SHORT COMMUNICATION

Design and construction of a multipath vessel phantom for interventional training

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ABSTRACT. This short communication reports on the design and construction of a catheter manipulation skill enhancement phantom for use by residents and fellows outside the clinical environment. The phantom contains a variety of path trajectories and vessel diameter transitions, allowing trainees to manipulate catheters through vessel paths of varying difficulty. The multipath phantom, which is easy to construct and provides easily visualised paths, provides a simple, cost-effective training platform to facilitate and accelerate interventional training.

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X-ray fluoroscopically guided percutaneous transluminal catheterisation plays an important role in the diagnosis of vascular and cardiac disease. Improvements in balloon, stent, coil, guidewire and catheter technology have transformed catheter-based procedures from a solely diagnostic intervention to a routine therapeutic intervention. Currently, training residents and fellows on safe and efficient catheter manipulation is achieved under the guidance of an experienced interventional physician in the clinic. This apprenticeship training method is expensive and time-consuming for the trainer, and may not guarantee sufficient development of core interventional skills: the dexterity required to manipulate the catheter and inject contrast while simultaneously operating the X-ray imaging system and viewing images.

Although software simulators have been developed to assist with training [1–3], these simulators usually focus on micro-interactions of the catheter inside the vasculature, *i.e.* vascular friction. Although understanding micro-interactions is important, the skill of manipulating the catheter/guidewire while simultaneously operating the imaging system is overlooked.

In a parallel effort, vascular models have been described in the literature [4–11]. However, the application of these vascular models has typically been to optimise image reconstruction algorithms, perform haemodynamic studies and calibrate imaging systems. Vessel models can provide anatomically realistic vasculature, but for training purposes lack physiological variability. To emulate physiological variability during training, multiple phantoms with different geometrical considerations would be required, a time-consuming and costly

approach. Instead, the use of non-anthropomorphic phantoms, containing multiple vessel trajectories, can be used to assist training efforts. Recently, such phantoms have been used in catheter navigation studies, comparing conventional *vs* remote catheter manipulation [12–14].

A simple, cost-effective, non-anthropomorphic phantom has the potential to accelerate interventional training by providing a platform to learn the core skills required in the clinic. In addition, as a perpetual platform, a non-anthropomorphic phantom may provide specific catheter manipulation tasks to assess new catheter technologies, monitor the progression of core skill development in trainees and also provide a standardised platform for assessing the developed core skills of graduating trainees.

This technical innovation describes the design and fabrication steps of a simple, non-anthropomorphic phantom, termed the multipath vessel phantom, which is intended to complement current interventional training methods.

Methods and materials

Design considerations

To provide a variety of vessel trajectories, a two-dimensional (2D) non-anthropomorphic phantom was designed. Considerations during the design of the phantom were as follows:

- radiotranslucency;
- provision for a range of vessel complexity;
- inclusion of different vessel diameter transitions; (vein—small to large; artery—large to small);
- simplicity in construction;
- physiologically relevant physical size; and
- compatibility with flow.

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To provide a range of vessel complexity, a 2D pattern, as shown in Figure 1, containing vessel trajectories of varying angulations was conceived. Vessel angulations vary between 30° and 135° in order to simulate commonly encountered branch vessels within the neurovasculature. In addition to vessel angulations, on the left side of the phantom the pattern incorporates a transition from large to small diameter vessels (9.5–6.35 mm). On the right side of the phantom, the pattern is identical to that of the left side of the phantom, except vessel diameters transition from small to large (6.35–9.35 mm). Branching angles inside the phantom, ranging from 30° to 135° , provide the trainee with paths of varying difficulty. Manipulating the catheter through the left side of the phantom provides training similar to arterial intervention (*i.e.* large to small vessel diameters), while manipulation of the catheter through the right side of the phantom provides training similar to venous intervention (small to large). Furthermore, a catheter can pass from the left to the right side of the phantom (or vice versa), providing additional training paths. The vessel diameters selected are similar to the size of carotid arteries [15].

The size of the phantom is constrained to $30 \times 30 \text{ cm}^2$ thereby ensuring that the entire phantom is visible within the field of view (FOV) of clinical X-ray systems with a 30 cm FOV. X-ray systems with a FOV greater than 15 cm can easily visualise either the left side, right side or centre of the phantom during training.

Figure 1. Pattern of the non-anthropomorphic multipath training phantom (top view). The catheter is inserted into the phantom through either the bottom left or bottom right inlets. Inside the phantom, the catheter can be manipulated within vessels of three diameter sizes (dark grey, 9.5 mm; light grey, 6.35 mm; and black, 8 mm). Black circles indicate fasteners, which hold the two machined acrylic plates together.

To enable contrast injection, the phantom must also be flow compatible. This consideration is examined in the next section.

Phantom construction

For simple construction, the multipath phantom comprises two acrylic sheets, each measuring $30 \times 30 \times 1.27 \text{ cm}^3$ for an overall size of $30 \times 30 \times 2.54 \text{ cm}^3$. The pattern shown in Figure 1 was milled into each sheet using an automated three-axis numerically controlled milling machine with standard hemispherical mill bits (6.35 mm, 8 mm and 9.5 mm diameter).

Quick-disconnect fluid connectors (APC series, Cole Parmer Canada, Montreal, QC) are placed at the inlet and outlet of the multipath vessel phantom. A Y-connector is connected to an inlet, providing an access point for the catheter/guidewire and connection to a pump.

Finally, a small amount of room-temperature vulcanisation (RTV) silicone sealant is placed along each vessel trajectory, before mounting both plates together, and around the external edges of the phantom. This is done to eliminate fluid leakage from the phantom.

The constructed phantom is shown in Figure 2.

The multipath vessel phantom

Radiographic images of the phantom are shown in Figure 3. To highlight the various navigation paths, water was pumped through the phantom while iodinated contrast was manually injected into the left inlet (Figure 3a) or the right inlet (Figure 3b).

Flow through the phantom is highlighted by the diffusion of contrast. In areas of high flow and volume, more contrast is present; thus, a brighter image of the vessel is obtained. In the smaller diameter vessels there is lower flow and volume; thus, a lower concentration of contrast agent results in reduced image contrast between the vessel lumen and the rest of the phantom. As shown in Figure 3, the diffusion of contrast throughout the phantom is not uniform. The varied contrast throughout the phantom will allow trainees to practise catheter manipulation in a variety of visualisation scenarios, similar to clinical intervention, where some vessels are difficult to visualise after contrast injection.

Discussion

Core catheter-based interventional skills are required in common medical interventions, including angiography, balloon and stent placement, coil deposition and intracardiac electrophysiology studies. Trainees currently develop core skills and therapeutic skills simultaneously in the clinic under the guidance of experienced interventionalists—a costly method. Using a simple, cost-effective phantom, core skills may be developed outside the clinic, reducing cost and patient risk. In addition, this phantom can be used to provide quantitative assessment of new catheter guidance techniques [12–14].

(a)

(b)

Figure 2. (a) The constructed multipath vessel phantom with the Y-connector (b), labelled for catheter manipulation through the phantom's left side. The set-up is configured with the Y-connector attached to the left inlet of the multipath vessel phantom. All other connectors on the phantom act as outlets. For catheter manipulation through the phantom's right side, the Y-connector is attached to the right inlet and the left inlet becomes an outlet.

Consideration towards a simple to construct cost-effective phantom to provide core interventional skills training has led to the presented multipath vessel phantom. The six design considerations outlined previously were all met. The multipath vessel phantom is radiotranslucent, contains a variety of path trajectories for training and is compatible with fluid for contrast injection. In addition, the phantom is easily constructed using two acrylic sheets and common machining tools. The simplistic construction will allow most centres to independently construct and validate this phantom. Furthermore, the computer aided design files can be easily modified to accommodate advanced tasks.

As with any phantom, limitations exist. Vascular elasticity, three-dimensional (3D) geometry and friction are not mimicked by the multipath vessel phantom. These factors were intended omissions, as the phantom's purpose is to provide a cost-effective platform for core skill development. Softer materials, such as silicone elastomer, have previously been used to create realistic 3D geometry; these phantoms are not suitable for catheter manipulation as the soft materials cause the catheter to stick to them during manipulation and they can be perforated by a catheter or guidewire. Vessel perforation is not possible with the presented phantom owing to the rigid material used. Thus, the ability to simulate this complication *in vitro* is not possible. Instead, safe catheter

handling techniques can be taught and assessed with the phantom to reduce vessel perforation in a clinical setting, including advancing the guidewire before the catheter, always imaging while manipulating the catheter/guidewire, safe probing of vessel bifurcations with a guidewire and the effective use of contrast agents for visualisation. With these safe handling techniques taught before *in vivo* catheter manipulation, the trainer can focus on therapeutic skills development, which includes avoiding vascular perforation.

In addition to providing a simple platform for core skill development, the materials and construction of this phantom limit its susceptibility to geometric distortions caused by environmental factors (moisture, light and temperature) and ageing while the phantom is in use or placed in storage. These attributes improve the longevity of the phantom, which for long-term use only requires periodical replacement of the fluid connectors, thus providing a simple, cost-effective, long-term platform for core-skills training.

It should be noted that this multipath vessel phantom is not intended to replace current training methods, but instead to complement current methods by allowing core skills to be developed outside the clinic. Using the training phantom to develop core catheter handling skills will enable clinical training programmes to focus on therapeutic skill development such as inflating

(a)

(b)

Figure 3. Radiographs of the multipath training phantom injected with contrast via the left inlet (a) and right inlet (b). The catheter is clearly visible in both images.

balloons, placing stents or depositing coils. A study is currently under way to assess the validity of this phantom for skills training. The results of this study will be the topic of future work.

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