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New in vitro experimental model of aorta for training in intravascular ultrasonography (IVUS)

MAURÍCIO DE AMORIM AQUINO, MD, MSc
Vascular surgeon
Specialist in Angioradiology and Vascular Ultrasound
Head of Services for Vascular Surgery at Santa Izabel Hospital
Santa Casa da Bahia
Professor at the Medical Residency Program in Vascular Surgery at
Edgard Santos University Hospital, Federal University of Bahia
TATIANA OLIVEIRA DE SOUZA AQUINO
Nutritionist
Specialist in Enteral and Parenteral Nutrition
NATÁLIA BOONE ALVES
Nurse
Product Manager at Medicicor Comercial Eireli

Abstract

Objective: *The aim of this study was to develop a low-cost experimental model with excellent applicability to obtain intravascular ultrasound images that mimic the abdominal aorta and its main branches for IVUS demonstration and training.*

Methods: *Branched Dacron prothesis incorporated by tissue-mimicking agar was used in IVUS imaging studies (axial section images, ChromaFlo and 2D longitudinal reconstruction).*

Results: *IVUS images using the in vitro model had well-defined limits and precise branches locazation, as expected for endovascular procedures. The agar tissue-mimicking material proved to have satisfactory echographic density, without artifacts that would interfere in the analysis of the images. The model was practical for guidewire and IVUS catheter navigation with the possibility of reusing the same model several times in workshops (30 days under refrigeration and approximately 07 days at room temperature).*

Conclusion: *This experimental model proved to be satisfactory for training in the handling and analysis of images with IVUS (localization and measurement of diameters, area and distances in the* *aorta and its main branches). The low cost, easy preparation and possibility of varied conformations, allows for the applicability of phantoms for use with IVUS catheters in the simulation of multiple clinical scenarios.*

Keywords: Vascular phantom; Intravascular ultrassonography; Experimental model; Agar; Endovascular Procedures.

INTRODUCTION

Progress in the endovascular treatment of aortic diseases requires the use of advanced imaging techniques for adequate surgical planning and the precise execution of procedures [1,2,3].

The increase in endovascular treatment possibilities in the aortic region after branched prostheses and methods such as the Sandwich Technique and in situ fenestrated endoprothesis have given particular utility to intravascular ultrasound (IVUS), since it provides real-time imaging of the aorta for a more reliable measurement of the diameter, identification of thrombus or calcification, localization of branches and calculation of the distance between target vessels [3,4,5,6,7]. In addition, the use of IVUS reduces contrast volume and radiation doses in most procedures, as it reduces or even replaces the need for angiographies [7,8,9].

Adequate knowledge of the method and confidence in its application is fundamental for its use, with the learning curve being a delicate point in the process. Previous training, ideally on non-human models, takes greater advantage of the technique, allowing for better image recognition and material handling.

Ultrasound phantoms have been widely used for decades in academic research, industrial device design and professional training. Initially used for diagnostic ultrasound simulations, echocardiographic vascular access and studies of blood flow dynamics, they have also proved useful for IVUS [10,11,12,13,14,15].

Different phantoms are described in the literature, from structures with a simple, tubular, wall-only vessel (called “wall phantoms”), to complex, wall-less vascular models surrounded by realistic tissue-mimicking materials[10].

"Wall phantoms" are easier to fabricate, using solid materials as vessel mimicking materials, such as silicone and latex tubes. Frequently, they have a high ultrasound attenuation coefficient and no tissue-mimicking material in the surroundings, making them look like an unreal feature in ultrasounds and having an inadequate haptic response when interacting with IVUS devices [10,11,12].

In turn, the so-called "wall-less phantoms" are fabricated by creating an absence of vessel wall and lumen in a block of tissue-mimicking material. A hollow vessel is created, using a rigid lumen core, which is removed once the mold is defined. These phantoms do not incorporate a layer to mimic the vessel wall and, therefore, lack realism in IVUS images[10].

The ideal characteristics of a phantom depend on the intended application. Low-cost phantoms are available for some applications, for example, ultrasound needle guidance procedures and catheter handling in clinical training. However, only a few phantoms are acceptable for research on intravascular intervention because both tissues-mimicking surroundings and vessel visualization are required. An ideal model should also be hollow (for simulation of blood flow, if necessary) and haptic realistic for maneuvers with catheters and ultrasound probes. The ultrasound image in the simulator should show the vessel wall clearly, with liquid inside and the tissue around it[10].

Gel-based materials are a popular choice for ultrasound models. Agar has been used since the 1980s due to its easy availability and low cost. It has been demonstrated that agar makes a solid matrix, not vulnerable to fluctuations in ambient temperature (melting point of 78° C) and with a speed of sound transmission close to 1540 m / s - corresponding to the average speed of sound in tissues [11,16].

In this study, we seek to develop a low-cost experimental model with excellent applicability for obtaining an anatomically realistic ultrasound image of the abdominal aorta and its main branches, for IVUS demonstration and training.

MATERIAL AND METHODS

The experimental in vitro model production was carried out in two stages:

1. Abdominal aorta model and it main branches (celiac trunk, superior mesenteric artery, renal, iliac and hypogastric arteries) fabrication, performed using a bifurcated Dacron® prosthesis. The branches were sutured in the prosthesis according to the most common anatomical arrangement, height and position around the circumference (clock position). (Figure 1).

2. Tissue-mimicking material fabrication and blood-mimicking fluid, using agar, water and plastic box (Figure 2), in which the previous model remains wrapped and submerged.

The segments of the Dacron® prosthesis corresponding to the external iliac arteries were exteriorizated by counter-openings in the closed plastic box, in order to allow an access route for the IVUS catheter navigation. In this way, the experimental model of gelatine is protected against external damage, the presence of air in the system is reduced (preventing artifacts that may hinder the ultrasound visualization) and the water leakage from the system is prevented, which could damage other electrical components of the IVUS device.

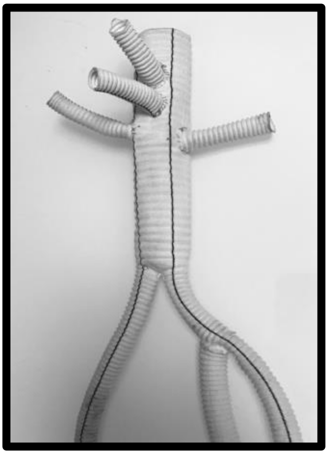

Figure 1. Modified Dacron prosthesis with branches.

Figure 2. A) Dacron prosthesis in an agar tissue-mimicking material. B) Plastic box with water and openings for exteriorization of the iliac branches.

To test this new experimental model in vitro for training professionals in the IVUS technique, we used the IVUS Digital Visions PV .035 and IVUS Digital Visions PV .018 (Philips) catheters, moving them along the prosthesis inside on guide wires for acquisition axial sections images, ChromaFlo images and two-dimensional (2D) longitudinal reconstruction (Figure 3).

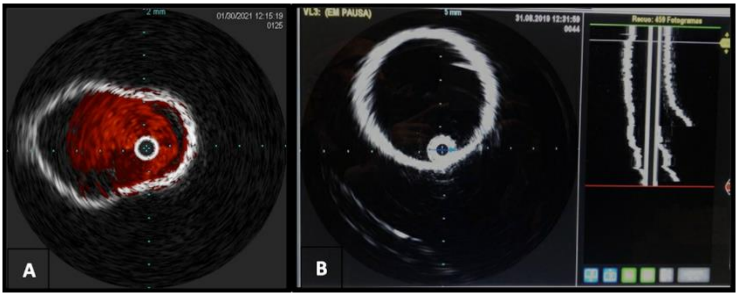

Figure 3. A) Phantom test with ChromaFlo. B) Phantom test with two-dimensional (2D) longitudinal reconstruction.

RESULTS

The analysis of the in vitro experimental model showed echographic images of a tubular structure that is easy to identify and with well-defined limits, with a precise localization of the branches sutured to the main body of the prosthesis. (Figure 4). The images also made it possible to perform usual measurements in endovascular procedures, such as calculating diameter and area (Figure 5).

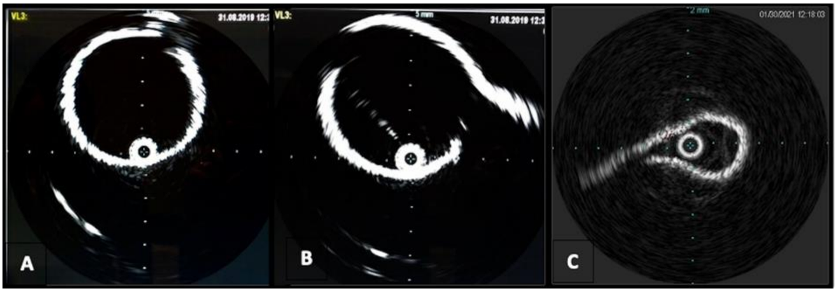

Figure 4. Phantom branch test with IVUS: A) Superior Mesenteric Artery B) Renal Arteries C) Hypogastric Artery.

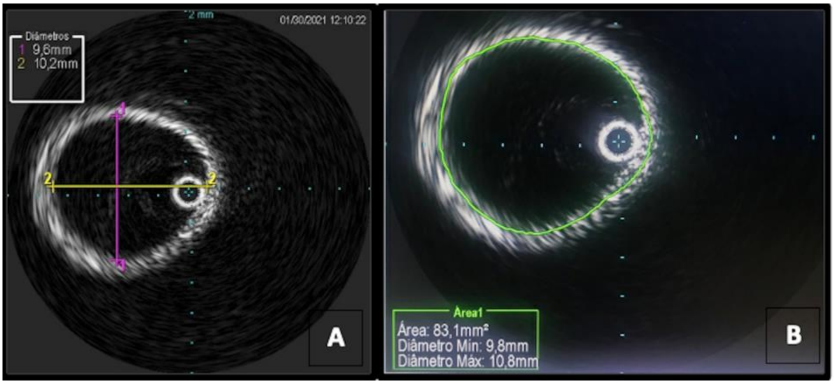

Figure 5. Diameter measurement (A) and area calculation (B) with IVUS.

The agar material surrounding the prosthesis proved to be of satisfactory echographic density, without promoting artifacts that would interfere with the analysis of the images obtained.

This model proved to be practical for navigation of guidewires and IVUS catheters with the possibility of reusing the same model several times in training and events (Fig 6); after use, the agar remains conserved for about 30 days if stored under refrigeration and approximately 07 days at room temperature. After agar wear, the Dacron® prosthesis and plastic box can be reused in new models, reducing costs and preparation time to be used for subsequent training sessions.

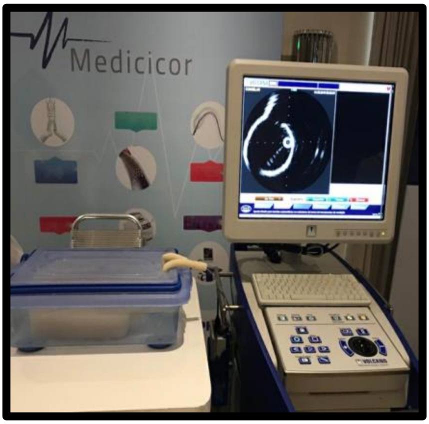

Figure 6. Phantom for hands on at scientific events.

DISCUSSION

Intravascular ultrasound has become an important adjuvant tool in the diagnosis and treatment of various vascular pathologies. Especially in the aortoiliac region, the use of this device allows for a detailed analysis of the vessel lumen with identification of thrombi and calcifications, localization of visceral branches and measurements of diameter and lengths for adequate programming and therapeutic execution.

The evolution in the treatment of aneurysms and aortic dissections - currently enabling the use of branched or fenestrated prostheses, in addition to the emergence of innovative surgical techniques such as the Sandwich Technique - expanded the endovascular treatment of these pathologies and brought the need to optimize the surgical time and reduction in radioscopy time and contrast volume, which is feasible with the use of IVUS by trained professionals.

The use of IVUS has already shown improved results both in elective procedures and in urgent situations in acute aortic syndromes. In a scenario that already requires surgical time optimization, the domain in handling IVUS catheters and images can make a difference to the patient's prognosis.

With the growing need for image quality improvement to increase the success rate of the procedure, avoid complications and reduce costs, the training of professionals for IVUS is necessary. Many health professionals are not used to ultrasound images; therefore, the most rational thing is to train them primarily on non-human models. Aiming at training professionals with the new technologies that arise with medical advances, the use of experimental models in vitro brings the possibility of training and repetition of the method with simulations in clinical scenarios closer to reality.

The development of these experimental models often requires the use of advanced technologies, which also increases their cost, not allowing easy access to the method. The cost of industrialized models makes it difficult to purchase because they are imported, paid for in foreign currency and with high import costs, in addition to being found mainly for training in echoguided puncture with the use of conventional ultrasound, but not for training of IVUS.

Simulators made with agar-based gels are inexpensive and quick and easy to produce, even by hand. They are durable at high temperatures, non-toxic and disposable, but lack long-term stability [15]. However, under ideal storage conditions, agar gels can remain stable for up to two and a half years, according to the technique described by Madsen in 1998 [17] and can serve as a perfect substitute for gelatin gels that suffer from temperature-dependent structural instability [15,16].

The developed model has the advantages of easy acquisition of materials and low total cost of manufacture. Values may vary depending on geographic localization and temporal variation. The plastic box and agar for making the model presented has a total cost of generally less than R$ 150,00 (about U$$ 30,00) in the period of making this article. The fragments of Dacron® prostheses can be obtained by remaining segments, without the use of arterial surgeries or as a donation from the manufacturers of those parts close to the sterilization expiration limit. Suture threads can be obtained in the same way as prostheses. The device is light, easy to mobilize and pack, and can be used to train professionals in the laboratory environment, as well as in events such as congresses and exhibitions.

Method limitations: The model used was made for use for a short period of time, keeping its properties for about 30 days, since no antifungals were added to the agar; such a resource, if conservation is necessary for longer periods of time, can be added, with conservation demonstrated to be for up to 2 and a half years [15,17]. Also, although this simulator has proven to be useful for making images with the

ChromaFlo function, it was not specifically designed to perform flow simulation - which is beyond the scope of this work. For this purpose, a fluid inlet and outlet can be incorporated into the model to withstand pressure infusion.

CONCLUSION

The in vitro experimental model for training developed by the authors proved to be satisfactory for training in the handling and analysis of images with IVUS, with the aim of simulating the analysis of the localization and measurement of diameters and distances in the aorta and its main branches. In addition to low cost, easy preparation, and reproducibility, the possibility of varied conformations and distribution of branches, allows for the applicability of the analysis resources, available in the IVUS catheter, in the simulation of multiple clinical scenarios.

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