Manufacturing Patient-Specific Phantoms to Treat Aneurysms Using Rotational Angiography and 3-D Modeling

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ABSTRACT

The purpose of this study is to manufacture a patient-specific phantom containing multiple aneurysms that can be observed and tested to determine the need for interventional treatment. The vasculatures for the phantoms are taken from unhealthy individuals using rotational angiography as part of a larger stroke study. Different neurovascular sections exhibiting aneurysms from five patients were combined into a single Circle of Willis with 3D modeling software. Physicians and investigators can use this phantom to test treatment options, such as stent deployments, and determine if these options are needed.

BACKGROUND

The vascular structure of a human body varies from patient to patient. Every aneurysm that is diagnosed is different in size, shape, severity, location, and risk. By taking real patient rotational angiography scans of upper body vasculature and modeling the volumes with 3-D software, we are prototyping printable and testable patient-specific phantoms. These phantoms are polyurethane reconstructions of human cerebral vasculature that can be perfused to recreate physiological flow dynamics. The process graduates from a computer volume to a physical 3-D model to a viable resource for aneurysm treatment, all without any patient invasive procedures.

METHODS AND MATERIALS

Volume Acquisition

As part of a larger stroke study, multiple patient volumes have been acquired from unhealthy patients that currently have sizable aneurysms and have a stroke risk. The volumes of the head and neck are acquired by neurosurgeons through rotational angiography and transferred to a digital directory on Toshiba's Vital Images Vitrea 6 Software. The Vitrea Software allows the user to manipulate patient volumes. Bone, veins, and other soft tissue are removed in part by the software tools, but the volumes also include noise and contrast errors. The desired vessels are user-selected with vessel and bone with assistance from the software that uses contrast to separate different tissues. The arterial vasculature is isolated by using the Vessel Grow tool and by sorting through the slices of the scans. Minor fragments of bone and soft tissue can still be seen on the volume but they are easily removed later on. The desired vessel sections are then converted to stereolithographic (STL) files and imported to Autodesk Meshmixer.
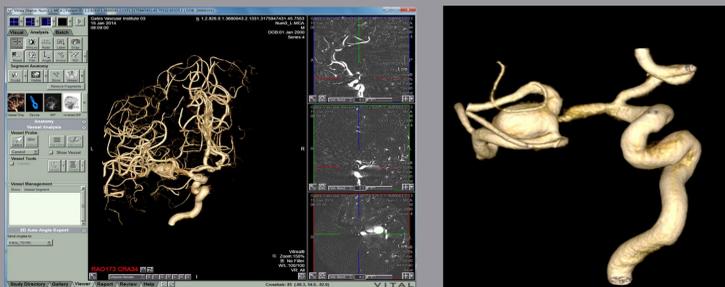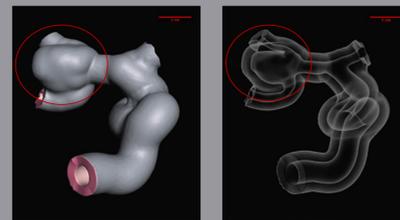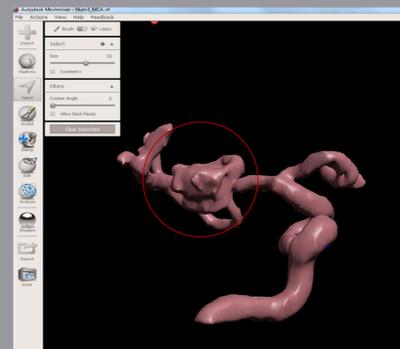

The specific aneurysm depicted above occurs at the Horizontal M1 post-bifurcation segment of the Left Middle Cerebral Artery. These images were taken from the final steps of editing on the Vitrea Software.

METHODS AND MATERIALS (cont.)

Volume Rendering

Using Autodesk Meshmixer, we remove fragments of soft tissue and bone, separate adjacently conjoined vessels, and reconstruct the vessel shapes that are rigid. The inspector tool manually and automatically repairs holes, non-manifolds, and small disconnected areas. Precaution is taken such that the shape of the vessels are not severely deformed or removed. Unwanted vessels, bumps, and other deformities are chosen with the selection tool and edited to best replicate the in vivo structure. A sculpting tool allows the user to deflate and inflate the vessel in areas where the Vitrea Software created errors. By selecting the entire structure and extruding in the normal direction, a 2.50 millimeter thickness is added. Inner bends and adjacent vessels of the structure have intersecting folds that are not printable. These errors are resolved by deleting the area of interest and replacing them with a single outer boundary. The volume is converted into a part and is meshed with other patient-specific aneurysms to create a complete Circle of Willis.

The top image displays the initial geometry of the aneurysm and the desired vasculature. The lower images display the fully edited volume with different shaders for visual analysis.

3-D Printing

The computer edited patient volume is printed by a Stratasys Eden 260V 3-D printer with TangoPlus FullCure930 Polymer, that has a soft rubber consistency. The printed phantom is produced with an accuracy of ±32 microns per slice. Polymer was cured by UV light in 70%, 80%, and 100% increments. The phantom is then carefully cleaned by catheter wire and water pressure to remove any fragments of support material.

RESULTS

Patient-Specific Phantom

The finished model has defined vessel pathways and a uniform thickness. Different shaders in Meshmixer allow for different views of the model and the ability to see inside the patient-specific volume. The volume can be rotated, blown up, or contracted. Most importantly, the volume is fully printable. If volumes are not needed at the present time, they can be saved as files for later use or analysis.

The 3D printer uses UV light to cure each layer of material.

RESULTS (cont.)

The patient-specific phantom is printed within a block for support. Extensions of vessels beyond the block, which mimic the carotid and cerebral arteries, allow for the testing of fluid flow through the phantom. The printed phantom has specific aneurysms from five different patients:

1. C7 communicating segment of the Right Internal Carotid Artery
2. Anterior side of precommunicating A1 segment of Left Anterior Cerebral Artery
3. Horizontal M1 post-bifurcation segment of the Left Middle Cerebral Artery
4. Lateral side of the C5 supraclinoid segment of the Left Internal Carotid Artery
5. Posterior side of the C5 paraclinoid segment of the Left Internal Carotid Artery
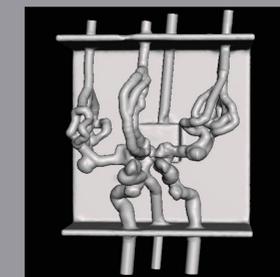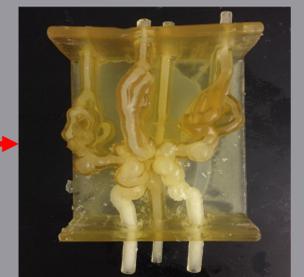
Meshmixer Model   Printed Model

CONCLUSIONS

The printed phantom is an accurate measurement of patient neurovascular anatomy. Multiple sections can be segmented from different individuals and combined into a common model. Rotational digital subtraction angiography can also be used to compare the accuracy of the phantom to the real anatomy. Imaging techniques are not completely accurate and parts of the anatomy may be distorted on the Vitrea Software. By combining high resolution images of the diseased segment of one patient's vascular anatomy with previous images from a healthy patient's surrounding vascular anatomy within reason, we can avoid estimations and reduce radiation exposure. Through this method, a patient will avoid having to go through any type of invasive procedure until it is clear that an intervention is required. Designing and printing anatomical 3D models has limitations including cost, strength, and time. Accurate 3D printers and their materials are very expensive so size and repetition of prints must be considered. The TangoPlus Polymer is fairly fragile and can fracture if too much force is applied, but it is flexible. When removing the support material, free hanging part are more susceptible to breaking under their own weight but this is taken into consideration during the design process.

REFERENCES

1. Autodesk, Inc., 2011. Autodesk Meshmixer Manual, latest ed. http://meshmixer.com/help/manual/MeshmixerManual.pdf
2. Osborne, A., 1999. Diagnostic Cerebral Angiograpghy, 2nd ed., Lippincott Williams and Wilkins, 530 Walnut St., Philadelphia, PA 19106, Chap. 4-8, pp. 83-153.

ACKNOWLEDGEMENTS