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Artificial Cerebral Aneurysm Model for Medical Testing, Training, and Research

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Abstract

Artificial models of cerebral aneurysms for medical training and testing of medical devices were constructed from corrosion casts of the main cerebral arteries of a human specimen. Three aneurysms with a variety of shapes were simulated at typical locations. Rigid and soft models were made of silicone using the ''lost wax'' technique. The transparent silicone models were anatomically accurate and reproducible copies of human vascular casts. These models could be connected in a closed circuit that used an electric pump to simulate pulsatile flow. Endovascular procedures and surgical clip application were performed under fluoroscopic or direct visual control. Surgical clipping, endoluminal coil manipulation, and consecutive hemodynamic changes were visualized by digital subtraction angiography and direct observation. The model provides trainee surgeons with an understanding of clinical conditions. New medical devices, such as platinum coils, would be experimentally implanted in the model under stable conditions. These anatomically accurate and reproducible models of cerebral vasculature and aneurysms are valuable for medical testing, training, and research.

Key words: cerebral aneurysm, endovascular treatment, medical device, medical training, artificial model, detachable coil

Introduction

Artificial vascular models are useful for the preclinical evaluation of medical devices and implants.[2,9] The use of replicas allows the simulation of a stable endovascular environment and the introduction of circulation circuits allows the simulation of variable flow conditions.[2,3] Control of these parameters can optimize preclinical evaluations by engineers and physicians, consequently limiting the use of animal models to the mandatory simulation of biological aspects.

Human vascular models with and without aneurysms have been made by the lost wax technique, which allows an exact copy of the vasculature, to investigate flow dynamics and study human arterial hemodynamics.[1,5,6] This methodology can provide an unlimited number of wax copies from the initial human cast.[2] This anatomical reproducibility establishes stable in vitro conditions for medical training or device testing, although in vivo conditions are difficult to create experimentally. We believe that this model is also useful for medical training and testing of treatment devices.

Here we describe an artificial model of cerebral aneurysms.

Description of the Model

I. Preparation of vascular model

A corrosion cast of the vascular lumen of the craniocervical arteries was obtained from a nonfixed human specimen (a 72-year-old female) by injection of methylmethacrylate. The resulting complex vascular cast was simplified by eliminating the small branches to leave a clean arterial mold consisting of the aortic arch and the right carotid system, including the main branches of the internal carotid artery. The lumina of three saccular aneurysms of different sizes and shapes were simulated on

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this simplified arterial cast by placing berry-like methylmethacrylate structures of different sizes at the level of the anterior and posterior communicating arteries and at the bifurcation of the middle cerebral artery. These locations are typical for the development of lesions in the presence of a dominant A_1 segment and a large posterior communicating artery on the right. Subsequently, multiple wax copies of the original cast were created by prosthetic dentistry techniques. Rigid and soft vascular models were produced using silicone from these wax copies.

Rigid model: The rigid model consisted of a transparent silicone block containing a cavity reproducing the arterial cast. After the initial wax model was constructed, direct access to the aneurysm cavities was added to allow cleaning after the implantation of coils, by extending the aneurysm cavity with a straight tube (5 mm in diameter) to the model surface. The modified wax model was secured in a molding box and embedded in liquid silicone, which solidified into a solid transparent block. After the silicone cured, heating the model allowed the wax to drain through the multiple holes connecting the vascular lumen to the model surface. The resulting vascular openings could be fitted to tubes that allowed the model to be connected to a circulation circuit, and the tubes reaching from the aneurysm dome to the model surface were occluded with removable plastic obturators.

More proximal vascular segments such as the aortic arch and its branches were also constructed using a similar construction technique, which allowed for the construction of different vascular segments in a modular fashion.

Soft model: The soft model was prepared with visco-elastic properties and a wall thickness that approached the in vivo diameter by manually painting four to six thin layers of liquid silicone onto the wax copies to simulate the human arterial wall. After the silicone cured, the wax was melted, resulting in a carotid artery model with a thin wall and three aneurysms.

II. Endovascular procedure

Endovascular training or evaluation of a preclinical device used the rigid carotid artery aneurysm model together with the rigid aortic arch model, which were easily connected with a simple ''push and pull'' system (Fig. 1). Silicone tubes of adequate length were added to obtain the correct distances according to femoral arterial access, allowing simulation of the transfemoral approach. Then, the model was connected to a pump to simulate pulsatile blood flow. Model endovascular procedures can be monitored by both videorecording and digital subtraction angiography imaging techniques, including road-mapping. After initial imaging of the model, the aneurysms were filled with detachable coils (Fig. 2). Aneurysm embolization procedures were performed with both electrically[4] (Guglielmi detachable coil: GDC) and mechanically[9] (Detach Coil System: DCS) detachable platinum coils using methods similar to those in current clinical practice. After the procedure, the coils could be easily retrieved with an L-shaped probe by removing the obturators from the rigid model.

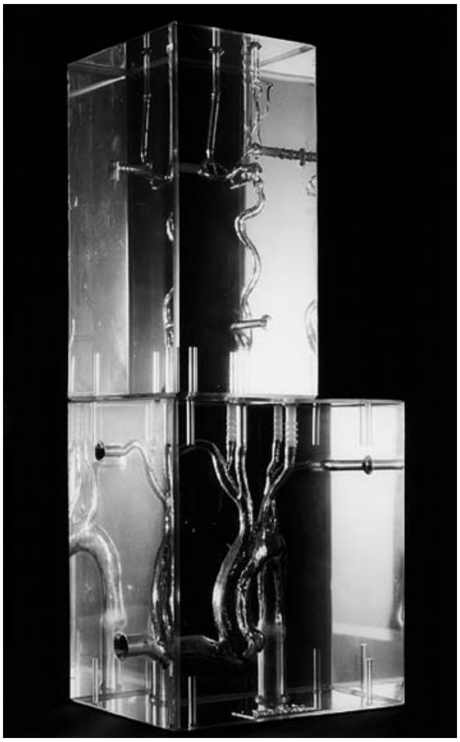

Fig. 1 Photograph of the right carotid artery rigid model with three aneurysms located at the origin of the posterior communicating artery, in the anterior communicating artery, and at the bifurcation of the middle cerebral artery. The silicone block can be connected to an aortic arch silicone block with a simple ''push and pull'' connection system. The white obturators are connected to each aneurysm cavity.

The soft carotid artery model (Fig. 3) provided similar conditions when connected to the pulsatile pump circuit. Digital subtraction angiography was performed before and after coil embolization of each aneurysm (Fig. 4). The implanted coils were easily retrieved through the vascular lumen using the L-shaped probe, and the model could be used again.

The whole training procedure can also be per-

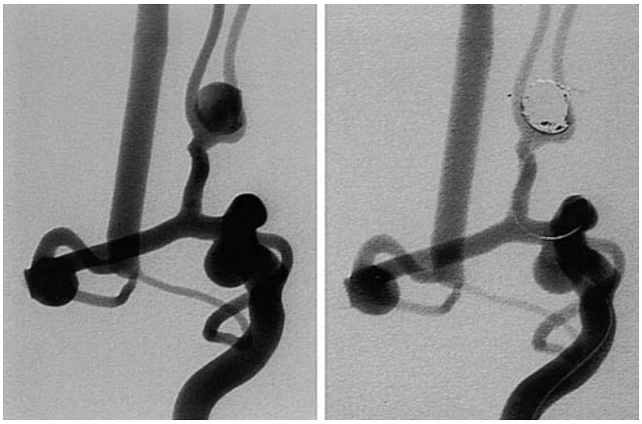

Fig. 2 Digital subtraction angiograms (anteroposterior oblique view) of the right internal carotid artery rigid model showing the three aneurysms at the origin of the posterior communicating artery, in the anterior communicating artery, and at the bifurcation of the middle cerebral artery. *left*: Before coils were placed, *right*: after coils were placed in the anterior communicating artery aneurysm.

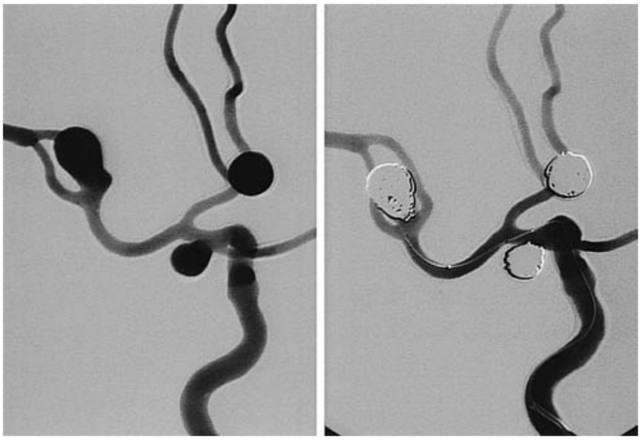

Fig. 4 Digital subtraction angiograms (anteroposterior oblique view) of the right carotid artery soft model showing the three aneurysms at the origin of the posterior communicating artery, in the anterior communicating artery, and at the bifurcation of the middle cerebral artery. *left*: Before coils were placed, *right*: after coils were placed in all three aneurysms.

Fig. 3 Photograph of the right carotid artery soft model with three aneurysms. The posterior communicating artery aneurysm has been clipped, and coils placed in the aneurysm at the bifurcation of the middle cerebral artery.

formed under direct observation when no radiological equipment is available, because both models are transparent.

III. Surgical clip application

Training for surgical clip application used the soft model, which has visco-elastic wall characteristics similar to those of a human carotid artery. The surgeon experienced the procedure of clip application which was similar to that of a human aneurysm (Fig. 3).

Discussion

The surgical treatment of cerebral aneurysms requires manual skill that develops with technical experience,[11] so surgeons are best trained under the careful supervision of senior staff. The use of endovascular treatment for cerebral aneurysms has become widespread in only a few years[7,8,10] since the introduction of the GDC.[4] Training in this technique requires a steep learning curve, with the most improvement seen during the first 100–200 cases.[7,9] The application of clips and the placement of endovascular implants such as coils have similar requirements for training and experience.

The increase in the numbers of technical solutions to cerebrovascular aneurysms means that not all training programs will have access to sufficient case material for training in current surgical and endovascular techniques. Although the technical aspects of an intervention are just one element of successful treatment, learning these can then free trainees to concentrate on other aspects, such as anatomy, that are also relevant to treatment. Additional training methods can enhance the surgeon's technical experience and should be considered as complementary educational tools.

The present artificial models were derived from human vascular corrosion casts by molding, as previously described by the ''lost wax'' technique, which allows for an exact copy of human vasculature.[6] The soft aneurysm model in particular provides a good training opportunity for aneurysm clipping for inexperienced neurosurgeons. Our model can also be used in variable anatomic contexts to allow for optimal training before the clinical use of devices, such catheters, wires, coils, and clips, under stable conditions. The preclinical training of surgeons using the artificial silicone models allows experiences of direct visual control[2,3] and insight into the folding pattern of coil introduction and the impact of manipulating proximal catheters and other devices.

The models are compatible with all current medical imaging methods, including magnetic resonance imaging, computed tomography, digital subtraction angiography, ultrasound, and intravascular ultrasound.[2,3] However, the excellent translucency of the silicone model allows for direct visual control, thereby avoiding the need for imaging equipment during evaluation, research, or training. Photographic documentation or video recording of devices within the model can be easily obtained even under conditions in which current diagnostic equipment, such as fluoroscopy, cannot be used.

Our artificial but realistic human vascular models provide reproducible test conditions to evaluate medical devices and train medical personnel, and the ideal environment for preclinical experimentation and exercises. The absence of biological conditions excludes biocompatibility testing, but the models can prevent unnecessary and expensive animal use.

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Commentary on this paper appears on the next page.

Commentary

Dr. Sugiu and his collaborators have presented a novel and interesting model that simulates the human cerebral vasculature for purposes of testing, training and research. These models very accurately approximate the human intracranial circulation and the digital angiograms provided in the publication are of excellent quality. These models can be of significant benefit for the purposes outlined by the authors. In particular, I believe this model would be of benefit in testing new endovascular devices and for endovascular training. For surgical practice, the model is probably of less value but certainly does provide some benefit for training inexperienced surgeons. As pointed out by the authors, surgical management of intracranial aneurysms is but one aspect of the overall management of patients of intracranial aneurysms. Furthermore, application of the clip, which can be simulated with this model, is but one aspect of the surgical procedure required to cure intracranial aneurysms. Necessary skills such as opening the sylvian fissure, evacuating subarachnoid blood, opening the lamina terminalis, and avoidance of injury to surrounding neural and vascular structure are all extremely important aspects of aneurysms that cannot be simulated with this model. The model does, however, provide trainees with the opportunity to gain experience in the application of multiple clip constructs such as fenestrated clips and tandem clipping to avoid distortion of the parent vessel. Given the fact that there are inadequate animal models for intracranial aneurysms on which to practice these skills, I believe the authors have provided a useful tool for our specialty.

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The preparation of artificial models of the human cerebral vasculature that allow professionals in training to develop the necessary ability to deal with human subjects is extremely welcome. A perfect model is yet to be made, so in many instances animal sacrifice will still be necessary. Nevertheless the authors' efforts have contributed significantly to the development of a simple yet effective method of mimicking the real life situation. The method is in our opinion more suitable for individuals who pursue the career of endovascular surgery and could play a role in the development of new endovascular techniques dedicated to vascular surgery.

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The authors have developed a model of cerebral aneurysms through a series of procedures using corrosion casts, wax copies and silicone. In comparison with previous studies (refs. 2 and 3 of this article), they advanced further by making a 'soft' model by manually painting thin layers of liquid silicone onto the wax copies, simulating the human arterial wall, and by applying the model to the practice of endovascular coil embolization and surgical clip application for cerebral aneurysms.

In addition to the simulation of aneurysms, this technique seems to have great potential for application to various cerebrovascular diseases, as the authors have already illustrated in the field of arteriovenous fistulas (ref. 2). Since the introduction of the Guglielmi detachable coil embolization technique, development of microsurgical skills for dealing with cerebral aneurysms has become of great concern to young neurosurgeons as well as residents in training. Intensive training is also required to be a good neurointerventionist. In this respect, development of an artificial cerebral aneurysm model seems to be very important. I expect the authors to present data about the physical characteristics of the model, compared with the human situation, and to further elaborate this model to simulate more realistic circumstances in treating cerebral aneurysms.

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