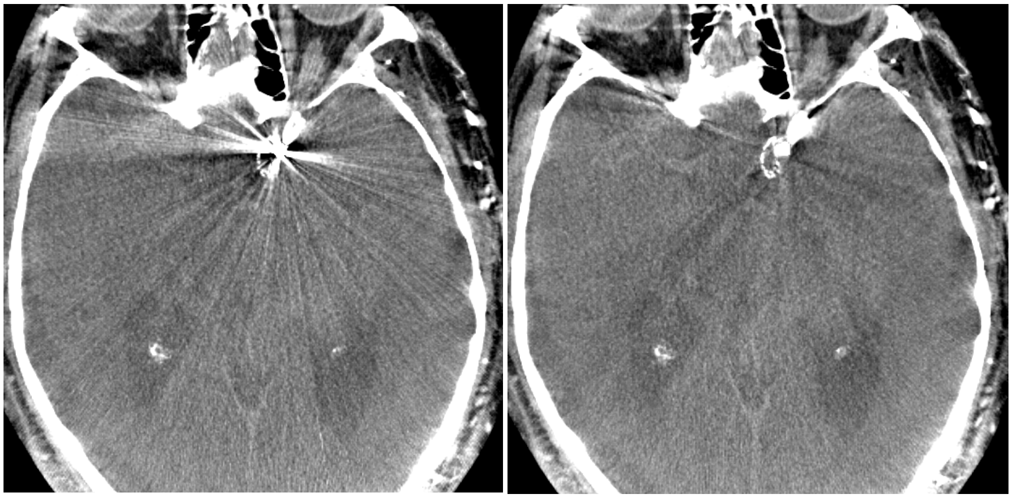
METAL ARTIFACT REMOVAL
IN C-ARM CONE-BEAM CT

GROUP 4
CAROLINA CAY-MARTINEZ, MARTA WELLS

REPORT #3
PHANTOM CONSTRUCTION



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

THE JOHNS HOPKINS UNIVERSITY
ADVANCED COMPUTER INTEGRATED SURGERY

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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

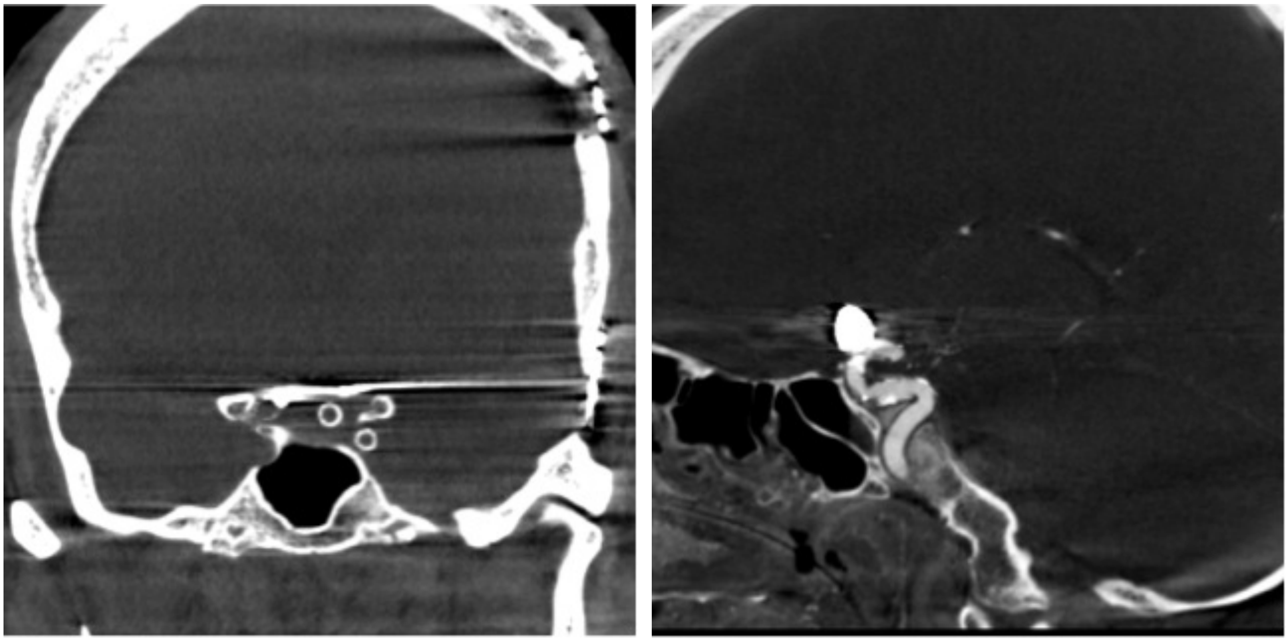
Available for project use was a hollow, anthropomorphic, RANDO brain imaging phantom (natural human skeleton in tissue-equivalent plastic; The Phantom Laboratory, GreenwichNY), referred to as 'scarecrow', provided by the Johns Hopkins I-STAR lab. The phantom could hold materials with x-ray attenuation properties capable of simulating cerebral tissue, contrast vasculature and metal objects used in surgical interventions (coils, clips and liquid embolic systems).

The most basic measurement of a CT scanner is a line integral of the linear attenuation coefficient, μ, of the object at the effective energy of the scanner. A scanner reconstructs the value of μ at each pixel within a cross-section. However, different CT scanners have different x-ray tubes, which in turn have different effective energies. In order to compare data from different scanners, CT numbers, known as Hounsfield units, are computed from the measured linear attenuation coefficients at each pixel. Note that Hounsfield units of the same object are dependent on the beam energy and the geometry of the CT scanner. Following are Hounsfield units of various materials imaged at 100 KeV relevant in the construction of the phantoms.

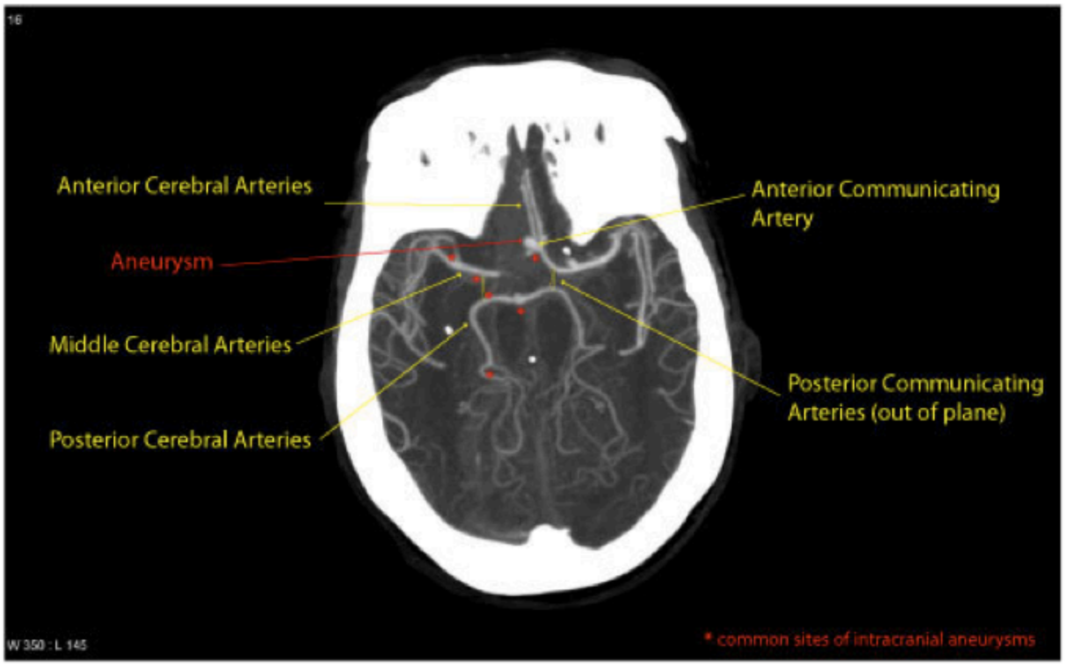
Material	HU units (approximations)	Notes
Air	-1000	
Water	0	
Fat	-100	
Blood	+30 TO +70	Higher values indicate ICH
Grey matter	+45	
White matter	+30	
CSF	+10	
Muscle	+40	
Bone	+400 to +2000	
Iodine	+10	(0.4 mg/mL, 100kev)
Iodine	+20	(2 mg/mL, 100kev)
Iodine	+50	(5 mg/mL, 100kev)
Iodine	+95	(20 mg/mL, 100kev)

II. Size and location of intracranial aneurysms

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 ruptured aneurysms (in order) are: anterior communicating artery (ACoA), middle cerebral artery (MCA), posterior communicating artery (PCoA); pericallosal artery (PerA), internal carotid artery (ICA) bifurcation, and basilar artery (BA) bifurcation lesions were least common and were found approximately equally. For unruptured aneurysms the most common sites are: MCA, PCoA, ACoA, and cavernous ICA. All of the abovementioned arteries are part of the Circle of Willis. The mean size of all ruptured aneurysms is 10.8 mm, significantly larger than the mean size of all unruptured aneurysms 7.8 mm; the median sizes were 10 mm and 5 mm, respectively. The sizes range from less than 3 mm to greater than 25 mm.[1]



Patient images of metal artifacts produced by coils in aneurysm located on the Circle of Willis.
Images provided by Radvany, M.D.



Intracranial Aneurysm Case Vignette.
Image provided by http://www.radrounds.com/photo/intracranial-aneurysm-case

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[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.

III. Neurovascular interventions: composition of metallic materials

Coils used in endovascular coiling procedures for the treatment of aneurysms 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. Due to the spherical shape of aneurysms and the flexibility of coils to conform to the aneurysms' shape, metal spheres are the simplest objects to simulate the shape of the coils.

Stents used in stent-assisted coil embolization for the treatment of intracranial aneurysm 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.

Clips used in microsurgical clipping are typically made of titanium. Aneurysm clipping consists in 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.

IV. First Phantom Construction: Metal Spheres

The first phantom construction contained 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 specific 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

Available for project use were various plastic spheres provided by the Johns Hopkins I-STAR lab, as shown in the figure below. The plastic spheres were placed in two parallel z-axis planes, six spheres on each plane. Their placement was not of utter importance; this first phantom was used primarily 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 diameters range from less than 3 mm to greater than 25 mm, the mean of unruptured aneurysms being 7.8 mm. Coiling of the aneurysm can be approximated with metal spheres of diameters within this range. Three sizes of metal spheres were used to simulate coiling: 1/8 in. (3.174 mm), 1/4 in. (6.35 mm), and 1/2 in. (12.7 mm).

Coils used in endovascular coiling are typically made of flexible platinum. Other metal materials have also been included to simulate the attenuation properties of metal stents and clips, which are typically made of platinum, titanium, stainless steel and nitinol.

Nine metal spheres were used in the imaging phantom: three titanium grade 5 spheres of diameter 3.174 mm, 6.35 mm and 12.7 mm each, three 316 resistant stainless steel spheres of diameter 3.174 mm, 6.35 mm and 12.7 mm each, and three tungsten carbide spheres of diameter 3.174 mm, 6.35 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	Clips / nitinol stents	Red
316 Stainless Steel	Coils	Green
Tungsten Carbide	Platinum coils	Blue

*316 stainless steel composition: Carbon, 16-18.5%, Chromium, 10-14%, Nickel, 2-3%, others

Image Acquisition Technique

NOT-COMPLETE!! A C-arm Cone-Beam Axiom Artis Zee (Axiom Artis Zeego, Siemens Medical Solutions, Elangen, Germany)was used. A Head DynaCT acquisition was obtained by using the following parameters:-second rotation; increment; matrix in projections; total angle; ~/s, ~ frames/s, system dose μGy/frame, total of projections. Image reconstruction was performed on a commercially available dedicated workstation (Leonardo with DynaCT; Siemens Medical Solutions).

Method

In order to deploy the metal spheres into the brain equivalent jello, they were glued to plastic rods (both the glue and rod materials are invisible to CT imaging) in order for them to be inserted and removed without melting the jello. They were inserted with water as lubrication, so as to not obtain any air cannals that will be visual in the image, as close to the clivus as possible. Phantom head was stabilized and held carefully held constant throughout the experiment. The plastic spheres were placed before the imaging of the phantom (in conjuction with the jello) and careful consideration of the positions of the plastic spheres was taken as to not re-position them. Members present in the acquisition were: Jeffrey Siewerdsen, Martin Radvany, Adam Wang, Carolina Cay and Marta Wells) Following are the images taken and notes regarding the process:

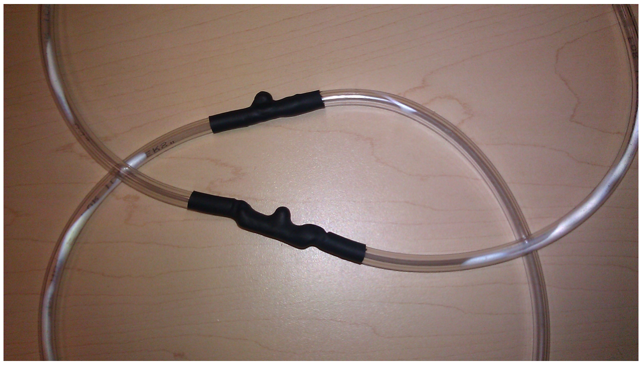
Image Number	Metal Components	Notes
1	No metal spheres	Control (v.1): 12 plastic spheres in various locations.
2	3.174 mm, steel (small green)	
3	3.174 mm, tungsten (small blue)	
4	3.174 mm, titanium (small red)	
5	6.35 mm, steel (medium green)	
6	6.35 mm, tungsten (medium blue)	
7	6.35 mm, titanium (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. FOV 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.

IV. Second Phantom Construction: Stent-Assisted Endovascular Coiling

The second phantom construction contained an aneurysm vessel model, plastic spheres with contrast that approximates the simulation of blood clots, surgical clips and stents. Also used during the image acquisition is an iodine contrast solution. All model materials simulated relevant tissues and instruments found in a interventional radiographic stent-assisted endovascular coiling procedure.

Simulated Vessel Component

A preliminary testing vessel model was constructed from **** plastic tubing and shrinkable plastic material. A plastic sphere and heat were used to mould an aneurysm shape into the shrinkable material and plastic tubing attached to the ends to simulate a vessel. See figure bellow.



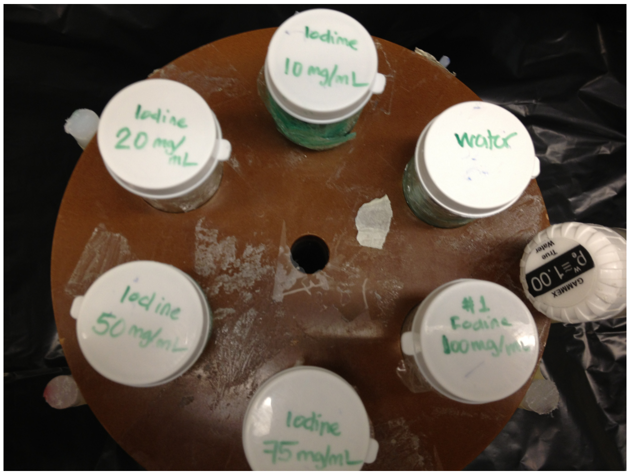
An ophthalmic aneurysm vessel model was acquired from Vascular Simulations.

Surrounding Vasculature Components

Four High-density Polyethylene plastic sphere were placed adjacent to the aneurysm vessel model to simulate blood clots.

*** 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/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 concentrations (100, 75, 50, 20, 10, and 0 mgI/mL) placed in a simple cylinder phantom along with seven unidentified plastic rods. Figure shown below:



Note that during the Zeego image acquisition procedure,

Metal Object Components