DEVELOPMENT OF CEREBRAL ANEURYSM COILS WITH EQUIVALENT VOLUME MAGNETIC SUSCEPTIBILITY TO BODY TISSUE THAT GENERATE SMALL SUSCEPTIBILITY ARTIFACTS IN MRI

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Introduction: Embolization procedures using platinum-tungsten (Pt-W) coils are widely used for treatment of cerebral aneurysms. However, some parts of the normal parent vessel (the normal blood vessel in which the cerebral aneurysm occurred) may not be displayed in MRI due to metal artifacts. Conversely, the aneurysm may appear to be occluded with the MRI, despite a residual aneurysm caused by an incompletely inserted coil. To remedy these problems, we developed aneurysm coils made of a gold-platinum (Au-Pt) alloy, for which the magnetic susceptibility is the same as that of human tissue.

Material & Methods: The magnetic susceptibility of human tissue fluctuates around the magnetic susceptibility of water (-9.05 ppm) according to the water content of the tissue. Therefore, a target magnetic susceptibility of -9 ppm may be appropriate for an artifact-free metal. However, few individual metals exhibit magnetic susceptibility close to -9 ppm and fewer still offer the non-toxicity, high corrosion resistance, and good mechanical properties that are demanded for medical device materials. Therefore, it is necessary to create an alloy that satisfies these conditions. From among the diamagnetic metals, we selected Au as a metal that should offer high biocompatibility and good mechanical properties, and created an Au-Pt alloy. Coils of this alloy were produced for use in cerebral aneurysm coil embolization procedures. MRI compatibility tests (ASTM F2052 [1], F2182 [2], F2213 [3]) of the Au-Pt aneurysm coil were performed based on US FDA standards and normal mechanical properties testing. All MRI experiments were performed on a 1.5T whole body MRI scanner (Magnetom Sonata, Siemens AG, Erlangen, Germany, maximum amplitude: 40 mT/m, slew rate: 200 mT/m/msec) and a CP head array coil. After first evaluating artifact size using a vascular phantom, the effect on blood vessel signals was evaluated in vivo using the abdominal aorta of rabbit. The vascular phantom was attached to aneurysm models made with silicone and produced blood flow (Fig. 1). The aneurysm model was then embolized with a Pt-W or Au-Pt aneurysm coil. The imaging protocol in the phantom study consisted of a spin echo sequence (TR: 500 ms, TE: 20 ms, pixel size: 0.5 × 0.5 mm, thickness: 2 mm, bandwidth: 125 Hz/pixel, Averages: 2) and gradient echo sequence (TR: 250 ms, TE: 15 ms, pixel size: 0.4 × 0.4 mm, flip angle: 30 deg., thickness: 2 mm, bandwidth: 130 Hz/pixel, Averages: 2) required for US FDA artifact evaluation (ASTM F2119 [4]) and 3D TOF acquisition (TR: 40 ms, TE :7.15 ms, pixel size: 0.4 × 0.4 mm, flip angle: 25 deg., thickness: 0.8 mm, bandwidth: 65 Hz/pixel, Averages: 1) with blood flow. The artifact size was measured using in-house software. In the in vivo study, the aneurysm model was attached to the rabbit abdominal aorta and images were obtained using 3D TOF acquisition (TR: 41 ms, TE: 9.21 ms, pixel size: 0.19 × 0.19 mm, flip angle: 25 deg., thickness: 0.8 mm, bandwidth: 65 Hz/pixel, Averages: 1). The artifact was evaluated using a MIP image created from scanned images.

Results: Tensile strength and breaking strength of the new Au-Pt aneurysm coil were approximately equivalent to those of the conventional Pt-W coil. The MRI compatibility (magnetically induced displacement force, magnetically induced torque, radiofrequency induced heating) of the Au-Pt aneurysm coil was confirmed. An image of the aneurysm model scanned using a gradient echo sequence in the phantom experiment is shown in Fig. 2. Artifacts were smaller with the Au-Pt aneurysm coil in all imaging sequences. A MIP image created from scanned images in the in vivo study is shown in Fig. 3. With the conventional Pt-W aneurysm coil, there was a partial absence of the vascular signal of the rabbit abdominal aorta, but this problem did not occur with the Au-Pt aneurysm coil. These results show that use of the Au-Pt coil results in a smaller susceptibility artifact than that obtained with the Pt-W coil, and suggest that the Au-Pt coil may allow a more precise observation of the status of a cerebral aneurysm embolus using MRI.

Discussion & Conclusion: Endovascular surgery under various types of fluoroscopy has become common in recent years. However, radiation exposure of patients cannot be avoided in fluoroscopy and a shift to use of MRI in endovascular surgery is desirable. In this investigation, we produced embolization coils from an Au-Pt alloy and showed that they significantly reduced the generation of artifacts in comparison with currently used coils. We believe that the new Au-Pt coils will prove to be extremely effective for endovascular surgery under MRI, which is likely to become more common in the future.

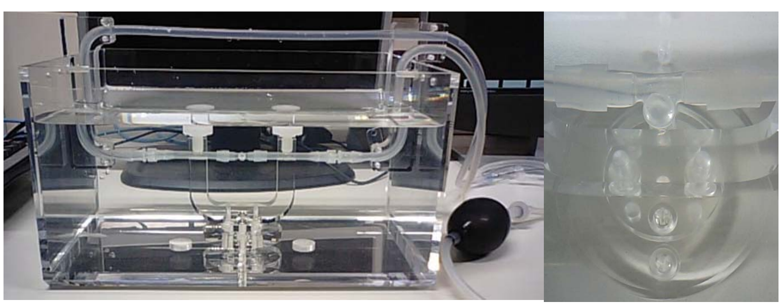

Fig.1. The vascular phantom was attached to aneurysm models made with silicone.

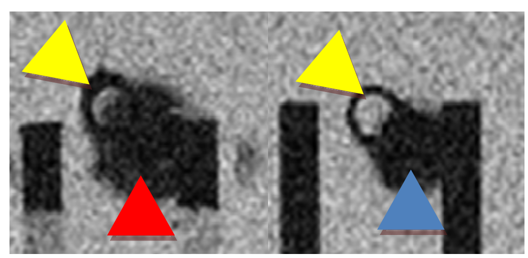

Fig. 2. In vitro testing. MRI (gradient-echo) evaluation of a Pt-W and Au-Pt coil filling an arterial embolization model. Compared to the Pt-W coil (red), the Au-Pt coil (blue) exhibits less artifact in the arterial embolization model and less encroachment inside the silicone tube (yellow).

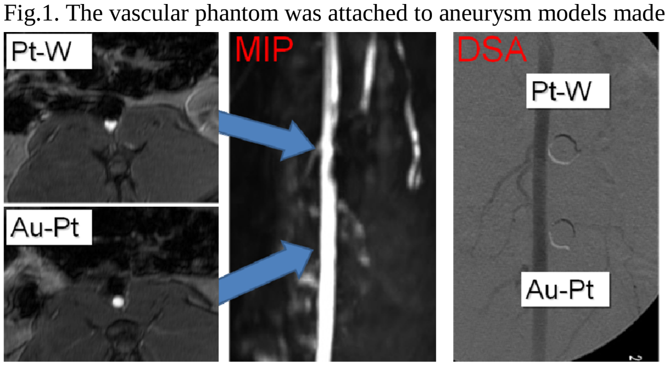

Fig. 3.
In vivo testing. TOF-MRA evaluation of aneurysm embolization models using a Pt-W and Au-Pt coil sewn onto a rabbit abdominal aorta. The angiography image (right) confirms placement of the Pt-W coil and Au-Pt coil on the rabbit abdominal aorta. The left images show the abdominal aorta and aneurysm embolization model cross-section. A MIP image (center) confirms loss of blood vessel signal due to artifacts adjacent to the Pt-W coil only. No artifact effects were observed adjacent to the Au-Pt coil.

References: [1] ASTM F2052, Annual Book of ASTM Standards, Vol. 13.01. [3] ASTM F2213, Annual Book of ASTM Standards, Vol. 13.01.
[2] ASTM F2182, Annual Book of ASTM Standards, Vol. 13.01. [4] ASTM F2119, Annual Book of ASTM Standards, Vol. 13.01.