Metal artifact removal
In c-arm cone-beam ct

Group 4
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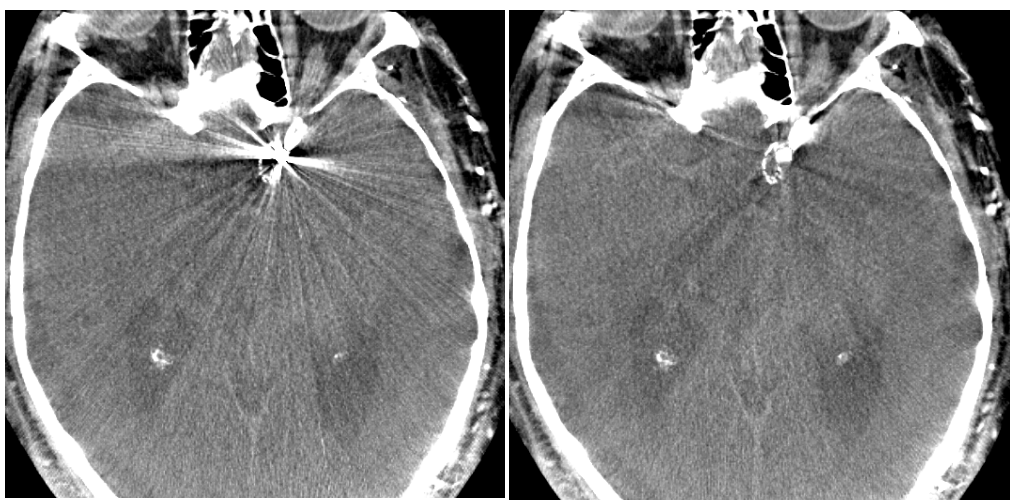
Report #3
Phantom Construction and Image Acquisition



CT image of coil before and after MAR algorithm application
Image provided by Radvany, MD

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Neurovascular interventions of diseases such as aneurysms, intracranial stenosis and arteriovenous malformations (AVMs) include the use of clips, coils, stents and other metal-based materials, and depend on 3D computer tomographic (CT) imaging acquisition in the surgical environment. The presence of these dense metals cause streaking artifacts and degradation of the image quality in the acquired CT images. Construction of various brain imaging phantoms that emulate various endovascular interventional procedures used in the treatment of aneurysms (e.g. endovascular coiling, stent-assisted endovascular coiling, and aneurysm clipping), comprised of the various metal objects (e.g. coils, clips, and embolization agents), simulated contrast vasculature and simulated soft-tissue inserts, will provide CT imaging data for a quantitative analysis and assessment of image quality and MAR algorithm segmentation accuracy.

I. Introduction

Artifacts arising from stents, coils and clips currently challenge C-arm cone-beam CT (CBCT) guidance of neurovascular interventions. Metal artifact removal algorithms (MAR) that diminish such artifacts for improved guidance and verification have been newly developed. To evaluate the performance of such algorithms, preclinical studies of an anthropomorphic head phantom emulating three endovascular interventions for the treatment of intracranial aneurysms were conducted using a robotic C-arm (Zeego, Siemens) for 3D CT imaging. Considerations for accurate simulation of clinical cases included: size and location of aneurysms, properties of metal components used in interventional procedures and accurate portrayal of surrounding soft-tissue vasculature.

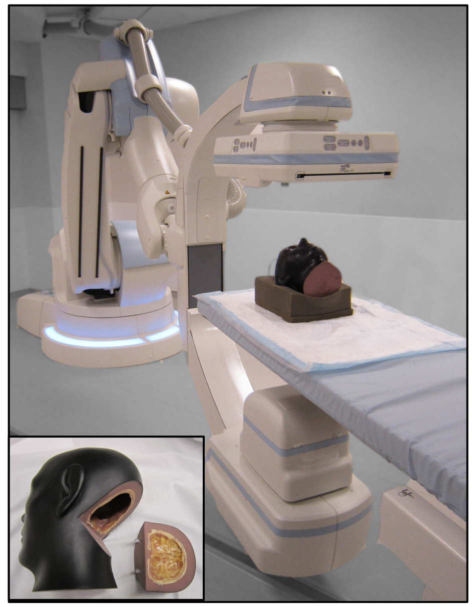
Both ruptured and unruptured aneurysms are typically located in the anastomotic system of arteries that sits at the base of the brain, known as the Circle of Willis. The most common sites for unruptured aneurysms (in order) are: middle cerebral artery (MCA), posterior communicating artery (PCoA), anterior communicating artery (ACoA), and cavernous internal carotid artery (ICA). The abovementioned arteries reside in the cerebral arterial circle. The mean size of ruptured aneurysms is 10.8 mm, while the mean size of unruptured aneurysms is 7.8 mm. Aneurysm sizes may range from less than 3 mm to greater than 25 mm.[1]

Endovascular treatments for intracranial aneurysms include: stent-assisted endovascular coiling, microsurgical clipping and endovascular embolization. Coils used in endovascular coiling procedures are typically made of flexible platinum (stainless steel coils are also available, but less common) and are shaped like thin springs. The coil conforms to the aneurysm shape and seals of the opening of the aneurysm. Depending on the size of the aneurysm, more than one coil may be needed to completely conform and seal off the aneurysm. About 33-37% of the spherical volume the coil forms when inside the aneurysm is metal.

Stents used in stent-assisted coil embolization are self-expanding stents made typically of nitinol; a nickel and titanium metal alloy. During a stent-assisted embolization, a thin wire (embolic coil) is threaded through a catheter into the affected area of the brain in order to fill the weakened portion of the vessel. Due to anatomic features, including wide necks and incorporation of important branches, endovascular coiling using stent assisted embolization proves a more successful method of treatment.

[1] **WEIR, Bryce, M.D., et. al.,** "Sizes of ruptured and unruptured aneurysms in relation to their sites and the ages of patients" Journal of Neurosurgery, 96 (2002): 64-70. Print.

Clips used in microsurgical clipping are typically made of titanium. Aneurysm clipping consists of isolating the aneurysm from normal blood circulation without blocking any of the small perforating arteries nearby. It is an invasive procedure; a craniotomy and retraction of brain matter is needed to locate the aneurysm and place the clip across the base, or neck. The blades of the clip remain tightly closed; they remain on the artery permanently.



Non-adhesive liquid embolic agents are used for endovascular embolization of intracranial aneurysms. The material is an ethylene vinyl alcohol copolymer dissolved in the organic solvent dimethyl sulfoxide (DMSO) opacified with tantalum powder. Once coming into contact with an ionic solution the DMSO dissipates and the material solidifies into a spongy, cohesive material.

The hollow anthropomorphic head phantom used for the simulation of these procedures consisted of a natural human skeleton in tissue-equivalent plastic (The Phantom Laboratory, Greenwich, NY). An opening at the posterior base of the skull allowed the intracranial space to be filled with brain-equivalent gelatin, relevant soft-tissue simulating plastics, prototype vasculature and metal components.

All scans were performed on a C-arm cone-beam Axiom Artis Zee (Axiom Artis Zeego, Siemens Medical Solutions, Elangen, Germany) with a flat panel detector. Standard DynaCT head acquisition were obtained involving the following parameters: 70 kV, 20 second rotation, ~235 mA tube current, 0.4° increments, 496 frames, ~30 frames/s, and a ~8000 μGym^2 dose area product.

II. First Stage Phantom: Metal Spheres

The first stage phantom incorporated metal spheres of different diameters and attenuation properties, as well as various plastic spheres that provided a range of relevant contrasts in neurovascular imaging, if not a one-to-one, exact simulation of low-contrast brain tissues. Metal spheres were the simplest materials to simulate both the shape and sizes of coiling spheres and the composition of the different metallic objects used in endovascular procedures.

Surrounding vasculature components

The following twelve plastic spheres were inserted in the brain-equivalent gelatin: two polypropylene, two low-density polyethylene, two high-density polyethylene, two acrylic, two nylon, and two acetal. The plastic spheres were placed in two parallel z-axis planes, six spheres on each plane. Their placement was not of utter importance; their primary use was to measure the HU units of the spheres and determine the relevant soft tissue (CSF, white or grey matter, etc.) they approximated.

Material	HU units (approximations)	Simulated neurovascular tissue
Polypropylene	-100	Fat
Low-density polyethylene	+10	CSF
High-density polyethylene	+40	Grey/white matter
Acrylic	+100	High-contrast agent
Nylon	> 100	High-contrast agent
Acetal	> 100	High-contrast agent

Metal Object Components

Aneurysm located in the cerebral arterial circle have diameters that range from less than 3 mm to greater than 25 mm; the mean of unruptured aneurysms being around 8 mm. Materials used for coils, stents, clips and liquid embolus include platinum, titanium, stainless steel and nitinol. In order to accurately simulate the clinical case of intracranial aneurysm coiling and embolization, three diameters and three materials of metal spheres were used: 3.2 mm, 6.4 mm, and 12.7 mm in spheres of titanium, steel and tungsten.

More Specifically, nine metal spheres were used in the imaging phantom: three titanium grade 5 spheres of diameter 3.2 mm, 6.4 mm and 12.7 mm each, three 316 resistant stainless steel spheres of diameter 3.2 mm, 6.4 mm and 12.7 mm each, and three tungsten carbide spheres of diameter 3.2 mm, 6.4 mm and 12.7 mm each. Note that tungsten, atomic number Z = 74, is used as a substitute for platinum, atomic number Z = 78, due to their similar attenuation properties. All metal spheres were acquired from McMaster-Carr®.

Material of metal spheres	Simulated metal object	Color coding
Titanium	Titanium clips / nitinol stents	Red
316 Stainless Steel	Steel coils	Green
Tungsten Carbide	Platinum coils	Blue

Method

The plastic spheres were introduced into the semi-hardened brain-equivalent gelatin pre-image acquisition. During image acquisition, the metal spheres were inserted and removed from the intracranial cavity individually. In order to achieve this, they were attached to a plastic rod and inserted with lubrication, so as not to introduce air into the gelatin, as close to the clivus and stella as possible in order to approximate real-case scenarios of common intracranial aneurysm location. The phantom head was stabilized and held constant throughout the experiment. Careful consideration of the positions of the plastic spheres was taken as to not re-position them. 29 total images of varying phantom configurations were taken.

Note that the 12.7 mm tungsten sphere detached from the plastic rod. It had to be further introduced into the phantom; its final location was in the anterior part of the frontal lobe.

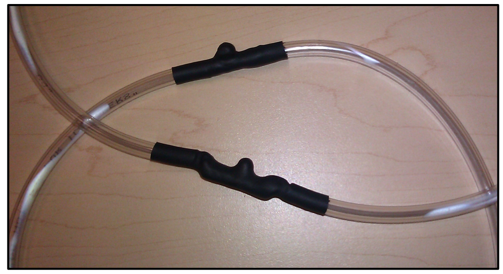
The experimental steps and image acquisition up to the 14th image needed to be repeated due to data truncation (loss of information). The field of view was successfully adjusted. Members present in the acquisition were: Jeffrey Siewerdsen, Marty Radvany, Adam Wang, Carolina Cay and Marta Wells. Following are the images taken and notes regarding the process:

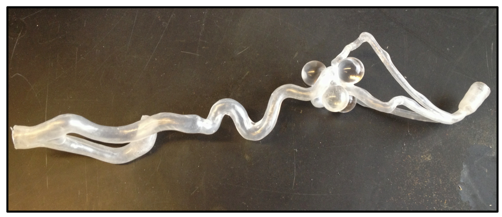
Image Number	Metal Components (color coding)	Notes
1	No metal spheres	Control (v.1): 12 plastic spheres in various locations.
2	3.174 mm, steel (small green)	
3	3.174 mm, tungsten (small blue)	
4	3.174 mm, titanium (small red)	
5	6.35 mm, steel (medium green)	
6	6.35 mm, tungsten (medium blue)	
7	6.35 mm, titanium (medium red)	
8	12.7 mm steel (large green)	
9	12.7 mm tungsten (large blue)	Sphere detached from plastic insertion rod, was inserted further into phantom.
10	12.7 mm titanium (large red)	Includes the 12.7 mm tungsten positioned in frontal lobe.
11	No metal spheres	Control (v.2): 12 plastic spheres in various locations and 12.7 mm tungsten in frontal lobe
12	3.174 mm, titanium (small red) & 3.174 mm, steel (small green)	Patient right & patient left, respectively.
13	3.174 mm, steel (small green)	Image acquisition aborted. Data truncation was noted on all previous images. Field of view (FOV0 corrections were made.
14	3.174 mm, steel (small green)	
15	3.174 mm, tungsten (small blue)	
16	3.174 mm, titanium (small red)	
17	6.35 mm, steel (medium green)	
18	No metal spheres	Control (v.2): 12 plastic spheres in various locations and 12.7 mm tungsten in frontal lobe.
19	6.35 mm, tungsten (medium blue)	
20	6.35 mm, titanium (medium red)	
21	12.7 mm steel (large green)	
22	12.7 mm titanium (large red)	
23	3.174 mm, titanium (small red) & 3.174 mm, steel (small green)	Patient right & patient left, respectively.
24	3.174 mm, titanium (small red) & 3.174 mm, steel (small green)	3.174 mm, steel (small green) adjusted ~5mm to position both spheres in same plane.
25	3.174 mm, tungsten (small blue) & 3.174 mm, steel (small green)	Patient right & patient left, respectively.
26	3.174 mm, tungsten (small blue) & 3.174 mm, steel (small green)	Adjusted to position both spheres in same plane.
27	3.174 mm, tungsten (small blue) & 3.174 mm, titanium (small red)	Patient right & patient left, respectively. Spheres noted to be slightly out of plane.
28	3.174 mm, tungsten (small blue) & 3.174 mm, titanium (small red)	Adjusted to position both spheres in same plane.
29	3.174 mm, tungsten (small blue) & 3.174 mm, titanium (small red)	Adjusted to position both spheres highly out of plane.

III. Second Stage Phantom: Stent-Assisted Endovascular Coiling

The second stage phantom incorporated an aneurysm vessel model, plastic spheres with contrast that approximates the simulation of blood clots, surgical coils and stents. The varying acquisitions included the use of a non-enhanced saline solution and a contrast-enhanced iodine solution. All model materials simulated relevant soft-tissues and instruments found in an interventional angiographic stent-assisted endovascular coiling procedure.

Simulated Vessel and Surrounding Tissue Components





A preliminary testing vasculature vessel model was developed from 6.4 mm diameter vinyl plastic tubing and heat-shrinkable plastic material. A 3.2 mm plastic sphere and heat-application were used to mold an aneurysm shape into the shrinkable material. The preliminary model was not used in any phantom testing.

A 3D vascular tree aneurysm vessel model was acquired from Vascular Simulations. Four High-density Polyethylene plastic spheres were placed adjacent to the aneurysm vessel model to simulate blood clots. Six High-density and Low-density Polyethylene rods were placed in the surrounding tissue to simulate non-contrast enhanced blood.

Iodine contrast and x-ray angiography is used in stent-assisted endovascular coiling to quantify blood flow and to map the vessel anatomy. In clinical cases, the cardiovascular system filters and dilutes the iodine before it reaches the cerebral arterial circle. In the presented phantom model, an ideal concentration of iodine (mgI/mL) was found such that it would produce a contrast attenuation of about 1100-1200 HU. In order to find the correct iodine dilution, a phantom was created that contained: six solutions of different iodine contrast agent (Omnipaque) concentrations (100, 75, 50, 20, 10, and 0 mgI/mL) placed in a simple cylinder phantom along with seven unidentified plastic rods.

Metal Object Components

In a clinical case of stent-assisted endovascular coiling procedure, a thin guide wire is threaded through a catheter into the affected area of the brain and a stent is deployed in order to fill the weakened portion of the vessel. Components used in this phantom coiling include: 0.36mm diameter Neuro Guide Wire (XXXX), 0.75 mm diameter infusion catheter (XXXX), 4.50 mm diameter stent (DePuy, Codman), 12mmx42cm Resistant Coil (XXXXX, DePuy), 8mmx20cm Resistant Coil (BXXXXX, DePuy), and 7mmx16cm Resistant Coil (XXXXD, DePuy).

Method

Two 6.35mm diameter holes were drilled in the anthropomorphic phantom skull pre-image acquisition. One hole was positioned superior-anterior XXXX, the other inferior-posterior XXX; locations were chosen for vessel accessibility advantages. The vasculature tree aneurysm model was placed such that the superior opening exited the superior-anterior XXX hole, while the inferior opening exited the inferior-posterior holeXX. The three HDP and three LDP plastic rods were then placed in the hardening gelatin surrounding the vasculature tree (careful consideration taken so as to not introduce air). A 30mgI/mL iodine solution was prepared for contrast-enhanced precedures. During image acquisition, a 4 mm diameter

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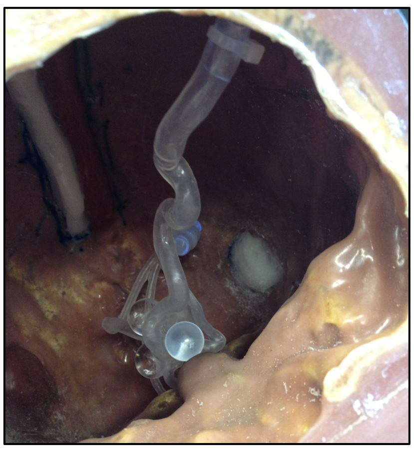
Hemostasis Introducer and an 8 Fr. Introducer sheath were placed in the superior-anterior opening of the phantom to create a seal. The phantom was placed in a prone position, opposite normal L-R orientation. Tubing of inferior-posterior opening was kept clamped and out of the FOV during procedures. A volume of 180 mL proved to be enough to displace the solution inside the phantom. Equipment was flushed with the solution inside the phantom previous to introduction to ensure non-dilution.

Note that the first stent deployment was unsuccessful due to the incompatibility in size between the stent delivery system and the infusion catheter. The catheter was replaced and a new stent system was deployed. Iodine contrast needed to be heated in order to activate the stent deployment. The second stent deployment was successful.

Although 3 coils were introduced, the aneurysm was not fully coiled. Clinician estimates that approximately 50% of the aneurysm volume was successfully coiled. Members present in the acquisition were: Marty Radvany, Adam Wang, Carolina Cay and Marta Wells XXXX . Following are the images taken and notes regarding the process:



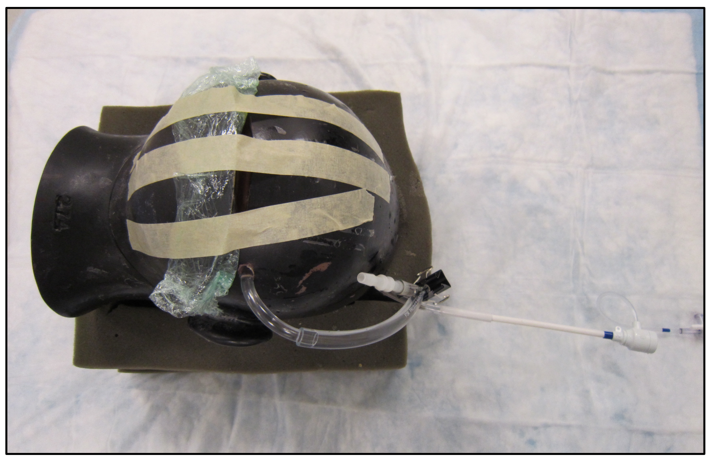


Image Number	Components	Notes
1	Non-contrast distilled water in vessel	Control Image
2	30mgI/mL iodine contrast in vessel	
3	30mgI/mL iodine contrast in vessel, 0.36mm Neuro Guide Wire	Image used to verify position of wire in relation to aneurysm
4	30mgI/mL iodine contrast in vessel, 0.36mm Neuro Guide Wire, 0.75 mm infusion catheter	Image used to verify position of catheter in relation to aneurysm
5	30mgI/mL iodine contrast in vessel, 0.36mm Neuro Guide Wire, 0.75 mm infusion catheter, 4.50 mm stent	Previous catheter replaced by new 0.95 mm infusion catheter in order to load stent. Image used to verify stent deployment
6	30mgI/mL iodine contrast in vessel, 0.36mm Neuro Guide Wire, 0.75 mm infusion catheter, 4.50 mm stent	
7	Non-contrast water in vessel, 0.36mm Neuro Guide Wire, 0.75 mm infusion catheter, 4.50 mm stent	
8	30mgI/mL iodine contrast in vessel, 0.36mm Neuro Guide Wire, 0.75 mm infusion catheter, 4.50 mm stent, 18 Stretch Resistant Coil (12mmx42cm)	
9	30mgI/mL iodine contrast in vessel, 0.36mm Neuro Guide Wire, 0.75 mm infusion catheter, 4.50 mm stent, 18 Stretch Resistant Coil (12mmx42cm), 14 Stretch Resistant Coil (8mmx20cm), 10 Stretch Resistant Coil (7mmx16cm)	
10	Non-contrast water in vessel, 0.36mm Neuro Guide Wire, 0.75 mm infusion catheter, 4.50 mm stent, 18 Stretch Resistant Coil (12mmx42cm), 14 Stretch Resistant Coil (8mmx20cm), 10 Stretch Resistant Coil (7mmx16cm)	
11	Non-contrast water in vessel, 18 Stretch Resistant Coil (12mmx42cm), 14 Stretch Resistant Coil (8mmx20cm), 10 Stretch Resistant Coil (7mmx16cm)	Stent, wire and catheter removed
12	30mgI/mL iodine contrast in vessel, 18 Stretch Resistant Coil (12mmx42cm), 14 Stretch Resistant Coil (8mmx20cm), 10 Stretch Resistant Coil (7mmx16cm)	

Detailed list of materials used in procedure (no specific order): NEED BRANDS!!!!

(3) Three-way stopcock with rotating adaptor
(3) Rotating Y-connector
(1) 4.00 mm Hemostasis introducer
(1) 8 Fr. Introducer sheath
(1) Delivery microcatheter (0.635mm)
(1) Neuro Guide Wire (0.36mm)
(1) Guide wire with hydrophilic coating (0.36mm)
(1) 0.75mm Infusion catheter
(1) 0.95mm Infusion catheter
(2) 4.5mm Codman stents
(1) 18 Stretch Resistant Coil
(1) 14 Stretch Resistant Coil
(1) 10 Stretch Resistant Coil

IV. Third Stage Phantom: Surgical Clipping

Simulated Vessel and Surrounding Tissue Components

Metal Object Components

Method

V. Fourth Stage Phantom: Liquid Embolization

Simulated Vessel and Surrounding Tissue Components

Metal Object Components

Method

Actual Schedule

MAR project milestones	Date	Notes
Project selection	2/09	
Clinical and technical background research	2/10-2/16	
First stage phantom construction	2/21	
Image acquisition of first phantom in Zeego (C-arm Cone-Beam CT)	2/28	
Calibration of Zeego (C-arm Cone-Beam CT)	03/19	
Reconstruction and application of MAR algorithm to first phantom images	03/20	
Iodine phantom construction	03/21	
Image acquisition of iodine phantom in Zeego	03/29	
Image acquisition of second phantom in Zeego	04/05	
Reconstruction and application of MAR algorithm to second phantom images	04/08	
Third stage phantom construction		