability.**

■ RESULTS: **All of pre-planned microcatheters matched the vessel and aneurysm anatomy. Seven required no microguidewire assistance in catheterizing the aneurysm whereas 3 required guiding of a microguidewire. All of the microcatheters accurately aligned the long axis of the aneurysm. The pre-planned microcatheter shapes demonstrated stability in all except in 1 large aneurysm case.**

■ CONCLUSION: **When a 3D printing rapid type prototyping technology is used, a patient-specific and optimal microcatheter shape may be determined preoperatively.**

INTRODUCTION

To achieve complete coil occlusion of an intracranial aneurysm, a stable microcatheter position is the single most important factor (2, 5). A well-designed shape for the microcatheter is crucial in achieving this occlusion. To form the ideal shape on a microcatheter for coiling of an intracranial aneurysm, thorough understanding of the 3-dimensional (3D) anatomy of the access vessel and the axis of the aneurysm is required. In neuroendovascular surgery, 3D rotational angiogram has provided excellent aid in this. The 3D vessel image created and handled through the workstation has major advantage over the conventional angiogram in that it allows multiple arbitrary views of a vessel to aid in the better understanding of the complex anatomy. Despite the advantages of the 3D imaging technology, it is still difficult to understand the exact 3D anatomy of a vessel and an aneurysm, because the 3D image is paradoxically studied through a 2-dimensional (2D) computer, screen where a correct depth perception is difficult to achieve (10).

For a better understanding of the anatomy of the aneurysm and its access vessel, we fabricated patient-specific aneurysm models by using a 3D printer. Using these patient-specific

Key words
- Aneurysm
- Coiling
- Microcatheter shaping
- Rapid prototyping
- Three-dimensional printing

Abbreviations and Acronyms
2D: 2-dimensional
3D: 3-dimensional
ABS: Acrylonitrile-butadiene-styrene
ACoA: Anterior communicating artery
ICA: Internal carotid artery

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models, we pre-planned and validated the shape of the microcatheter for stability before the endovascular coiling. We describe our preliminary results of the accuracy, safety, and feasibility of using a patient-specific microcatheter made on 3D aneurysm model for coiling of an intracranial aneurysm.

METHODS

Patient Selection

This study was conducted in accordance with the Institutional Review Board policy. Ten consecutive patients undergoing elective endovascular coiling between April 2013 and December 2013 at our institution were included in this study. Informed consent was obtained from all patients. Ruptured, fusiform, and partially thrombosed aneurysms were excluded.

Because all the intracranial aneurysm coiling procedures were elective, fabrication of the 3D aneurysm models, microcatheter pre-planning, and validation were completed at least 1 day before the treatment.

Fabrication of 3D Solid and Hollow Aneurysm Models

Details of the 3D solid and hollow aneurysm model fabrication are described elsewhere (6). In summary, the Digital Imaging and Communication in Medicine data from the 3D rotational angiography were loaded to 3D visualization and measurement software (Amira; VSG, Burlington, Massachusetts, USA). The required artery segment was extracted and converted to a Standard Triangulated Language file (surface data as an aggregation of fine triangular meshes). An acrylonitrile-butadiene-styrene (ABS) 3D solid model was then fabricated with an UP! Plus 3D printer (OPT, Tokyo Japan). A 3D hollow aneurysm model was fabricated with use of the 3D solid model as a mold. A molding silicone (M8012; Asahi Kasei-Wacker Silicone, Tokyo, Japan) mixed with a hardening agent (4% volume base) was layered on the ABS 3D solid model. After solidification of the silicone, the ABS was liquefied by immersing the model in a xylene bath. The time required for manufacturing the model was 12–24 hours, and the cost of the material was about 150 JPY per each model. No discrepancies were observed among the 3D solid and hollow models and the original angiography.

Microcatheter Pre-planning

Using the sold 3D aneurysm model, we curved a microcatheter shaping mandrel to align the outer curve of the vessel (**Figure 1B–C**). All mandrels were shaped by an endovascular trainee (A.H.) under the supervision of the senior surgeon (K.N.). The curve was determined on the basis that the microcatheter courses along the outer curve of a given vessel (**Figure 1E–F**). Typically, 3 major curves proximal to the aneurysm were formed on the mandrel. For example, for a paraclinoid internal carotid artery (ICA) aneurysm, petrous-cavernous segment, ophthalmic segment, and ICA-aneurysm axis curves were reproduced on the mandrel (**Figure 1B–C** and **Figure 2**, *arrows*). The tip of the mandrel was 45 degrees overangulated (**Figure 2**, *curved arrow*) to the axis of the aneurysm (**Figure 2**, *dotted line*) to accommodate for catheter relaxation. Using the mandrel, we shaped a test Echelon 10 microcatheter (Covidien ev3, Irvine, California, USA) by steaming for 30 seconds.

Validation of the Pre-Planned Microcatheter Shape

The compatibility of the pre-planned microcatheter shape to the targeted aneurysm was tested with the 3D hollow aneurysm model. The 3D hollow aneurysm was catheterized with the pre-planned microcatheter and observed under fluoroscopy or visually inspected. The compatibility of the catheter shape was validated if the microcatheter tip aligned the long axis of the aneurysm (**Figure 1D**). After validation, the pre-planned mandrel was determined the shape for the procedure and was autoclaved for clinical use.

Endovascular Treatment

The technique for endovascular coil treatment has been previously described (1, 8). All cases were performed under general anesthesia via the use of high-resolution biplane digital subtraction angiogram. All patients were pretreated with 100 mg of aspirin and 75 mg of clopidogrel daily 2 weeks before the procedure and discontinued at 1 month after the procedure. All procedures were performed under systemic anticoagulation with heparin achieving activated clotting time over 250 seconds. Using the sterilized pre-shaped mandrel, we formed the pre-determined curve on an Echelon 10 microcatheter by steaming for 30 seconds except in patient 5. In this case, an Excelsior 1018 microcatheter (Stryker Neurovascular, Fremont, California, USA) was also used. After guiding catheter placement, the pre-shaped microcatheter was advanced into the aneurysm and was packed as densely as possible with coils of the surgeon's preference (K.N.). Adjunctive coiling technique such as balloon neck remodeling, double microcatheter, and balloon neck remodeling with double microcatheter were used as required. No stent-assisted coiling was performed in this series. Intravenous heparin at 500 IU/h was continued for 24 hours postoperatively. A complication was defined as any clinical adverse event related to the procedure. Immediate aneurysm occlusion was evaluated by use of the method reported by Roy et al. [(9) complete occlusion; residual neck; residual aneurysm]. Clinical outcome was assessed by the modified Rankin Scale at 1 month postprocedure follow-up in clinic.

Accuracy of the Microcatheter Shape

We hypothesized that an accurately shaped microcatheter will automatically select the targeted aneurysm and confer stability to the catheter throughout the coiling procedure. Accuracy of the microcatheter shape was evaluated by 2 parameters: the aneurysm catheterization method and microcatheter tip alignment with the long axis of the aneurysm.

Catheterization method was graded as follows: excellent: successful aneurysm catheterization with either antegrade or retrograde microcatheter shift; moderate: with microguidewire guiding; and poor: failed catheterization requiring reshaping. Microcatheter tip alignment was evaluated as accurate if the catheter tip aligned the aneurysm axis without alteration of the microcatheter shape.