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ARTICLE

Endovascular technique simulator for Neuroradiology learning

Simulador de técnica endovascular para aprendizado de Neurorradiologia

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ABSTRACT

Background: Vascular cerebral infarction (or stroke) is recognized as the third leading cause of death worldwide, and acute arterial occlusion comprises the main mechanism underlying ischemic stroke. Cerebrovascular diseases are treated by intracranial endovascular interventions employing minimally invasive intravascular techniques, such as neuroimaging. Conducting practical training in this area is a necessary task since patient safety is a considerably significant factor. There has been a steady increase in scientific research focused on validating endovascular simulation as a tool for training interventionists in endovascular procedures. Current literature confirms the idea that there is a beneficial role of simulation in endovascular training and skill acquisition and technique improvement. **Objective:** To develop an endovascular technique simulator for learning Neuroradiology. **Methods:** The methodology consisted of developing a simulator using 3D printing technology. **Results:** A literature search was carried out, commencing in August 2017, through consultation of the Medical Literature Analysis and Retrieval System Online (MEDLINE) and Latin American and Caribbean Health Sciences Literature (LILACS) databases, using the PubMed and BIREME websites, respectively. Meetings were held between the neuroradiologist specialist and programmers to develop the simulator, which was carried out in three phases: design of the arterial system, design of the prototype of the arterial system in computer graphics, and confection of the arterial system simulator in 3D. **Conclusion:** The simulator is ready for testing by residents and can enable the student to learn through simulations that reproduce, as realistically as possible, the situation to be subsequently experienced using a concrete tool.

Keywords: Endovascular Procedures; Education.

RESUMO

Introdução: O acidente vascular cerebral (AVC) é a terceira causa de morte em todo o mundo e uma oclusão arterial aguda é o principal mecanismo subjacente ao AVC isquêmico. As doenças cerebrovasculares são tratadas por intervenções endovasculares intracranianas utilizando técnicas intravasculares minimamente invasivas, como a neuroimagem. Realizar treinamento prático nessa área é uma tarefa necessária, pois a segurança do paciente é um fator considerado significativo. Houve um aumento constante de pesquisas científicas focada na validação da simulação endovascular como uma ferramenta para treinar intervencionistas em procedimentos endovasculares. A literatura atual confirma a ideia de que existe um papel benéfico da simulação no treinamento endovascular e na aquisição de habilidades e aprimoramento da técnica. **Objetivo:** Desenvolver um simulador de técnica endovascular para o aprendizado de Neurorradiologia. **Métodos:** Desenvolvimento de um simulador utilizando a tecnologia de impressão em 3D. **Resultados:** Realizou-se uma pesquisa bibliográfica da literatura, tendo início em Agosto de 2017, com consulta feita ao banco de dados *Medical Literature Analysis and Retrievel System on Line* (MEDLINE) e Literatura Latino-americana e do Caribe em Ciências da Saúde (LILACS), por meio respectivamente dos sites PubMed e BIREME. Foram realizadas reuniões entre o especialista em Neurorradiologia e os programadores para desenvolver o simulador, que foi realizado em três fases: desenho do sistema arterial, desenho do protótipo do sistema arterial em computação gráfica e confecção do simulador do sistema arterial em 3D. **Conclusão:** O simulador está pronto para ser testado por residentes, podendo possibilitar ao aluno aprender por simulações que reproduzem, da forma mais realista possível, a situação a ser vivenciada posteriormente usando uma ferramenta concreta.

Palavras-chave: Procedimentos Endovasculares; Educação.

INTRODUCTION

Acute vascular cerebral infarction, recognized as the third main cause of death worldwide, is commonly described as a stroke and represents the leading cerebrovascular disease. It is detected by a sudden onset of neurological deficit and brain or retinal cell death due to prolonged ischemia. In turn, a transient episode of neurological dysfunction caused by cerebral,

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medullar, or retinal ischemia, without the presence of acute infarction, is denominated a transient ischemic attack (TIA)[1].

Acute arterial occlusion is the primary mechanism underlying acute ischemic stroke, with large vessel arterial occlusion being identified acutely in most patients[2]. In approximately 20% of patients, no arterial occlusion can be identified. These patients spontaneously recanalize or have small vessel lacunar stroke, exhibit milder neurological symptoms, and continue to have excellent neurological outcomes[3]. Patients with large artery occlusions tend to present severe neurological symptoms from the start, a higher clot factor, and poor development. Recanalization of these great artery occlusions is associated with better neurological outcomes[4].

Another key factor that determines the outcome of a stroke is the time to achieve arterial recanalization. In an experimental study, irreparable damage to neurons could be observed within minutes of a critical drop in cerebral blood flow[5]. There is still a healthy debate regarding the existence of a fixed time window, although there is no doubt that faster recanalization greatly increases the chance of achieving a better neurological outcome[6]. In addition to intracranial arteriosclerosis, intracranial arteriovenous malformations (AVMs), and dural arteriovenous fistulas or dural AVMs, cerebrovascular diseases such as stroke are treated by intracranial endovascular interventions using minimally invasive intravascular techniques. There is clinical and scientific evidence demonstrating the application, safety, and efficacy of endovascular techniques for the treatment of cerebrovascular diseases[7].

In this context, standardizing teaching for training for all these techniques represents a unique challenge.

In the traditional learning model, the surgical trainee acquires skills in an individualized teaching situation using the patient as teaching material. Although patient safety is justified by the fact that a senior surgeon guides the operations, such teaching no longer meets the requirements of modern surgical skill training. Compelling grounds for this are the desire for greater uniformity in training, growing public demand for "quality assurance", and a major change in operating techniques. Vascular surgery, in particular, has undergone a significant change in daily practice due to the evolution of endovascular techniques[8,9].

There are data substantiating that the experience and training of the operator when performing neuroradiological procedures is a vital determinant in the outcome of the operation. In order to ensure quality of care, the Accreditation Council for Graduate Medical Education (ACGME) published training requirements for interventional neuroradiology (INR)[10]. However, today there are only seven INR training programs in the United States that are approved by the ACGME.

Both the ACGME and the various neuroscience societies around the world recognize that all candidates should receive training in diagnostic cerebral angiography with a minimum performance of 100 cervical-cerebral angiographies under the supervision of a qualified physician[10]. This minimum requirement reflects the linear decrease in complications and the reduction in fluoroscopy duration observed after the first 100 procedures. Typically, the required diagnostic experience is gained within a preliminary year before the start of ESNR (European Society of Neuroradiology) intervention training, in a way that the total training time comprises a minimum of two years. This preliminary year allows the development of the skill set needed to learn intervention techniques. These skill-sets include familiarity with the use of needles, catheters, and guides, as well as basic knowledge of radiation safety and patient assessment, management procedures, and basic interpretation of angiography imaging[10].

The current training standards consist of the cognitive and technical prerequisites required to competently practice interventional neuroradiology (INR)[10].

In 2004, the Food and Drug Administration (FDA) suggested that the use of simulators should be an integral part of training for interventionists who wish to perform carotid artery stenting (CAS) procedures. Consequently, the last decade has witnessed a steady increase in scientific research focused on the validation of endovascular simulation as a tool for training novice and experienced interventionists in endovascular procedures[11,12].

Rapid advances in simulator technology now allow the individual interventionist to upload and incorporate patient-specific digital imaging and digital communication (DICOM) data (computed tomography — CT; magnetic resonance imaging — MRI) into the simulation software. This new concept of patient-specific analysis offers the opportunity for the trained interventionist to rehearse and plan the procedure on the actual patient's anatomy before performing the intervention[13]. Thus, the correct choice of endovascular tools, reduced use of contrast and fluoroscopy, and optimal endovascular team preparation can result in improved patient safety.

Several studies reported a remarkable influence on the behavior of interventionists who performed difficult CAS interventions, especially for the selection of optimal fluoroscopy angles, selective catheters, and devices for accession to the common carotid artery (CCA). Also, inexperienced interventionists often altered their stent and balloon dilation strategy. Interestingly, the trial provided the participants with an excellent opportunity to assess the complexity of the case, thus performing a more experienced intervention[14,15,16].

Consequently, endovascular simulation can be used to increase safety in the hemodynamic room or the operating room through staff training by practicing a specific scenario before treating the actual patient with the entire team.

Currently, several simulator models are commercially available, such as the AngioMentor Express (Simbionix USA Corp., Cleveland, OH, USA); the Vascular Intervention System Trainer (VIST) (Mentice AB, Gothenburg, Sweden), and the SimSuite (Medical Simulation Corporation, Denver, CO, USA). These are high-cost acquisition simulators that require ongoing maintenance, rendering them difficult for Brazilian educational institutions to access.

Given the above-mentioned data, there is a need to develop a simulation system for training and pre-surgical learning, which may result in advantages during operations for both the medical team and the patient, with consequent possible better postoperative conditions for the patient.

METHODS

Development of the simulator

The simulator was developed using 3D printing technology by a Neuroradiology specialist, mechanical engineers, and graphic designers, and is divided into two parts: external support and transport structure and arterial system.

External support and transport structure

The outer structure consists of a case measuring 77 cm in length, 36 cm wide, and 18 cm high (Figure 1). The case is made of *Pinus elliottii* wood covered with PVC on the outside to simplify cleaning, as well as being materials without X-ray opacity.

The walls are 80 mm thick, and the four corners present 2-cm wooden pillars which offer stability and strengthening of the structure. In the center of the right-side face, when viewed from above, there is a wooden handle with a thickness of 2 × 2 cm for transportation.

The model has six sides, one anterior, one posterior, one upper or cranial, and one lower or caudal, and two lateral sides, one right and one left.

The anterior side consists of a 50-mm thick cover that can be slidably removed in the caudal-cranial direction, which provides access to the inside of the simulator. The purpose of this side is a possible resolution of technical problems.

On the lower or caudal side of the simulator, at two points situated 8.5 cm from the lower face, there are two holes where an introducer for access to the simulation system of an individual's arterial system measuring approximately 170 cm is located. Access is by means of a 6 F (French, scale) valve introducer (Boston Scientific Boston, MA, USA).

Arterial system

The arterial system was designed by means of a freehand drawing by the author, based on normal anatomy according to a circulatory system model found on the internet (Figure 2A).

At first, a model of the entire arterial system was constructed using a white PVC (polyvinyl chloride) hose measuring 60 cm long with 1" (inch) in diameter, and 0.5-cm walls. A hot air blower was utilized to model the hose and to obtain the angulation of the aortic arch, using the anatomical basis of the arterial system as a parameter. The cranial face of the aortic arch curvature was modeled with epoxy resin on a PVC dummy. Since transparent hoses are considerably flexible and did not support the curve of the arterial system, with this manufactured model, the spatial idea of the part of the simulator's circulatory system was formatted (Figure 2B). The model was redesigned and scaled graphically with measurements, undulations, and curves at angles similar to those of a healthy adult arterial system, without variations or pathologies, based on a 3D printer-compatible circulatory system design purchased from turbosquid.com. Initially, we attempted to print on the 3D printer using flexible material (Figure 2C), which, in order to maintain the curvatures and angles similar to anatomical parameters, would require significantly thick walls. Walls measuring 15 mm thick would hinder the construction of the aortic arch with sufficient clearance. Due to the non-viability of flexible material, we

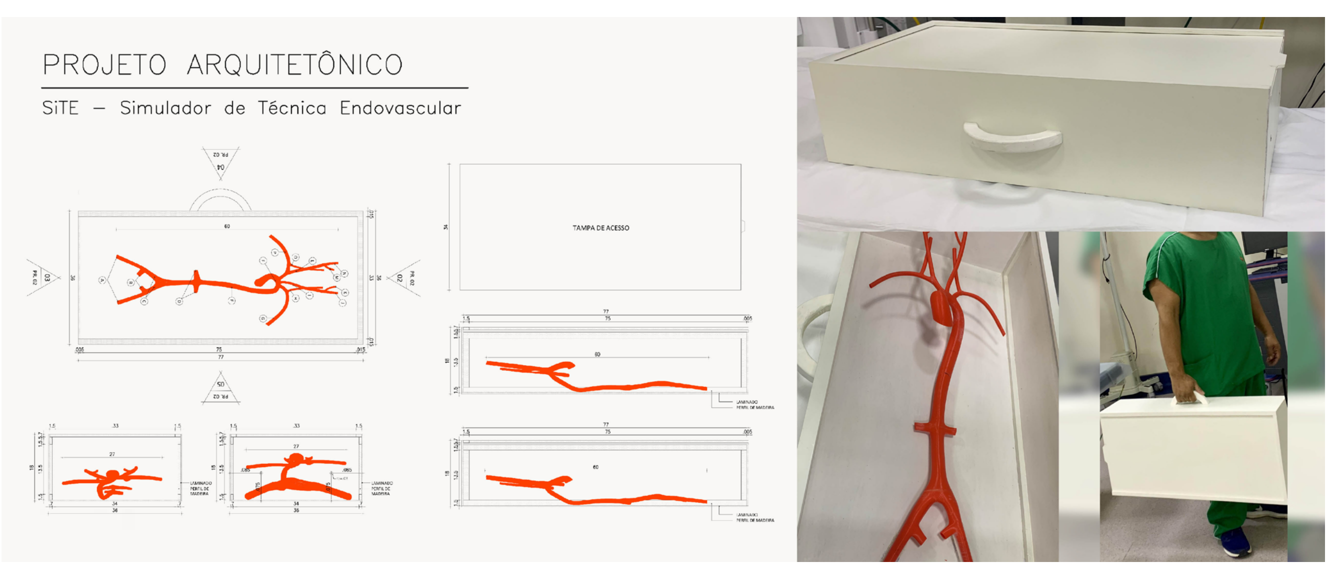

Figure 1. Architectural project and simulator.

decided to opt for a lighter, more rigid material, with walls and X-ray opacity (Figure 2D).

The prototype of the human circulatory system that was designed in a 3D computer graphics printer program contains a real-like arterial system including arterial segments in the direction of femoral blood flow, ascending aorta, aortic arch, brachiocephalic trunk containing the right common carotid artery, as well as the proximal portions of its branches, the right subclavian artery segment measuring 14 cm, and the right vertebral artery measuring 11 cm, which exits at 2 cm from the beginning of the subclavian artery. On the same upper portion of the aorta, at 2 cm from the brachiocephalic trunk, emerges the left common carotid artery, measuring 14 cm in length, which ends at its bifurcation, from where the left internal carotid artery looms with 4 cm in length, as well as the external carotid artery (medially), measuring 3 cm long.

The aortic arch has a right to left and anteroposterior angle. On its upper side, before descending, the left subclavian artery emerges and has an upward path. Before shifting its direction laterally, the left vertebral artery emerges cranially 2 cm from the aorta, measuring 11 mm in length.

The descending aorta begins at the end of the arch and has a smooth caudal orientation. Within 24 cm, the renal arteries emerge from both lateral sides and measure 2 cm in length. In the infra-renal segment of this prototype, the aorta measures 10 cm and bifurcates into two iliac arteries 4 cm from its beginning in caudal direction, which, in turn, also bifurcate, originating a branch of its medial side towards the midline, corresponding to the internal iliac artery, which, in this prototype, measures 2 cm long. The external branch continues caudally for 8.0 cm, comprising the femoral artery, through which two equidistant points from the upper lateral edges, where the distal end of the introducer was placed, which is the access of the system with catheters and guides (Figure 3).

RESULTS

An endovascular simulator was developed for use in neuroradiology learning.

Usage techniques

The simulator should be used without liquids and on a hemodynamic table, and the catheter and guides should be controlled on the device monitor at the equipment's lowest fluoroscopy rate (pulse rate). The simulator should be placed on the distal end of a hemodynamic table, with the distal part located where the head is normally situated (Figure 3). All radiological protection equipment should be employed, with a screen, ceiling protector, and a table skirt, and the operator must wear an apron and thyroid protector.

Endovascular technique

In order to perform the selective catheterization of the supra-aortic vessels, a vertebral curve or HeadHunter 5 F catheter should be inserted into the introducer, to the right of the simulator, and navigated with the left hand to move it forward. The right hand should be used to mobilize the table, accompanying the distal end of the catheter and guiding it until reaching the aortic arch. During this course, it is essential to recognize if the catheter is moving or not towards the contralateral femoral artery and bilateral renal arteries (Figure 2D).

The hemodynamic arch should be positioned in a way that allows the visualization of the open aortic arch. Therefore, the right hand should hold the proximal end of the catheter in order for both hands to perform rotational, clockwise, and counterclockwise movements, with a few centimeters to advance and retract to first catheterize the brachiocephalic artery, right vertebral artery, right carotid artery, right internal carotid artery, and right external artery play horizontal and rotacional movements (Figure 4).

After catheterization, the catheter should be retracted to the arch, and the table should be repositioned with the right hand. Next, the left internal and external carotid should be catheterized, the table should be retracted and, if necessary, the arch should be mobilized for better visualization, followed by catheterization of the left and vertebral subclavian

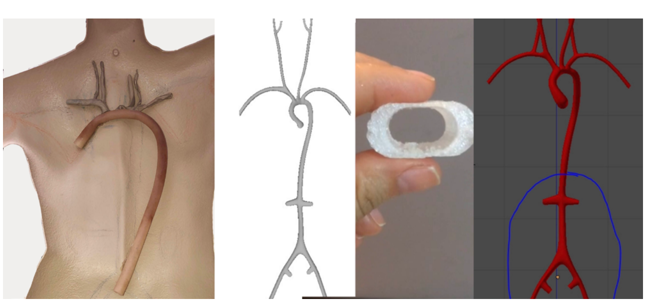

Figure 2. (A) Initial mockup. (B) Initial design acquired on the turbosquid.com website. (C) Flexible material. (D) Redesign of the cranial and caudal extremity.

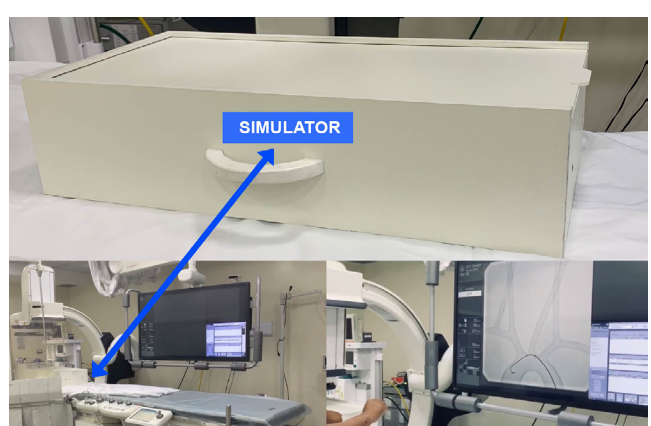

Figure 3. Arterial system of the simulator on the hemodynamic table and the operator at the usage position, with a monitor showing the imaging of the arterial system by fluoroscopy.

arteries. These previous steps should be repeated with the 0.35" x 180 cm guide, always 2 or 4 cm in front of the catheter. After passing the guide, the catheter should be advanced over it.

Following all catheterizations, the vertebral curve catheter should be removed. This procedure should be repeated with the Simons I curved catheter.

Subsequently, the material should be removed with view of the exit until the end of the aortic arch (Figure 5).

DISCUSSION

Diagnostic arteriography is the initial step to obtain praxis for the endovascular technique since, through it, the physician acquires the notion of working with long, flexible instruments, in which only two movements comprise the grounds of the technique, rotational and horizontal[17,18].

The developed simulator has the purpose of training the haptic perception of these movements, which are the basis of the endovascular technique. The controls are visualized on the screen of the hemodynamic machine, and the target is located next to the operator, who conducts lateralized movements, unlike other techniques where the target is in front of the operator. The review that assessed the efficacy of simulators showed that simulation enhances learning and trainee performance allowing for repetitive training until the acquisition of competence[19].

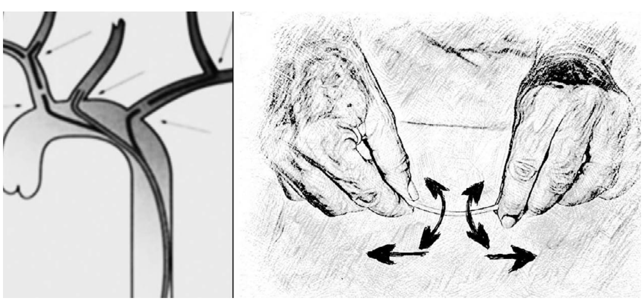

Figure 4. Horizontal and rotational movements.

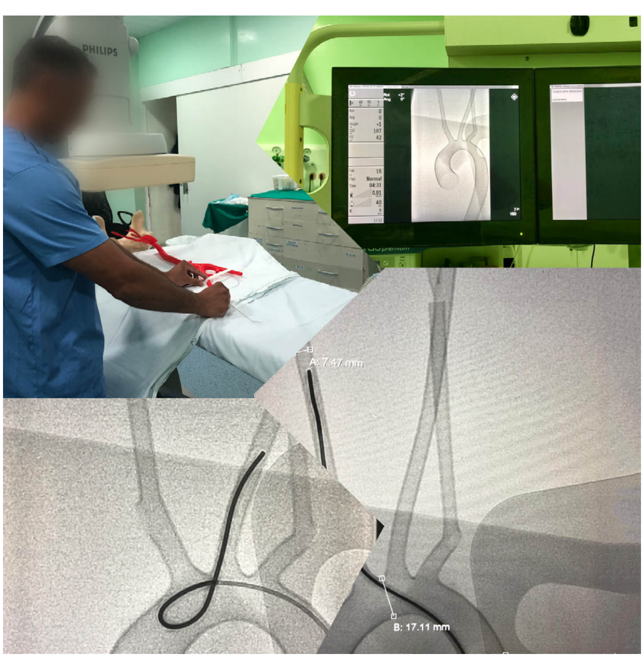

Figure 5. Operator to the right, accessing the system. Radiopaque images of the simulator without its case.

Given this simulator has the function of training the basic or structural movements of the endovascular technique and the spatial notion on the hemodynamic machine screen, a dry and radiopaque simulator was selected to perform catheter and guide training. No puncture or vascular access, nor contrast use was performed, as contrast administration is currently carried out by injectors and the 3D Road Map, an essential function in hemodynamic machines. Since the puncture of arteries and veins occurs similarly to the puncturing of other peripheral vessels, this topic was not added in the simulator.

There are data substantiating that the operator`s experience and training in the performance of neuroradiological procedures is a vital determinant in the results. Thus, the use of the endovascular simulator promotes more safety to the resident, resulting in a less traumatic process for patients and better postoperative conditions[20,21]. Since the endovascular system is technically quite complex, the simulator becomes a useful teaching and skill acquisition tool.

There are four types of endovascular simulation: virtual simulation, live animals, *ex vivo* materials, and 3D-printed vessels. Virtual simulators, such as the ANGIO Mentor (Simbionix, Cleveland, OH, USA), the Vascular Intervention System Trainer (VIST) (Mentice AB, Gothenburg, Sweden), and the SimSuite (Medical Simulation Corporation, Denver, CO, USA), are the most common. In addition to being durable, they enable replication of patient-specific situations, come in several models and carry low risk, but with low median fidelity, little haptic response, with high acquisition and maintenance costs[22].

The simulations in live animals enable high fidelity, but high costs and ethical problems as well. Simulations using placenta have the advantages of low cost, high accuracy, and low risk, but are single-use and do not reproduce human cervical vessels[22].

In this context, the simulators with capability for 3D-printing of vessels have the advantage of being able to replicate or reproduce specific lesions and vessels and display acceptable haptic responses for endovascular use. However, they have the disadvantage of being cost-dependent regarding the material of which they are made; their durability depends on the equipment utilized, and requirements for maintenance, in some cases due to the use of fluids and connections, in addition to the flexibility not always being similar to that of vessels[23].

The proposed simulator is an original prototype. It is printed in 3D, with solid and hollow molds, with thin and resistant walls, which allows carrying reality-like simulations without loss of the shape. The part that simulates the arterial system was printed in thermoplastic PLA (Polylactic Acid) on a 3D-printer that employs fused deposition modeling (FDM), of the brand 3DCCLONER. It was developed for use without fluids, and consists of a single piece, requiring no connections or devices to keep curves and angles similar to humans. It was developed with materials that are able to simulate the flexibility of the arterial system.

A next step will be the validation of the endovascular simulator through usability testing with residents in neuroradiology, neurosurgery, and vascular surgery. The implementation of training on a simulator prior to patient care enables more effective learning, with several features to be implemented in the future.

In conclusion, a physical simulator of the endovascular system was developed, and applied in the teaching and training of residents in Neuroradiology, Neurosurgery and Vascular Surgery. In addition, a patent application was filed.

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