Eur J Vasc Endovasc Surg (2017) ■, 1—7

A simulator for training in endovascular aneurysm repair: The use of three dimensional printers

I.O. Torres [*], **N. De Luccia**

Discipline of Vascular and Endovascular Surgery, Department of Surgery, São Paulo University Medical School, São Paulo, Brazil

WHAT THIS PAPER ADDS

This research highlights some options for producing a patient specific simulator for training in endovascular aneurysm repair using three dimensional (3D) printing technology. The cost effective production of 3D printed models using desktop machines may be a solution for institutions that cannot afford virtual or other commercially available simulators to train residents. Further development of 3D printers is required, but the simulators produced in this study led to an improvement in residents' surgical performance and increased their self confidence.

Objectives: To develop an endovascular aneurysm repair (EVAR) simulation system using three dimensional (3D) printed aneurysms, and to evaluate the impact of patient specific training prior to EVAR on the surgical performance of vascular surgery residents in a university hospital in Brazil.
Methods: This was a prospective, controlled, single centre study. During 2015, the aneurysms of patients undergoing elective EVAR at São Paulo University Medical School were 3D printed and used in training sessions with vascular surgery residents. The 3D printers Stratasys-Connex 350, Formlabs-Form1+, and Makerbot were tested. Ten residents were enrolled in the control group (five residents and 30 patients in 2014) or the training group (five residents and 25 patients in 2015). The control group performed the surgery under the supervision of a senior vascular surgeon (routine procedure, without simulator training). The training group practised the surgery in a patient specific simulator prior to the routine procedure. Objective parameters were analysed, and a subjective questionnaire addressing training utility and realism was answered.
Results: Patient specific training reduced fluoroscopy time by 30% (mean 48 min, 95% confidence interval [CI] 40—58 vs. 33 min, 95% CI 26—42 [$p < .01$]), total procedure time by 29% (mean 292 min [95% CI 235—336] vs. 207 [95% CI 173—247]; $p < .01$), and volume of contrast used by 25% (mean 87 mL [95% CI 73—103] vs. 65 mL [95% CI 52—81]; $p = .02$). The residents considered the training useful and realistic, and reported that it increased their self confidence. The 3D printers Form1+ (using flexible resin) and Makerbot (using silicone) provided the best performance based on simulator quality and cost.
Conclusion: An EVAR simulation system using 3D printed aneurysms was feasible. The best results were obtained with the 3D printers Form1+ (using flexible resin) and Makerbot (using silicone). Patient specific training prior to EVAR at a university hospital in Brazil improved residents' surgical performance (based on fluoroscopy time, surgery time, and volume of contrast used) and increased their self confidence.

Article history: Received 7 November 2016, Accepted 16 May 2017, Available online XXX
Keywords: 3D printing, EVAR, Patient specific, Simulations, Training

INTRODUCTION

Aortic aneurysm is a common clinical condition that poses a considerable threat to patients' lives.[1,2] Prior to 2000, 99% of abdominal aortic aneurysm (AAA) repairs were performed with open surgery, but catheter based minimally invasive interventions have rapidly become the preferred initial treatment.[3] This change requires a shift in approach for training vascular surgeons.[4,5]

Currently, supervised training with progressive exposure to procedures is the norm.[4] However, training based on simulations may shorten the learning curve and avoid exposing patients to unnecessary risks.[5] Attempts at endovascular aneurysm repair (EVAR) simulations date to 1998 with the use of silicone rubber models.[6] Recently, there has been a movement towards computer based

* Corresponding author. Discipline of Vascular and Endovascular Surgery, Department of Surgery, São Paulo University Medical School, São Paulo, Brazil.
E-mail address: inezohashi@gmail.com (I.O. Torres).

http://dx.doi.org/10.1016/j.ejvs.2017.05.011

simulations.[7,8] However, these simulations require expensive devices that are prone to technical failure and require regular calibration and maintenance.[5,7,9]

Three dimensional (3D) printing is a technology available worldwide that allows the production of graspable models based on images built on a computer.[10–12] Recently, a variety of medical applications of 3D printing have been reported.[9,13,14]

The two objectives of this research were to develop a patient specific simulation system for training in EVAR using 3D printing technology and to evaluate the impact of patient specific training prior to EVAR on the surgical performance of vascular surgery residents in a university hospital in Brazil.

MATERIALS AND METHODS

This study was performed at São Paulo University Medical School from March 2014 to March 2016. It was approved by the ethics committee at Plataforma Brasil (www.saude.gov.br/plataformabrasil, CAAE 19826213.1.0000.0068).

During the first year of the study, EVAR was performed without pre-operative simulation training. In the second year, the aneurysms of all patients with infrarenal AAA undergoing elective EVAR at the Department of Surgery, São Paulo University Medical School, São Paulo, Brazil, were 3D printed and used in patient specific training sessions prior to surgery.

Production of 3D printed aneurysms

The process of 3D printing an aneurysm required 1 week and consisted of four steps[14]: image acquisition, image post-processing, 3D printing, and aneurysm post-processing (Fig. 1).

First, computed tomography (CT) scans were conducted in a GE multislice scanner with 64 channels (GE, Boston, MA, USA). Second, the Digital Imaging and Communications in Medicine (DICOM) files from the CT scanner were processed using TeraRecon iNtuition Unlimited software (Aquarius version 4.3; TeraRecon, San Matteo, CA, USA). A 3D reconstruction of the aorta was generated, and the image was exported as a Standard Tessellation Language (STL) file. Then, using Mesh Mixer (Mesh Mixer 2.8, Autodesk, Inc., San Rafael, CA, USA) or Magics Software (Magics, 3-matic®; Materialise, Leuven, Belgium), smoothing was applied on the surface of the aorta and errors in the digital mesh were corrected. The image produced was a solid model that represented the aorta lumen. The surface of the aorta was digitally thickened (to 1.5 or 2 mm), and the space occupied by the lumen was subtracted to create the primary hollow models.

Thereafter, the file was sent to a 3D printer. Three 3D printers and five materials were tested to identify a technology that allowed the production of resistant, transparent, and navigable aneurysms at reasonable cost (Fig. 2). The materials were specific to each 3D printer. Materials 1–4 allowed the aneurysms to be primarily printed as hollow models. The aneurysms made with material 5 were produced by curing silicone over a 3D printed solid aneurysm. After being printed, primary hollow aneurysms had their support material extracted, ruptures repaired, were exposed to ultraviolet light for 48 h, and reinforced with silicone. The aneurysms produced using Form1+ were printed in three pieces that were assembled with resin and laser. For solid aneurysms, silicone was applied to the external surface and cured for 24 h. The silicone was then cut, removed from the solid model, and restored.

The aneurysms were connected to a pulsatile flow system. Training occurred with indirect vision provided by a camera connected to a 24 inch Philips Monitor. Images from the camera are shown in Fig. 3.

Residents' surgical performance was analysed in a prospective trial.

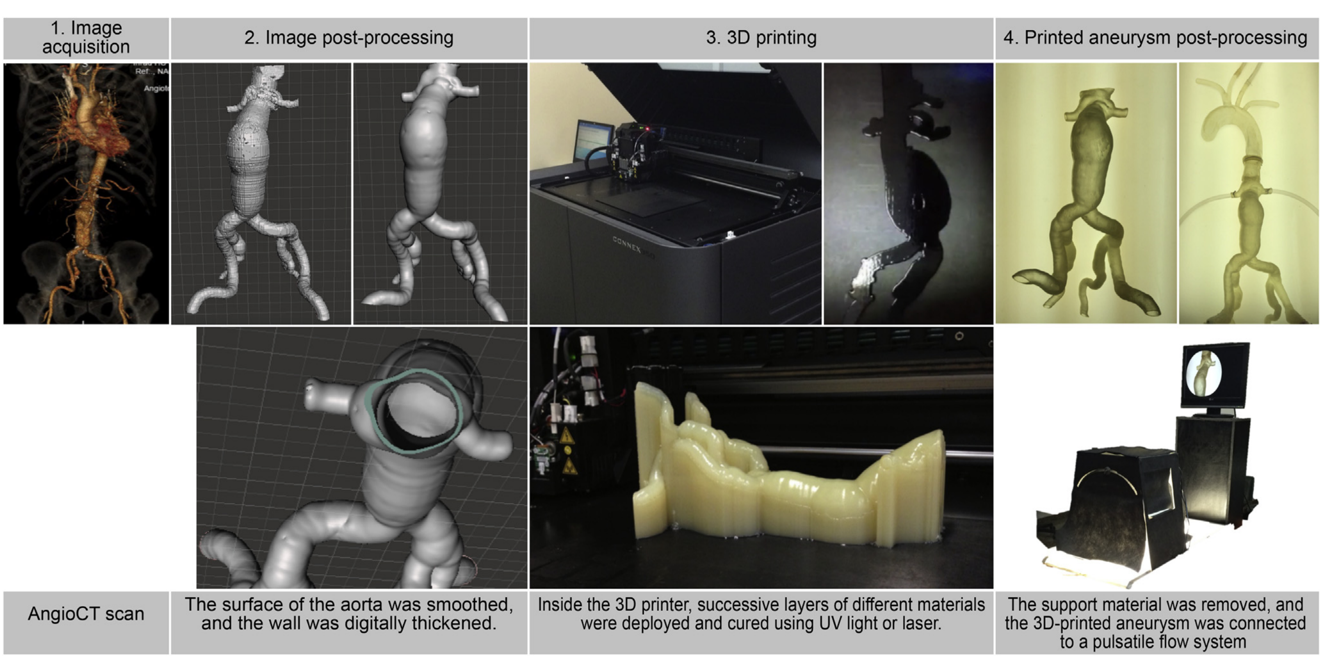

Figure 1. Steps taken in producing a three dimensionally (3D) printed aneurysm. *Note.* CT = computed tomography; UV = ultraviolet.

Please cite this article in press as: Torres IO, De Luccia N, A simulator for training in endovascular aneurysm repair: The use of three dimensional printers, European Journal of Vascular and Endovascular Surgery (2017), http://dx.doi.org/10.1016/j.ejvs.2017.05.011