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A. Chiriac,
N. Dobrin,
Georgiana Ion,
A. Iencean,
I. Poata



Efficiency of 3d simulation models in emergency microsurgical clipping of intracranial aneurysms

A. Chiriac¹, N. Dobrin², Georgiana Ion², A. Iencean², I. Poeta¹

¹ "Grigore T. Popa" University of Medicine and Pharmacy, Iasi, ROMANIA

² "Prof. N. Obu" Emergency Clinical Hospital, Iasi, ROMANIA

ABSTRACT

The latest developments in three-dimensional printing technology both in terms of equipment and materials offer a new opportunity in the microsurgical treatment of intracranial aneurysms. 3D printed model of the patient's aneurysms enables optimal anatomical visualization with personalized preoperative planning. This is a retrospective study of a series of 16 patients suffering from ruptured intracranial aneurysms, admitted and microsurgically treated based on rapid 3D printed models to our clinic from September 2016 to March 2018. We analyzed the dates concerning patient demographics, clinical, surgical technique and outcomes correlated with the data of the 3D-printed replica used for planning emergency surgeries.

1. INTRODUCTION

Even if according to numerous international specialized studies, the endovascular treatment of intracranial aneurysms remains the first-line treatment, the microsurgical clipping technique is a necessary option, imposed by many particular anatomical-clinical situations. Also, an excellent trained vascular microneurosurgical team will definitely put the two intervention techniques on equal terms.

It is well known that extremely careful microsurgical planning is absolutely essential for achieving optimal postoperative results. Thus, by avoiding excessive manipulation of the parenchyma and intracranial vessels, with a significant reduction in the time of intervention, the main predisposing factors for intraoperative (aneurysmal rupture) and postoperative complications (vasospasm, infections, etc.) are eliminated. With the development of 3D printing technology, 3D simulation models have been adopted by the field of microneurosurgery [4,6]. The technology offers the advantage of 3-dimensional views of cerebral vessels and aneurysms from various angles, and of practicing the optimal clips construction for total aneurysm neck occlusion. Such 3D simulation models may improve our concepts of aneurysm configuration and approach and clipping

Keywords
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Corresponding author:
A. Chiriac

"Grigore T. Popa" University of
Medicine and Pharmacy, Iasi,
Romania

chiriac_a@hotmail.com

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technique selection. [2,3,8] Therefore, in this paper we aim to present our experience in the manufacture of aneurysmal simulation models by 3D printing technique and to investigate the possible effects of the application and utility of this printing system in emergency microsurgical clipping.

2. MATERIALS AND METHODS

2.1. Patients information

In this study 16 patients with intracranial aneurysms treated in our department from September 2016 to March 2018 were retrospectively selected. These were separated into two groups, 8 cases that benefited from microsurgical clipping after analysis and simulation of this technique on a preoperatively printed 3D model and 8 cases in which microsurgical clipping was performed only on the basis of 3D imaging analysis. A similarity in the location of aneurysms was followed in the selection of the two groups.

2.2. Image data generation and post-processing

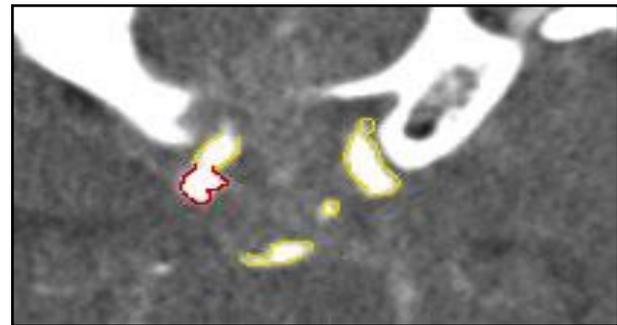
Dynamic CTA imaging was obtained for all patients using a dynamic volume CT scanner with 32 detectors Toshiba Aquilion CT (Canon Medical Systems USA, Inc.). The scan parameters were as follows: scan interval, 16 cm; portal rotation time, 350 s; slice thickness, 0.5 mm; field of view (FOV), 240 mm; tube potential, 120 kV; and tube current, 218 mA. During the scanning process, the reconstruction with layer thickness (0.5 mm) and interval (0.5 mm) was obtained.

The images thus obtained were exported in standard digital imaging and medical communication (DICOM) format to a computerized unit for 3D image processing and reconstruction. They are imported into Mimics17.0 (Materialize, Leuven, Belgium) software. Mimics allow the automatic extraction of soft and cerebral tissue around the skull with the highlighting of cerebral vascularisation in 3D reconstruction. The image threshold should be carefully adjusted to display the image of the vessels as clearly as possible. The threshold segmentation method is combined with manual segmentation to obtain the most important region of interest (ROI). Also, interfering bone structures could be removed for better ROI (aneurysm region) exposure (Fig 1). The resulting 3D image is stored and sent as STL files. The procedure

was performed together by a neurosurgeon and a software expert from our team.



Figure 1. Vascular tree and aneurysmal lesion segmentation on 3D Angio CT acquisitions. images



2.3. 3D aneurysm model printing

The 3D aneurysm printed models were obtained using an Objet Connex 350 3D printer (Stratasys, Eden Prairie, MN, USA) or a Zortrax Inkspire printer (Zortrax S.A., Olsztyn, Poland). The manufacturing process of the 3D-printing machine is based on Fused Deposition Modeling (FDM) technologie. To make the prototype models, two types of semi-rigid and rigid materials were used as PLA (polylactic acid) and ABS (acrylonitrile-butadiene-styrene) filaments. Thus, to form the object, the printer heats the thermoplastic filament cable into liquid form and extrudes it layer by layer (Fig. 2).

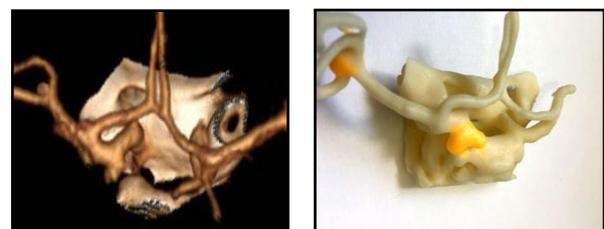


Figure 2. 3D Angio CT vascular tree and aneurysmal lesion and 3D printed models

2.4. Preoperative planning

All the models thus obtained were analysed by the vascular neurosurgery team in the preoperative period. Thus, 3D printed models were used to propose the most optimal approach to reach the target aneurysm. Also, a selection of clips regarding their size and shape as well as the configuration of their application on the aneurysmal neck was proposed and practiced. Model-based preoperative plans were correlated with CTA-based imaging to verify the value of the model in preoperative planning.

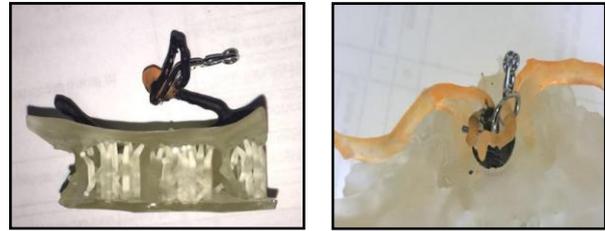
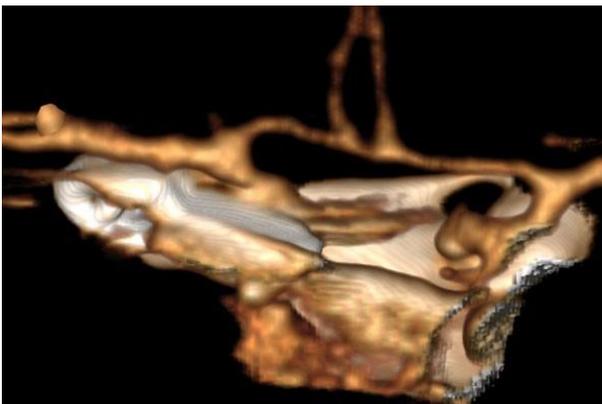
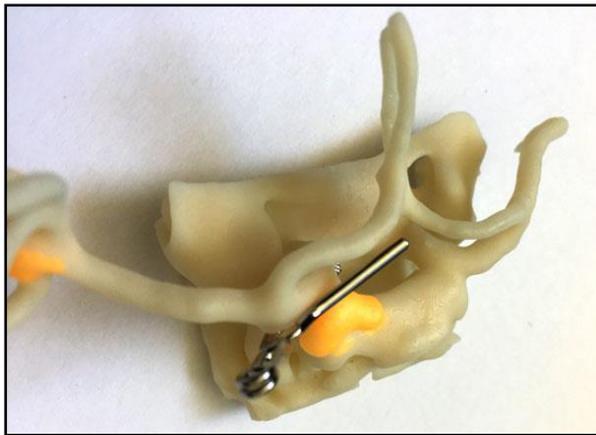
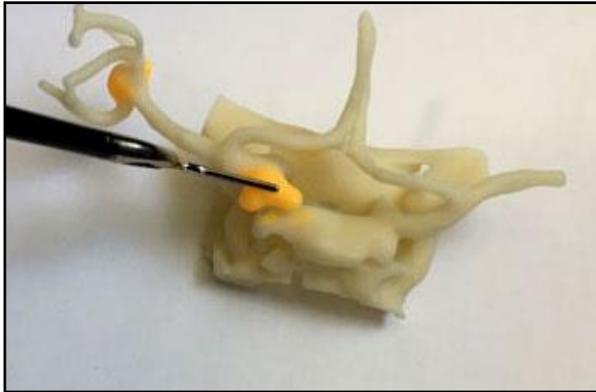


Figure 3. Preoperative clipping simulation on 3D printed models and postinterventional 3D Angio CT

3. RESULTS

Our study included 16 patients with a total of 16 ruptured intracranial aneurysms. For all these patients, a 3D printed model was created and they benefited from microsurgical clipping of the aneurysm based on a preoperative planning simulated on these models. All surgeries were performed under general anesthesia by the same neurosurgical team. The mean age was 46 ± 7 , with a median of 43.5 and a range of 35–65 years. About 62% ($n = 10$) of our patients were female with a female-to-male ratio of 1.6. Regarding the location of the aneurysms, there were 7 at the Acom level, 3 at the MCA bifurcation, 3 at the Posterior com and 2 at the terminal level of the internal carotid artery bifurcation and one at ophthalmic segment. The standard pterional approach for aneurysm clipping was followed in 11 of patients, whereas the other 5 of patients were treated through the fronto-pterional approach.

The conformation of the intraoperative clipping of the aneurysms, both in terms of arrangement and number of clips used, was similar in 13 of the cases to that practiced on the 3D printed models in the preoperative planning. In two cases, an additional clip had to be used for the complete and safe occlusion of the aneurysm. In one case, due to an atheromatous plaque at the level of the aneurysmal neck, which required the cutting of the aneurysmal sac and its extraction, and in the other case, as a result of the appearance of a rupture at the aneurysmal neck level during the microsurgical dissection. About 81% ($n = 13$) of the patients had a GOS of 5 and 19% ($n = 3$) had a GOS of 4. The median production time used for the models described in this manuscript was 4.25 h (range: 3.50–5.00 h). The average duration of microsurgical clipping interventions was 3h10, varying between 4 and 5 (Table1).

Patient	Age (years)	Sex	Lesion	Size mm	Clips configuration on model	Clips used in surgery	Residual neck	3D model production time	Surgical procedure time (h)
1	35	F	R MCA	7/6	Slightly curved	Same	No	3.50	3.00
2	65	F	ACoMA	6/5	Straight+ Slightly curved	Same	No	4.30	3.30
3	43	M	PCoMA	7//7	Angled laterally	Same	No	5.00	2.50
4	51	F	ACoMA	4/3	Bayonet+strait	Same	No	4.50	3.10
5	38	M	ACoMA	8/6	Straight x 2	Same	No	4	3.10
6	44	F	Oft ICA	11/9	Straight x2 +fenest.	Same	No	4.10	3.50
7	56	F	R MCA	5/6	Slightly curved + fenest.	Same	No	4.20	3.20
8	37	M	PCoMA	6/4	Straight	Same	No	4.55	2.30
9	40	F	ACoMA	4/3	Angled laterally	Same	No	4.40	3.00
10	55	M	Ter ICA	5/4	Angled laterally	Same	No	4.30	3.20
11	37	F	PCoMA	10/7	Straight x 2	Same	No	4.00	4.00
12	40	M	ACoMA	7/6	Straight x 2	Same	No	4.30	3.00
13	35	F	L MCA	8/7	Straight+fenest.	Same	No	4.10	5.00
14	41	M	Ter ICA	4/3	Straight	Same	No	4.50	3.15
15	53	F	ACoMA	5/4	Straight	Same	No	4	2.50
16	60	F	ACoMA	4/4	Slightly curved	Same	No	4	3.10

Table 1. Patients, aneurysms and interventions dates

DISCUSSION

The technology of printing 3D models has become more and more popular in the field of medical applicability. This was mainly due to the increased availability, ease of use and affordability of 3D printers [1,4,6]. Numerous publications have described the increased applicability of 3D printing in intracranial aneurysm modeling and its benefits preoperatively [7,9].

One of the main difficulties during the microsurgical treatment of intracranial aneurysms is the selection of the appropriate clip(s) to be implanted according to anatomical variations. It is well known that surgical planning is essential [1,8], to avoid excessive manipulation of intracranial vessels and prolonged surgical time, which are predisposing factors of mechanical vasospasm and intraoperative aneurysmal rupture [9]. The results of this work describe a simplified and rapid method of manufacturing individualized 3D models and report the effects of its application to the choice and simulation of the pre-surgical approach. The total time used to create a 3D model experienced a spectacular evolution from a week, initially (Wurm et al) to 24 hours (Faraj et al) and later to 4-6 hours (Błaszczuk et al). The average total time required to make the 3D printed model in our study (from CTA acquisition to the finished model) was approximately

4.25 hours. This is registered in the direction of rapid prototyping in order to perform emergency surgical interventions.

Regarding the statistical comparison between the clipping configuration practiced preoperatively on the 3D printed model and the one performed during the microsurgical intervention for aneurysm occlusion, we note that this was not significant. Also, the analysis regarding the number, shape and dimensions of the clips used for each intervention compared to those proposed and practiced preoperatively on the 3D models showed a statistically no significant difference. All this demonstrated the relevance of using these 3D printed vascular models in preoperative interventional planning. These results are based on an observational analysis and objective evaluation of the diameter, length and thickness measurements of the aneurysm on the 3D printed model in relation to the computerized radiological image.

Although 3D printing technology has gained increased popularity in vascular neurosurgery due to its proven safety, feasibility, accuracy, efficacy, reproducibility, and cost-effectiveness, there are still several hurdles to overcome before the technology is fully incorporated into routine neurosurgical practice. As other reports have shown, an important limitation is determined by the lack of a standardized

production method that governs the assimilation of 3D models. This is due to a great variability in terms of the type of printers used, the 3D printing technology used and, perhaps most importantly, the characteristics of the resin materials used in the reconstruction process.

The use of 3D printed aneurysm models will also be a great success in the future, as they have proven to be an excellent tool in practical simulations, specialized educational training, as well as in educating patients and their families. [1,2,5]

CONCLUSIONS

The 3D printed model of the aneurysm is a precise, hands-on simulator, which allows neurosurgical specialists to plan and practice microsurgical intervention preoperatively even for emergency cases. They greatly improve their anatomical understanding of aneurysms, define surgical techniques and enhance their skills to choose of suitable clips and optimal clips arrangements.

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