Technical Report

3D Printing of Preoperative Simulation Models of a Splenic Artery Aneurysm: Precision and Accuracy

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Rationale and Objectives: Three-dimensional (3D) printing is attracting increasing attention in the medical field. This study aimed to apply 3D printing to the production of hollow splenic artery aneurysm models for use in the simulation of endovascular treatment, and to evaluate the precision and accuracy of the simulation model.

Materials and Methods: From 3D computed tomography (CT) angiography data of a splenic artery aneurysm, 10 hollow models reproducing the vascular lumen were created using a fused deposition modeling-type desktop 3D printer. After filling with water, each model was scanned using T2-weighted magnetic resonance imaging for the evaluation of the lumen. All images were coregistered, binarized, and then combined to create an overlap map. The cross-sectional area of the splenic artery aneurysm and its standard deviation (SD) were calculated perpendicular to the *x*- and *y*-axes.

Results: Most voxels overlapped among the models. The cross-sectional areas were similar among the models, with SDs <0.05 cm^2. The mean cross-sectional areas of the splenic artery aneurysm were slightly smaller than those calculated from the original mask images. The maximum mean cross-sectional areas calculated perpendicular to the *x*- and *y*-axes were 3.90 cm^2 (SD, 0.02) and 4.33 cm^2 (SD, 0.02), whereas those calculated from the original mask images were 4.14 cm^2 and 4.66 cm^2, respectively. The mean cross-sectional areas of the afferent artery were, however, almost the same as those calculated from the original mask images.

Conclusion: The results suggest that 3D simulation modeling of a visceral artery aneurysm using a fused deposition modeling-type desktop 3D printer and computed tomography angiography data is highly precise and accurate.

Key Words: 3D printing; additive manufacturing; aneurysm; rapid prototyping; splenic artery.

INTRODUCTION

Three-dimensional (3D) printing, also known as additive manufacturing or rapid prototyping, is a technology in which a 3D object is synthesized from digital data. 3D printing is attracting increasing attention in the medical field. Although a range of 3D printing techniques, including stereolithography (STL), selective laser sintering, inkjet printing, and fused deposition modeling (FDM), have been developed for industrial use, cost and speed are important considerations for the clinical "bedside" application of the technique. In FDM, one of the most widely used and least costly techniques, a 3D model is built on a layer-by-layer basis by extruding a melted filament of thermoplastic material from a nozzle.

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The safety and effectiveness of interventional radiology procedures depend on the operator's experience and the extent of understanding of the patient's anatomy. In this regard, it would be useful if 3D printing could be applied to the preoperative simulation of the anatomy relevant to interventional radiology procedures. Previous studies have investigated the application of 3D printing to the production of hollow intracranial aneurysm models for the simulation of surgical and endovascular treatments (1–7). However, its application to visceral artery aneurysms has been extremely limited (8). Because of the way it works, it is difficult to construct complex structures such as hollow vascular models compared to simpler structures. For success in pre-procedure simulation and subsequent treatment, the model must precisely and accurately resemble the anatomic feature; however, to our knowledge, no study has evaluated the precision of aneurysm models.

The purpose of the present study was to apply 3D printing to the production of hollow visceral artery aneurysm models for the simulation of endovascular treatment, and to evaluate the precision and accuracy of the simulation model. From 3D computed tomography (CT) angiography data of a splenic

Figure 1. A 66-year-old man with a 2-cm splenic artery aneurysm. Maximum intensity projection (MIP) images created from the original computed tomography (CT) angiography data (left) and from T2-weighted magnetic resonance (MR) data of a 3D-printed hollow aneurysm model filled with water (right).

artery aneurysm, to this end, we created hollow models reproducing the vascular lumen using an FDM-type desktop 3D printer, and scanned them using T2-weighted magnetic resonance (MR) imaging for the evaluation of the reproducibility of the intravascular space after filling them with water.

MATERIALS AND METHODS

Model Fabrication

The 3D CT angiography data of a splenic artery aneurysm found in a 66-year-old male patient with rectal cancer were used to construct 3D-printed models (Fig 1). The CT data were obtained using an Aquilion ONE scanner (Toshiba Medical Systems, Tochigi, Japan). The field of view was 350 mm with a matrix of 512 × 512; spatial resolution was 0.683 × 0.683 mm. The slice thickness was 0.5 mm with no gap. The aneurysm was 2 cm in diameter and had one afferent and two efferent arteries. Approval for this study was obtained from the ethical committee of our institution.

The CT data were transferred to an image analysis workstation (AZE Virtual Place Raijin 3.40, AZE, Tokyo, Japan). Mask images of the splenic artery aneurysm and the afferent and efferent arteries were created using surface-shaded display with a threshold of 220 HU, 3D object selection, and region cutting. The mask images were binarized to 0 or 255 and inverted to obtain a hollow model. The inverted mask images were imported to a DICOM viewer (OsiriX 6.5.2) and converted to an STL file using 3D surface rendering with a threshold of 128. The STL file was imported to 3D mesh software (Meshmixer 10.9.332, Autodesk, San Rafael, CA) and checked for mesh consistency before 3D printing.

The exported STL file was converted to a cubepro file and printed using an FDM-type desktop 3D printer (CubePro, 3D Systems, Rock Hill, SC) with nylon material, a layer thickness of 0.2 mm, and no support material. To enable evaluation of precision and accuracy, 10 models were created. All models were coated with a fluorinated liquid repellent (OPTOACE, Daikin Industries, Osaka, Japan).

Figure 2 shows a summary of the steps followed in creating the 3D-printed models (Fig 3).

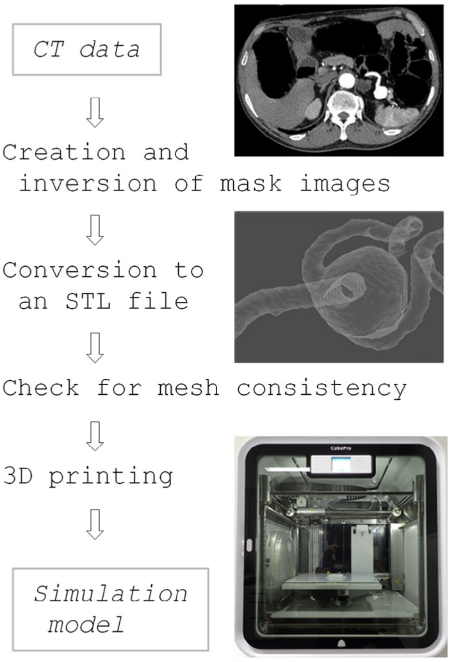

Figure 2. Summary of the steps for producing hollow splenic artery aneurysm models.

Model Evaluation

Each model was scanned using a 3.0-T MR scanner (MAGNETOM Skyra 3T, Siemens Healthcare, Erlangen, Germany) with a 32-channel head phased-array coil. After filling each model with water, T2-weighted images were acquired using a two-dimensional turbo spin-echo sequence in 60 slices (repetition time = 5200 ms; echo time = 88 ms; echo train length = 13; field of view = 80 × 160 mm; slice thickness = 0.7 mm with no gap; acquisition matrix = 160 × 320; scanning time = 4:42). The voxel size was 0.5 × 0.5 × 0.7 mm.

Image analysis was performed using MATLAB 7.13 (Mathworks, Sherborn, MA) and statistical parametric mapping 8 software (http://www.fil.ion.ucl.ac.uk/spm) developed in the Wellcome Department of Imaging Neuroscience, Institute of Neurology, University College London. All T2-weighted images were coregistered with the original mask images and resliced. Histogram analysis (histogram bin