Zirconia-Polyurethane Aneurysm Clip

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■ OBJECTIVE: **Susceptibility artifacts from metal clips in magnetic resonance (MR) imaging present an obstacle to evaluating the status of clipped aneurysms, parent arteries, and adjacent brain parenchyma. We aimed to develop MR-compatible aneurysm clips.**

■ METHODS: **Considering the mechanical and biologic properties, as well as MR compatibility of candidate materials, a prototype clip with a zirconia body and a polyurethane head spring (zirconia clip [ZC], straight, 9-mm long) was developed. The closing forces, opening width of blades, and in vitro and in vivo artifact volumes in 3 tesla MR imaging were compared among the prototype and commercial metal clips such as a Yasargil clip (YC, curved type, 8.3-mm long) and a Sugita clip (SC, straight type, 10-mm long). An in vivo animal study was performed with a canine venous pouch aneurysm model.**

■ RESULTS: **The closing forces (N) at 1 mm and 8 mm from the blade tip were 2.09 and 3.77 in YC, 1.85 and 3.04 in SC, and 2.05 and 4.60 in ZC. The maximum opening widths (mm) was 6.8, 9.0, and 3.0 in YC, SC, and ZC, respectively. The in vitro artifact volumes of YC, SC, and ZC in time-of-flight MR imaging were 26.9, 29.7, and 1.9 times larger than the respective real volumes. The in vivo artifact volumes of YC, SC, and ZC were respectively 21.4, 29.4, and 2.6 times larger than real ones.**

■ CONCLUSIONS: **ZC showed the smallest susceptibility artifacts and satisfactory closing forces. However, the narrow opening width of the blades was a weak point.**

INTRODUCTION

After surgical or endovascular treatments of cerebral aneurysms, imaging follow-up is important because subsequent treatment or follow-up plans can be made on the basis of the status of treated aneurysms. Typical imaging modalities include computed tomographic angiography, magnetic resonance angiography (MRA), and digital subtraction angiography (DSA). The effectiveness of imaging tools in evaluating treated aneurysms differs somewhat by treatment modality, considering magnetic resonance (MR) susceptibility artifacts caused by metal clips,[1,2] beam-hardening artifacts created by coils in computed tomography,[3,4] and some complications related to radiation, contrast, and invasiveness of DSA. Recently, there has been an increase in complex situations such as multiple aneurysms in a patient who was treated with surgical clipping for some aneurysms and coil embolization for the others, as well as remnant or recurring aneurysms that were retreated with the other modality.[5,6] In such situations, there is no choice but DSA for follow-up imaging. Thus we attempted to develop a new ceramic-polymer aneurysm clip with MR compatibility and

Key words
- Cerebral aneurysms
- Clips
- Polyurethane
- Susceptibility artifact
- Zirconia

Abbreviations and Acronyms
CCA: Common carotid artery
DSA: Digital subtraction angiography
GRAPPA: Generalized autocalibrating partially parallel acquisition
ICG: Indocyanine green
MR: Magnetic resonance
MRA: Magnetic resonance angiography
MRI: Magnetic resonance imaging
PDMS: Polydimethylsiloxane
SC: Sugita clip
TOF: Time-of-flight
T2WI: T2-weighted imaging
YC: Yasargil clip
ZC: Zirconia clip

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mechanical properties comparable with those of conventional metal clips in order to minimize the imaging artifact and complications related to radiation, contrast, and invasiveness.

METHODS

Preparation of Raw Materials for Ceramic-Polymer Clip

Commercial 3 mol% Y_2O_3-stabilized ZrO_2 (TZ-3Y-E grade, Tosoh, Tokyo, Japan) and TiO_2 (Titanium [IV] oxide, purity >98%, anatase form, Kanto Chemical, Tokyo, Japan) were used as raw ceramic materials for the clip blade. Both ZrO_2 and TiO_2 powder were placed in a cylindrical die of 11-mm diameter and pressed with 2000 psi of pressure for 10 minutes to fabricate a disk-shaped pellet of 2-mm thickness. To achieve higher packing density, both pellets were subjected to cold isostatic pressing at 200 MPa. The green compacts were carefully placed into an Al_2O_3 crucible and sintered in a convection furnace under an air atmosphere at 1450°C for 4 hours with a heating rate of 5°C/minute. Polyurethane and polydimethylsiloxane (PDMS) were selected as candidates for the polymer head spring.[7,8] Both polyurethane (Aidmer 78-185, Aidmer, Guandong, China) and PDMS (Yuil Tech., Daegu, Korea) sheets of 2-mm thickness were cut with a cylindrical metal punch of 11-mm diameter to fabricate disk-shaped specimens of 11-mm diameter. Both the polyurethane and PDMS sheets were pressed in metal molds with 1200 psi of pressure for 5 minutes at room temperature.

Design of Ceramic-Polymer Clip

The precise design of the aneurysm clip body and head spring was completed using solid modeling computer-aided design software (SolidWorks Corp., Waltham, Massachusetts, USA). The design mimicked that of the commercial 8.3-mm titanium Yasargil clip (YC; FT750T, Aesculap, Inc., Pennsylvania, USA). The total length of the ceramic-polymer clip was designed as 19.4 mm, the same length as YC. It was 1.5 mm wide, which was 0.5 mm thicker than the YC. The clip design was divided into 2 parts: blades and head spring. The blade length of the ceramic-polymer clip was set to 9 mm. The head size of the spring part was set to 6 mm to ensure visibility during the operation. To prevent the polymer spring from detaching, the inside part of the blade leg was designed in a rugged shape. The polymer spring was designed in 4 different shapes: hollow cube, moon, S, and I (**Figure 1**).

A YC (No. = FT752T [curved type, 8.3 mm long]; Aesculap, Inc., Center Valley, Pennsylvania, USA) and a Sugita clip (SC; No. = 07-940-02 [straight type, 10 mm long]; Mizuho Medical Co., Tokyo, Japan) were used as controls. The YC and SC were manufactured with a titanium alloy (Ti-6Al-4V) and a cobalt-chrome alloy (Co-Cr-Ni-Mo-Fe), respectively.[7-10]

Measurement of Closing Forces and Opening Width

The aneurysm clip and different shapes of the polymer spring were machined so that their closing force could be measured. After the design of the clip was finished, clips with an array of ceramic blade body components were machined using a high-precision laser cutting system for nonmetallic materials (VLS4.60, Universal Laser Systems, Scottsdale, Arizona, USA). A total of 8 different shapes of polyurethane and PDMS springs were machined using metal molds. The appropriate shapes of metal mold were prepared, and the polymer sheets

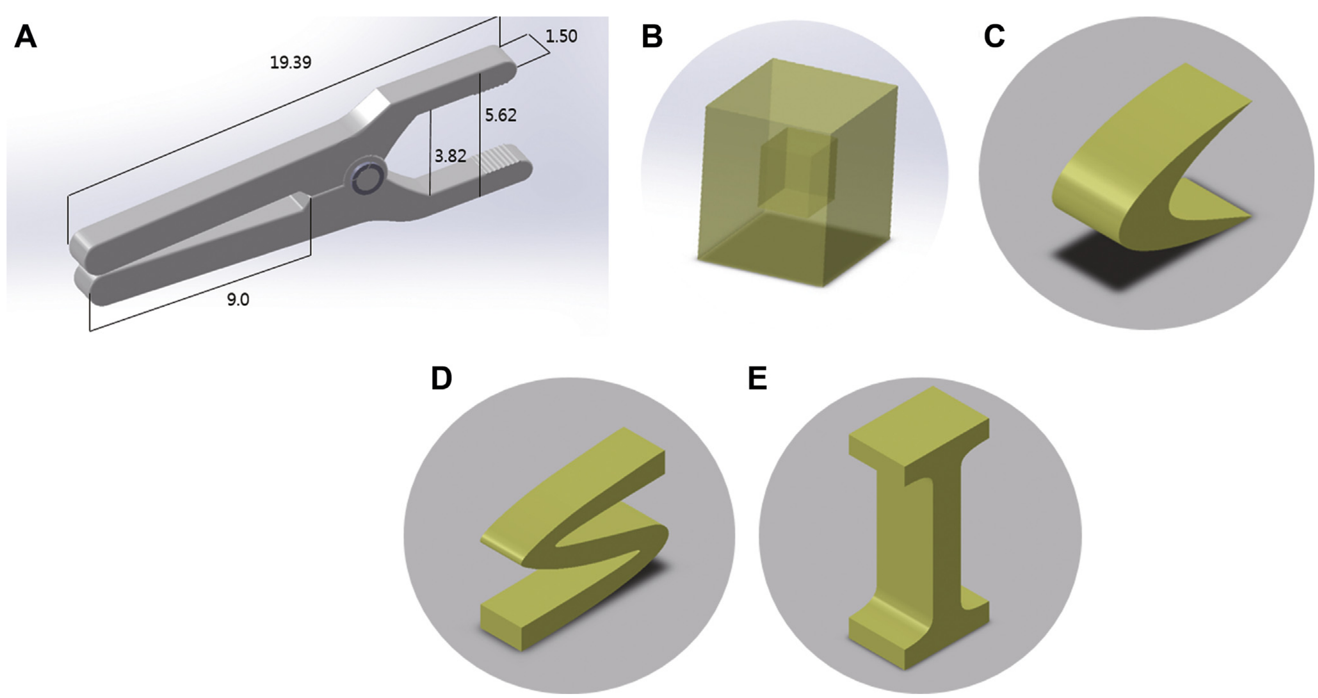

Figure 1. Design of the novel aneurysm clip including clip body (**A**) and head spring (**B**, hollow cube shape; **C**, moon shape; **D**, S shape; **E**, I shape).