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The 3D printed models technology for the management of intracranial aneurysms

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ABSTRACT

Management of intracranial aneurysms is still a therapeutic challenge, especially in cases of complex lesions. Thus, the improvement of the study and intervention planning possibilities correlated with the access to continuous professional training based on simulation and clinical diversity represent optimal conditions for the efficient solution of this pathology. The development of three-dimensional printing technology offers a new opportunity in the modern treatment of intracranial aneurysms. The aim of this study is to present some aspects related to the materials and methods of manufacturing simulation models of individual 3D printed aneurysms and their influence in the optimal management of these lesions.

Keywords
intracranial aneurysm,
3D printed models

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INTRODUCTION

Intracranial aneurysms are increasingly complex vascular lesions, both in terms of their shape and relationships with parent and adjacent vessels. These will require a much more elaborate interventional treatment, based on a much more careful anatomical study and a much clearly interventional planning.

The three-dimensional (3D) printing technology is a promising technique with more and more applications in the field of medicine. The development of 3D printing technology provides a new perspective for the treatment of intracranial aneurysm. The intracranial aneurysm 3D printing simulation models created on the basis of 3D angiographic imaging acquisitions offers technical, practical and educational support to both neurointervention specialists and young residents in professional training.

The aim of the present study was to presents our experience concerning the materials and methods of producing 3D printed individual aneurysm model and its significance in the treatment of intracranial aneurysm.

ANEURYSM MODELING

Angiographic imaging data generation and post-processing

CTA and 3D DSA images data acquisition were used for intracranial aneurism investigation and therapeutically management. Dynamic CTA images were acquired using a Toshiba Aquilion 32 CT scanner (Canon Medical Systems USA, Inc.). The scanning parameters used are: scan range - 16 cm, gantry rotation time 0.75, slice thickness 0.5 mm, field of view (FOV) 240 mm, tube potential, 120 kV and tube current 218 mA. A mean total scanning time was 21 s and DLP 930mGy. The 3D DSA images acquisitions were obtained on a clinical biplane C-arm System Toshiba Infinix (Canon Medical Systems USA). A 5 s conventional mask and fill run protocol (70 kVp, 0.36mGy/Fr, 200° and 133 images were used. The injection parameters were 2.5 mL/s for 7 s with 2 s X-ray delay using 100% contrast concentration.

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Anatomical 3D computer model reconstruction

The original 3D CTA or DSA imaging dates, in DICOM format, are extracted through the Picture Archiving and Communication System (PACS; eRAD, China) and imported into Mimics (Materialise 18, Leuven, Belgium), a medical reconstruction software suite. Mimics allowed the reconstruction of only the intracranial arteries or both arteries and the skull in the case of CTA after format conversion and threshold extraction. The image threshold must be carefully adjusted to expose the image of the vessels as clearly as possible. The method of threshold segmentation is combined with manual segmentation to obtain the most important region of interest (ROI). Also, surrounding tiny branches or interfering bony structures could be removed for a better ROI exposure (aneurysm region). Then, we used the 3D calculate function to reconstruct the computer model. It is then stored and sent out as STL format files.

Aneurysm 3D printing model fabrication

The STL format file is input into the rapid prototyping 3D printer machine (Objet Connex350 3D printer Objet Technologies Ltd, Rehovot, Israel) for virtual model fabrication. If plaster was initially used to make a solid model including the skull, blood vessels and aneurysm, they proved too rigid and fragile to simulate human blood vessels. Thus, to create a suitable model of aneurysm it is necessary to use three different materials for the reconstruction of the solid skull, flexible blood vessels and eventually the empty aneurysm. The new types of 3D printers Objet Connex500, offer the possibility to work with a mixture of rigid and flexible materials. A light-cured resin material for bone reconstruction and a different flexible resin material for vessels and aneurysm modelling were used. Both types of 3D models were manufactured with this method.

Interventional planning

All manufactured 3D models were studied by the team of vascular neurosurgeons in order to establish the most appropriate therapeutic approach. The shape, dimensions, orientation and relationships between the aneurysmal sac, its neck, the carrier vessel and the adjacent branches were carefully analyzed to establish the optimal interventional planning for each lesion. A microsurgical clipping or endovascular occlusion was decided. In case of microsurgical clipping the 3D model was used to choose the type of clips, to simulate access and clipping direction, and in more complex lesions to establish the optimal clips arrangement for a complete closing of the aneurysmal neck. For endovascular treatment, the printed 3D models helped both to choose the coils and the proper endovascular technique of aneurysms occlusion.

Images were exported in standard digital imaging and communication in medicine (DICOM) format to the 3D calculation software, Soft Mimics17.0 (Materialise, Belgium). Soft tissue and brain tissue around the skull was removed. The vascular and bone area was segmented by the software, and the virtual 3D angiogram was generated. The skull, intracranial artery and aneurysm were distinguished by different colors. Data from the segmented area was transformed into a STereoLithography (STL) format, which was used in the rapid prototyping machine.

Case presentation

A 43-years-old female patient was addressed to our Emergency Unit for sudden violent headache followed by a short episode of loss of consciousness 24 hours ago. At the neurological examination the patient was evaluated with GCS of 13 points presenting nuchal rigidity, confusion, somnolence, and no motor deficits. She was immediately investigated by CT scan that showed a subarachoidian hemorrhage in the basal cistern and both Sylvian fissures. The patient also presented intraventricular hemorrhage in the fourth and third ventricle (Figure 1).

After that an angio-CT was performed that revealed an anterior communicating artery aneurysm as a source of bleeding. (Figure 2). A 3D printed simulation model that comprised of entire vascular tree of aneurysm and parent artery and its branches was immediately manufactured. The 3D model was carefully studied by the neurovascular team and an endovascular aneurysm occlusion was decided for the next day after admission (Figure 3).

The patient was placed under general anesthesia by endotracheal intubation. Right femoral approach using 6F introducer sheath was performed and the right internal carotid artery catheterization was achieved with a 6F guiding catheter (Imager™ II, Boston Scientific). Different angulations biplane DSA series were obtained for an optimal working position. A road-mapping was used throughout the duration of the procedure for aneurysm occlusion. A microcatheter was then advanced over a microguidewire into the aneurysm dome. If the aneurysm remnant had a wide neck, the balloonassisted neck remodeling technique was used. 6 GDCs were then advanced and detached in the aneurysm until a complete agiographical occlusion was achieved (Figure 5). All catheters and the femoral sheaths were then removed from the femoral arteries and hemostasis was obtained by manual compression. Control cerebral CT scan was performed 5 days later. Anticoagulation was routinely continued 14 days after the procedure. The postoperative course was uneventful, with a progressive improvement of neurological status. After 14 days of hospitalization the patient was transferred to the Neurological department to continue the medical treatment.

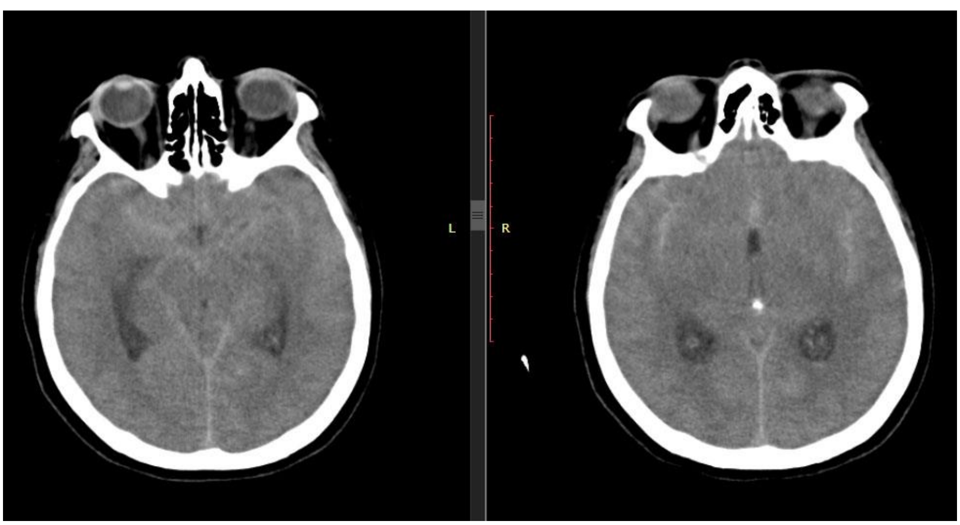

Figure 1. Diagnostic cerebral CT scan showing a SAH

Figure 2. Cerebral Angio-CT scan showing an anterior communicating artery aneurysm (arrow)

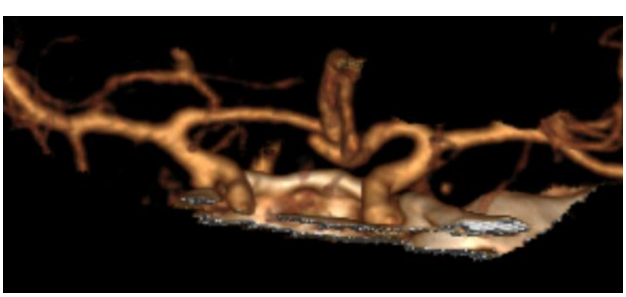

Figure 3.

Figure 3. Different view of the ACoA aneurysm on 3D-printed simulation models

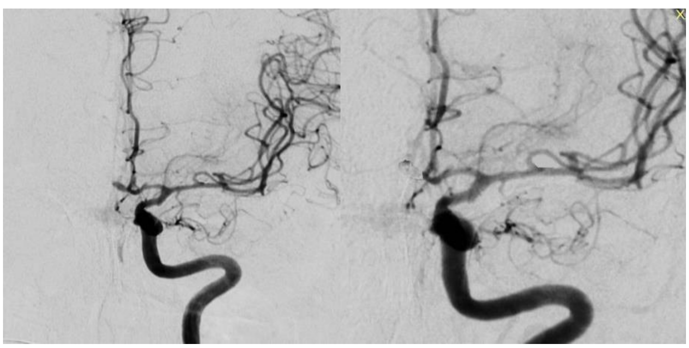

Figure 4. DSA images with the ACoA aneurysm pre and post coils embolization

Figure 5. Cerebral Ct scan control postembolizati

DISCUSSIONS

The development of materials and manufacturing technology through 3D printing has allowed the realization of vascular anatomical models as accurate as possible, with lower and lower costs. Gradually, the limitations of 3D printing technology represented by the creation of flexible vascular models of tubular type (hollow inside) were overcome allowing the production of high-precision anatomical articles with optimal haptic properties. Thus, 3D-printed simulation models based on DSA imaging can perfectly replicate the geometries of aneurysms, parent vessels, and adjacent vascular branches. The reconstruction and 3D printing of implants / models specific to each patient were based on the correlations between digital images and finite element analysis. The data of the computer models thus obtained are finally transferred to a 3D printing unit for the realization of the simulation model. The use of modern printers that allow the simultaneous use of various materials, sequential multilayer modeling technique or rotary model printing technique have contributed greatly to the introduction of this technique both in the current practice of treatment of intracranial aneurysms and in the professional training of vascular neurosurgery specialists[2,3,4,6].

Although major advances have been made in the treatment of cerebral aneurysms with or without subarachnoid haemorrhage, therapeutic management remains one of the most challenging decisions, especially in complex anatomical situations. Numerous studies have shown that the main determinants in establishing the therapeutic strategy are the angioarchitecture of the lesion (size, location and direction of the aneurysm itself), the anatomy of the pathway and preprocedural clinical status (WFNS or Fisher's degree of the patient) [8]. Ripley et al [9] reported that 3D printed simulation models make a major contribution both to decision-making and to the completion and efficiency of traditional techniques for the treatment of intracranial aneurysms.

With the development of the 3D printed simulation models that allow realistic reconstruction of the shape of the aneurysm, important changes influence the traditional aneurysm treatment not only on the fields of microsurgical clipping but also on the endovascular coiling.

If the microsurgical clipping treatment strategy was in the past exclusively based on an imaging analysis with or without 3D computer reconstruction, at present, the possibility of clip model selection (as shape, size and curvature), the clipping direction and clips successive arrangement for aneurysmal neck reconstruction are favoured by the realization of 3D printed simulation models.

In the case of endovascular interventions, the realization of simulation models by 3D printing can be a valuable tool both for the optimal choice of the implant type (whether we are talking about coils or stents) and for predicting possible vascular deformations due to endovascular implant insertion. This can help improve the intervention plan, avoiding possible complications by using inappropriate and unnecessary materials [6, 7]. In the case of difficult interventions such as stent-assisted coil occlusion in the basilar trunk or complex vascular bifurcations, their planning and vascular reconstruction are difficult, accurate mounting and positioning of implants are essential to allow complete aneurysmal occlusion while maintaining permeable its branches [5,6].

A retrospective study on the efficient use of endovascular materials showed an increase in costs of up to 30% when it was necessary to perform immediate emergency interventions compared to cases in which they were performed after a thorough study on 3D imaging and simulation model by 3D printing. The use of oversize or undersized implants, of additional types of devices not initially anticipated compared to those used in a standard procedure, lead to an increase in the average cost of some classic interventions. The authors concluded that an adequate preoperative planning based on an imaging and model study, correlated in certain situations on practical simulation on the model lead both to a minimization of costs and to an improvement and efficiency of the interventions results [1,4]. The cost of producing 3D printed models seems much more reasonable especially compared to the cost of an endovascular material.

Improving the planning of interventions based on 3D printed simulation models has led to the development of neurovascular training procedures (microsurgical clipping and endovascular embolization) for specialists in their professional training period. The growing limitation of access to cadavers or to a sufficient number of neurovascular intervention procedures was perfectly offset by the development of increasingly high-performance vascular models both as a material and as a design possibility.

Conclusions

3D printed simulation models offer the possibility of optimal visual exposure of intracranial aneurysms to help neurointerventionists for application of a more appropriate therapeutic strategy. Also, creation of anatomi¬cally accurate 3D printed aneurysm models demonstrated its utilities for continues professional training. Access to fast-printing 3D machines and materials with advanced properties at lower and lower costs will certainly lead to the increasing use of this technology in the therapeutic management of intracranial aneurysms.

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