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Development of personalised 3D printed abdominal aortic aneurysm models with use of different materials for clinical education and training in interventional radiology

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SHORT COMMUNICATION

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ABSTRACT

Background

3D printing is increasingly used in medical applications with studies proving its clinical value in surgical planning and simulation of complex surgical procedures. Use of patient-specific or personalised 3D printed models could serve as a useful tool in clinical education and training by practicing interventional procedures on the realistic physical models.

Aims

This study aimed to develop 3D printed personalised abdominal aortic aneurysm (AAA) models using different materials for the purpose of simulating interventional radiology procedure when performing endovascular aneurysm repair.

Methods

Anonymized Computed Tomography (CT) images of a sample case with an intrarenal AAA were selected to generate 3D volume data comprising AAA and arterial branches covering from celiac axis to common iliac arteries. The 3D segmented AAA model was printed with six different materials including resin, high impact polystyrene (HIPS), polyethylene terephthalate glycol (PETG), polylactic acid (PLA), polymethacrylate (PMMA), and thermoplastic polyurethane (TPU). The 3D printed models were scanned on a 192-slice CT scanner with and without use of contrast medium. Model accuracy in terms of AAA length and maximal transverse diameter was measured on original CT images and compared with that from these 3D printed models.

Results

The AAA models were successfully printed with these six different materials. 3D printed AAA models accurately replicated aortic aneurysm dimensions with mean differences less than 0.5 mm between measurements from original CT images and 3D printed models.

Conclusion

This study shows the feasibility of printing personalised AAA models with different materials with high accuracy of replicating aortic aneurysm. The 3D printed personalised models will be used to train interventional radiology trainees to develop their practical skills on performing endovascular aneurysm repair procedures.

Key Words

3D printing, Abdominal aortic aneurysm, Endovascular aneurysm repair, Accuracy, Model, Simulation

Introduction

Abdominal Aortic Aneurysm (AAA) is a common vascular disease that affects elderly patients. Conventional treatment of AAA by open surgery is associated with potential risks of intraoperative and post-operative complications, especially higher in patients with cardiovascular disease. Currently, minimally invasive Endo

Vascular Aneurysm Repair (EVAR) has been widely used in clinical practice to treat aortic aneurysm and aortic dissection due to its less invasiveness and lower complications when compared to the invasive open surgery[1-4].

Successful performance of EVAR requires technical skills such as manoeuvring catheters and guidewires to the aortic aneurysm regions where endovascular stent grafts are deployed so that the aneurysm is separated from systematic circulation. Successful EVAR procedure is indicated by gradual aneurysm reduction or shrinkage on Computed Tomography (CT) follow-ups to monitor aneurysm size changes and detect if there are any complications such as endoleaks or stent graft migration[5-10].

Although some simulators such as virtual reality simulation are available for training interventional radiologists or vascular surgeons to develop practical skills of EVAR procedures, they are not only expensive, lack of wide accessibility, but also limited to simulating the procedures on an average adult patients, thus lacking details of individual patient's anatomy. This can be overcome by using three-dimensional (3D) printing technology to develop patient-specific or personalised 3D printed aortic models for education and training purpose.

3D printing is increasingly used in medical applications with studies proving its value in many aspects ranging from medical education to pre-surgical planning and simulation of complex or challenging surgeries or procedures[11-20]. 3D printed heart and vascular models are shown to be highly accurate in replicating anatomical structures and vascular disease such as aneurysm, thus serving as a useful tool in simulation of EVAR during interventional radiology practice[21-30]. Despite some recent studies showing the clinical value and usefulness of 3D printed AAA models in guiding EVAR planning; there is lack of research on the selection of appropriate materials for developing realistic 3D printed aorta models. This study aims to address this research gap by testing several materials on printing a sample AAA case.

Materials and Methods

Selection of a sample case for 3D printing

De-identified DICOM (Digital Imaging and Communications in Medicine) contrast-enhanced CT angiographic images of a patient with an infrarenal AAA were selected in this study. Figure 1A shows the 3D visualisation of the selected case with a typical AAA location with extension to the common iliac arteries. CT scanning was performed on a 256-slice GE Revolution CT scanner (GE Revolution, GE Healthcare, Milwaukee, WI, USA) and images were acquired with slice thickness of 0.625 mm and 100 kV. CT images underwent a series of post-processing and segmentation steps with bony structures and soft tissues etc removed, while only contrast-enhanced aorta and its arterial branches along with aneurysm were kept in the final segmented volume data (Figure 1A and B). The segmented data were saved in Standard Tessellation Language (STL) format for 3D printing purpose (Figure 2).

Selection of 3D printing materials for model printing

We tested several printing materials from soft to rigid ones using different 3D printers with the aim of developing personalised 3D printed AAA models for clinical education and simulation. There are six materials used for 3D printing in this study: resin, High Impact Poly Styrene (HIPS), Polyethylene Terephthalate Glycol (PETG), Polylactic Acid (PLA), Polymethacrylate (PMMA), Thermoplastic Polyurethane (TPU). The models were printed with 3D printers including Formlabs 3 (model 1 printed with resin), Ultimaker 2+ Extended/Raise 3D N2 Plus (models 2-6 with PETG, PLA, HIPS, PMMA and TPU)[30].

CT scanning of 3D printing models

3D printed AAA models were scanned on a 3rd generation dual-source 192-slice CT scanner (SOMATOM Force, Siemens Healthcare, Siemens) with 80 kV, slice thickness of 1.0 mm with 0.7 mm reconstruction interval. CT scans were first done with these 3D printed models placed on the scanning table without having contrast medium, followed by submerging these models in a plastic container filled with a mixture of water and contrast medium. The contrast medium was diluted to 6% mimicking CT attenuation of 350 HU (Hounsfield unit) which is similar to that in the routine CT angiography attenuation (Figure 3)[23].

Results

The six AAA models were successfully printed. Figure 4 shows these 3D printed personalised AAA models with use of different materials, while Figure 5 are 3D reconstruction images of CT scanned models without the use of contrast medium. Figure 6 shows coronal reformatted images of the two selected 3D printed AAA models with use of contrast medium. Some air bubbles were noticed in the aortic aneurysm or arterial branch areas which could not be avoided when the models were immersed in the container.

Measurements of the length and maximal transverse diameter of aortic aneurysm were performed on original CT images and CT images of 3D printed models for comparison, with mean differences less than 0.5 mm (measurements from original CT *vs* those from without and with use of contrast medium), indicating high accuracy of the 3D printed models in replicating aortic aneurysm.

Discussion

This study shows the feasibility of printing personalised AAA models with use of different materials. CT scanning of these 3D printed models indicates the high accuracy of replicating aortic aneurysm between original CT images and CT scanned data.

3D printed aorta models have been reported in some studies for training and simulation of interventional radiology or surgical procedures, as well as providing guidance for accuracy device selection. Use of 3D printed models in simulating EVAR procedures has been shown to reduce procedure time, contrast medium and cannulation time when compared to the standard training approach [31-33]. With the tangible 3D printed model in hand, the physicians can manipulate and assess the diseased and vascular anatomy to their liking to gain tactile experience, which is especially useful for simulating surgical or interventional radiology procedures. Research on the use of 3D printed in interventional radiology training and simulation is limited according to a recent review[34]. Tenewitz and colleagues conducted a systematic review of 3D printed models for simulation training of interventional radiology trainees through searching various databases. They only identified four studies evaluating the use of 3D printed models for simulation and training in interventional radiology, while with two of them documented the usefulness of 3D printed vascular models in interventional radiology training[34-36]. Although positive feedback was achieved with use of 3D printed models for trainee simulation (medical students and radiology registrars) compared to commercial models, these two studies are limited in using a simple femoral artery access model, lacking complex anatomical configurations.

Our 3D printed personalised models (Figures 3-6) with accurate replication of aortic aneurysm and arterial branches covering from celiac axis to common iliac arteries could serve as a useful tool for training and simulation of EVAR procedures. This is an ongoing study with the aim of presenting these models to interventional radiologist trainees for practicing EVAR procedures on the models, thus expecting to enhance their confidence and practical skills before operating on the real patients [37-40].

Conclusion

In conclusion, we have developed personalised 3D printed AAA models with models printed using six different materials showing high accuracy of the printed models. However, most of the models are quite rigid lacking softness or elasticity. Inclusion of other materials such as silicone or Agilus30 will be considered in future studies to determine the most appropriate materials for printing AAA models. With recruitment of participants to practice their skills of EVAR procedures on these 3D printed models, we expect to obtain results on how these 3D printed aorta models can be used as a valuable education and training tool in clinical practice.

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Figures

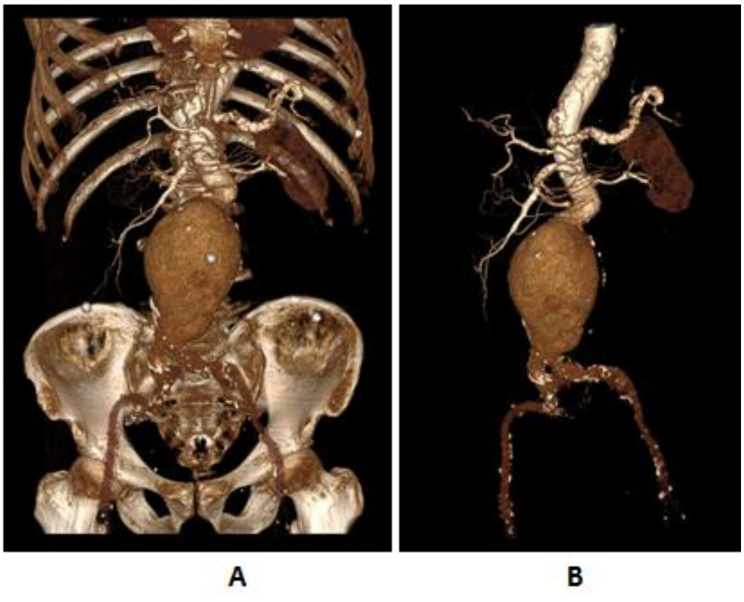

Figure 1: CT reconstructions of abdominal aortic aneurysm with image post-processing and segmentation. A: 3D reconstruction of AAA with soft tissues and other structures removed, while contrast-enhanced arteries and aneurysm and bones remaining. B: After further removing bony structures, only aortic aneurysm and arterial branches (and left kidney) are kept.

Figure 2: STL file of segmented aortic aneurysm data for 3D printing.

Figure 3: CT scanning of the 3D printed abdominal aortic aneurysm models with model immersed in a plastic container filled with contrast medium.

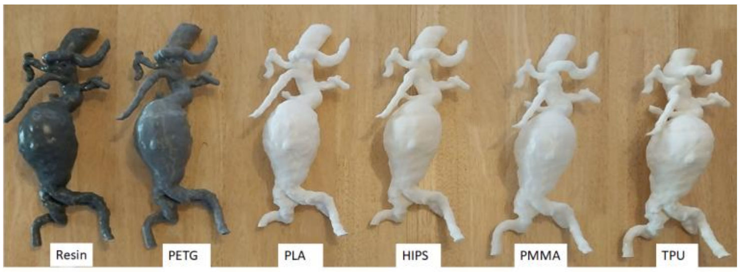

Figure 4: 3D printed abdominal aortic aneurysm models with use of six different materials.

Figure 5: 3D reconstruction of CT scanned images of 3D printed abdominal aortic aneurysm models with use of the above-mentioned six materials.

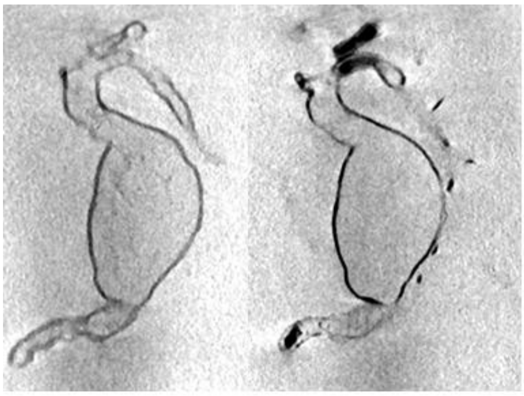

Figure 6: Coronal reformatted views of the first two 3D printed models with use of contrast medium. It is noted that air bubbles are present in the second model, especially in the arterial branch locations (right image).

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