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Modular simulation of neuroangiography and endovascular interventions in neuroradiology

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Abstract: A concept for a specialized phantom system for the simulations of diagnostic and therapeutic procedures in neuroradiology is presented. The modular simulator can be used for testing and training of both, established and new approaches in image guided catheter interventions. The 3D printing of anatomical vessel phantoms allows for the reproduction of specific features of the vasculature on the path of the catheter.

I. Introduction

The additive manufacturing of vascular phantoms for training purposes in medicine offers a wide range of possibilities. In neuroradiology, for example, this opens several new possibilities for training diagnostic and interventional neuroangiography.

While patient-specific 3D printed models of cerebral arteries are already in use in these areas [1], 3D printed models of arteries supplying cerebral arteries from the periphery are still rare. An endovascular intervention is usually performed via transfemoral access, although transradial access is also playing an increasing role. Transradial arterial access offers many advantages [2]. In particular, the risk of bleeding at the puncture site is significantly lower than with transfemoral approach, and pseudoaneurysms are less likely to form after the procedure. In addition, patients do not have to maintain strict bed rest after the procedure, which increases patient comfort. However, the physician requires a significantly higher level of skill to perform the procedure via transradial access [2]. Both approaches are important and both access routes must be trained extensively in a neuroradiologist's training. The further route from the transfemoral or transradial access is via the aorta, whereby the probing of the four brain-supplying neck arteries also requires relevant technical skills. Only when the probing of a neck artery has taken place successfully the probing of a cerebral artery can take place.

In effort to simulate the entire arterial access pathway to a cerebral artery using 3D printing, the size of conventional 3D printers or the small building platforms of 3D printers are limiting factors. Only with concepts that digitally disassemble the complete vascular system and physically bring it back together after 3D printing can a simulation succeed. It quickly becomes apparent that this type of modularization also has advantages. In particular, the ability to create different arterial access routes from different individual anatomies is decidedly appealing for neuroangiography training. With such modularization, the simulator can ideally be quickly adapted to the trainee's level of experience.

Here we present a modular neuroangiography simulator in the evaluation phase, which in design is suitable for simulating a transradial arterial access pathway in neuroangiography.

II. Material and methods

Clinical CT angiography data from routine clinical practice were selected, focusing on the aortic arch for the evaluation phase.

Segmentation of arteries was performed using Analyze Pro 1.0 (AnalyzeDirect, Overland Park, Kansas, USA), while a semi-automated approach using a region growth algorithm was applied. For this purpose, seed areas were defined at different points in the vessels. Small arteries were removed to simplify the 3D printing process and the simulator itself. The segmented anatomies were converted to .stl-format and imported into NetFabb Premium 2021.1 (Autodesk, San Rafael, California, USA). The .stl file was repaired using the automatic repair function implemented in NetFabb Premium.

The digital 3D model was broken down into smaller segments that fit on the building platform of the 3D printer. Several adapters were designed using Fusion 360 (Autodesk, San Rafael, California, USA). After digital connection of adapters and the anatomical models, data were exported to PreForm 3.1.0 (Formlabs Inc., Somerville, Massachusetts, USA) and the support material was digitally attached. Printing was performed on a Form 2 stereolithography printer (Formlabs Inc.) using a 25 micron

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layer thickness and clear v4 photopolymer resin (Formlabs Inc.). After the printing process, the post-processing steps wash-out, drying, post-curing with UV light and surface polishing were performed. The central units of the simulator are the modularized 3D-printed vascular phantoms, which are connected to a water tank and to a flow pump via narrow silicone tubes. Here, the setup is basically based on previous vascular simulators from our laboratory [3]. The simulator was evaluated in a clinical setting using an Azurion 7 FD 20/20 angiography system (Philips Healthcare, Best, The Netherlands). A diagnostic angiography of the brain-supplying neck arteries was performed by an experienced neuroradiologist using a standard Simmons-2 5F diagnostic catheter and iodine-containing contrast medium.

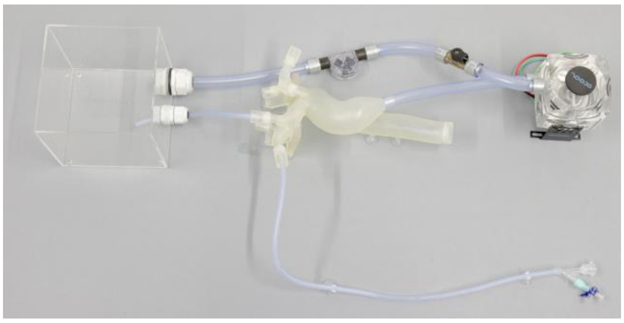

Figure 1: Overview of the simulator. With water reservoir, 3d printed aortic arch and pump (from left to right).

III. Results and discussion

The 3D-printed, modular neuroangiography simulator enables neurorangiography training in any conventional angiography unit. Due to the transparent material, control of the catheter position is possible not only with X-ray but also with a camera. Many adapters are available, which allow the connection to different arteries. In addition, different patient anatomies can be simulated.

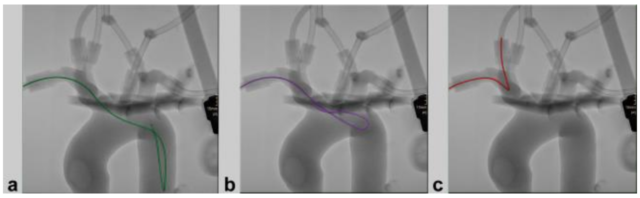

Figure 2: Angiographic evaluation of the modular simulator. a) Configuration of the Simmons 2 catheter in the aortic arch. b) Careful withdrawal of the catheter results in c) probing of the right common carotid artery, as in a real patient.

Clinical evaluation revealed realistic behavior of the wire and catheter in the simulator. In particular, the rotation of the Simmons-2 catheter towards the typical Simmons-2 curve, which is a particularly important step of transradial angiography, was achieved without problems.

Even in repeated attempts, the catheter could be configured via probing the ascending or descending aorta. As in reality, probing of the supraaortic arteries was then successful by gentle retraction (see Fig. 2 a-c).

Many other applications of the simulator are possible. Here, the extension of the simulator to intracranial simulation is of particular importance. Various vascular models of intracranial arteries can be introduced into the water tank, these can be 3D-printed models of intracranial aneurysms or of stenoses. This can greatly improve angiographic training in neuroradiology. The simulator can also be used for research, and in the long term a combination with magnetic particle imaging is also conceivable.

IV. Conclusions

Training in interventional neuroradiology is complex and much experience is needed to perform adequate diagnosis and therapy. By means of a modularized, 3D printed neuroangiography simulator, as presented in this paper, the training can be significantly improved.

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Author’s statement

Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use complies with all the relevant national regulations, institutional policies and was performed in accordance with the tenets of the Helsinki Declaration, and has been approved by the authors’ institutional review board or equivalent committee.

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