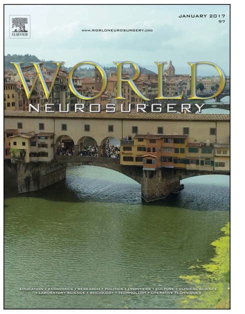
Journal Pre-proof



3D-printed head model in patient's education for micro-neurosurgical aneurysm clipping procedures.

Fredrick J. Joseph, PhD, Hanne E.R. Vanluchene, MSc, Johannes Goldberg, MD, David Bervini, MD, MAvdSurg

PII: S1878-8750(23)00555-7

DOI: https://doi.org/10.1016/j.wneu.2023.04.070

Reference: WNEU 20484

To appear in: *World Neurosurgery*

Received Date: 3 January 2023

Revised Date: 13 April 2023

Accepted Date: 15 April 2023

Please cite this article as: Joseph FJ, Vanluchene HER, Goldberg J, Bervini D, 3D-printed head model in patient's education for micro-neurosurgical aneurysm clipping procedures., *World Neurosurgery* (2023), doi: https://doi.org/10.1016/j.wneu.2023.04.070.

Credit author statement

Fredrick J. Joseph: conceptualization, methodology, writing – review & editing, supervision

Hanne E.R. Vanluchene: formal analysis, writing – original draft

Johannes Goldberg: investigation, resources

David Bervini: investigation, resources, writing – review & editing

3D-printed head model in patient's education for micro-neurosurgical aneurysm clipping procedures.

Fredrick J. Joseph[a], PhD; Hanne E.R. Vanluchene[a], MSc; Johannes Goldberg[b], MD; David Bervini[b], MD, MAvdSurg

[a]Image Guided Therapy, ARTORG Center for Biomedical Engineering Research, University of Bern, Murtenstrasse 50, 3008 Bern, Switzerland
[b]Department of Neurosurgery, Bern University Hospital and University of Bern, Freiburgstrasse 16, 3010 Bern, Switzerland

Corresponding author:
Fredrick J. Joseph, PhD,
Image Guided Therapy,
ARTORG Center for Biomedical Engineering Research,
University of Bern,
Murtenstrasse 50,
3008 Bern, Switzerland
Tel. +41 79 839 29 64
Fax +41 031 632 7576
Email: fredrickjohnson7@gmail.com

Keywords: 3D Printing, Communication, Informed Consent, Intracranial Aneurysm, Neurosurgery, Patient Education

Short title: Patient-Neurosurgeon communication

3D-printed head model in patient's education for micro-neurosurgical aneurysm clipping procedures.

Fredrick J. Joseph[a], PhD; Hanne E.R. Vanluchene[a], MSc; Johannes Goldberg[b], MD; David Bervini[b], MD, MAvdSurg

[a]Image Guided Therapy, ARTORG Center for Biomedical Engineering Research, University of Bern, Murtenstrasse 50, 3008 Bern, Switzerland

[b]Department of Neurosurgery, Bern University Hospital and University of Bern, Freiburgstrasse 16, 3010 Bern, Switzerland

Corresponding author:

Fredrick J. Joseph, PhD,
Image Guided Therapy,
ARTORG Center for Biomedical Engineering Research,
University of Bern,
Murtenstrasse 50,
3008 Bern, Switzerland
Tel. +41 79 839 29 64
Fax +41 031 632 7576
Email: fredrickjohnson7@gmail.com

Keywords: 3D Printing, Communication, Informed Consent, Intracranial Aneurysm, Neurosurgery, Patient Education

Short title: Patient-Neurosurgeon communication

ABSTRACT

Background: Computed Tomography (CT), Magnetic Resonance Imaging (MRI), and 3D reconstruction from Digital Subtraction Angiography (DSA) are currently used in clinical consultations for patients diagnosed with intracranial aneurysms; however, they have limitations in helping patients understand the disease and possible treatments. This study investigates the use of a 3D-printed model of the patients' neurosurgical anatomy and vascular pathology as an educational tool in outpatient clinics.

Methods: A 3D-printed model of a middle cerebral artery aneurysm was created for use during patient consultations to discuss microsurgical treatment of unruptured cerebral aneurysms. In total, 38 patients and 5 neurosurgeons were included in the study. After the consultation, the patients and neurosurgeons received a questionnaire to assess the effectiveness of the 3D-printed model as an educational tool.

Results: The 3D model improved the patients' understanding of the diagnosis, the aneurysm's relationship to the parent artery; the treatment process as well as the risks if left untreated. The patients found the 3D model to be an interesting tool (97%). The neurosurgeons were satisfied with the 3D-printed model as a patient encounter tool, they found the model effective during consultation (87%) and better than the conventional education tools used during consultations (97%).

Conclusion: Using a 3D model improves communication, enhances the patient's understanding of the pathology and its treatment and potentially facilitates the informed consent process in patients undergoing intracranial aneurysm surgery.

Keywords: 3D Printing, Communication, Informed Consent, Intracranial Aneurysm, Neurosurgery, Patient Education

INTRODUCTION

Surgeons' communication with their patients is pivotal in establishing a patient-surgeon relationship[1]. Surgeons must communicate the medical problem to the patient with grace and humility so they can visualize the clinical condition and understand the potential complications if left untreated. The patients' understanding of their treatment and post-surgical complications are integral to clinical and ethical compliance[2]. Increased knowledge of the procedure yields improved medical outcomes and quality of life following treatment[3].

Current patient education materials have shortcomings leading to low patient comprehension of neurological treatments[4]. In the past, it was noted that during neurosurgical consultations for cerebral aneurysm treatment, patients had a poor understanding of the treatment plan and incorrectly estimated the risks without or with treatment[5]. State-of-the-art tools, like patient imaging datasets, clinical textbooks, anatomical charts, and hand-drawn images, have helped neurosurgeons during consultations[6]. However, not all patients can visually interpret their medical problems before providing informed consent, leading to low patient comprehension. Different approaches exist to address the shortcomings of current patient education materials. Virtual reality (VR) has been used to educate patients during their neurological consultations[7]. Custom interactive 360° VR models are a powerful tool for enhancing patient education; however, the studied patient groups have included people of all ages who were highly educated. In the current study, we used a 3D-printed model as these models are possibly more suitable and convenient for lower-educated patients. In the last decade, 3D printing has helped surgeons in other specialties improve patient communication and satisfaction[8,9], and it is currently used as a patient education tool for neurosurgical interventions[10]. Studies on 3D-printed models report improved patient understanding, greater patient satisfaction, and an environment that promotes comfort and reduces anxiety[10]. A potential disadvantage of these models is that it can be emotionally confronting for the patient to visualize the problem and treatment options in a realistic way[10]. Combining these 3D models with other modalities like medical images is the most effective for patient education, and it shortens the time needed for patients to understand the disease, its treatment, and risks[10].

Patient education and discussion of treatment options is crucial when treating unruptured cerebral aneurysms, because patients are mostly asymptomatic[11]. The detection of unruptured cerebral aneurysms has increased as the use of magnetic resonance imaging (MRI) and computed tomography (CT) angiography has increased[12,13]. Patient education tools are necessary in cases of unruptured cerebral aneurysms before obtaining informed consent to clearly demonstrate the risks of leaving the aneurysm untreated, to describe the best treatment options and because patients are usually asymptomatic[14]. Furthermore, these tools are necessary to improve the patients' understanding of the relationship of the aneurysm to the parent and branching arteries as well as neighboring anatomical structures, which is essential when deciding on the treatment but also in the understanding of the risk of treatment[15]. 3D-printed models can be used as a patient education tool as they potentially provide a better view of the surgical procedure and accompanying craniotomy and then improve the informed consent process.

This study presents a patient consultation approach using a true-scale 3D-printed model for microvascular aneurysm clipping surgery. The study aims to discuss the effective means of communication enhancement subjectively from the information collected from the patients and the neurosurgeons without any comparison or evaluation of the data.

METHODS

Patient background

In total, 38 patients who were assigned to undergo microsurgical treatment of a saccular unruptured cerebral aneurysms were enrolled in the study between 2019 and 2022. The mean age of the patients was 55 years and ranged from 36 to 77 years. They had diverse educational backgrounds. 28 female and 10 male patients were included. Regarding the indication for elective surgical treatment, 20 patients were diagnosed with a middle cerebral artery (MCA) aneurysm (13 on the left and 7 on the right-hand side), 5 with anterior communicating artery (ACOM) aneurysms and 7 with internal carotid artery (ICA) aneurysms. In 5 patients, more than one aneurysm was diagnosed with the aim of treating all lesions through a single craniotomy.

Neurosurgeon background

Five neurosurgeons were involved in the study; three were fully trained neurosurgeons, and two were senior residents.

3D printing of the aneurysm model

Only one complex MCA bifurcation case was selected for 3D printing. The case was of a patient with a left MCA aneurysm with a maximal diameter of 14 mm (Figure 1). The 3D model was segmented using Amira 6.3 (Thermo Fischer Scientific, Massachusetts, United States). The skull was printed with a left pterional craniotomy approach to present the opening of the scalp for the clipping procedure. The case was 3D printed twice using Stratasys (Connex3 Objet260, Israel). All anatomical parts were printed individually with VeroWhite rigid material for the first copy

(Figure 2A). This model served as an explanatory tool for the patients to demonstrate the different involved anatomies. For the second copy, the different anatomical structures were printed and assembled, retaining the aneurysm and parent artery's positional relationship with the brain, skull, and Sylvian fissures (3D model is shown in Figure 2B). The aneurysm, arteries, and brain parenchyma were printed using TissueMatrix and GelMatrix (Stratasys Inc.9) flexible materials, as this allowed patients to touch and feel the fragile and thin structure of the aneurysm and its surroundings. The total cost spent on the 3D printing was 180 USD.

Patient consultation with the 3D-printed model

The solid printed model was presented to the patients during the consultation to explain the craniotomy approach (standard pterional approach), the vascular anatomy, and the risks in case of aneurysm rupture. The patients' imaging datasets (CT, MRI, DSA) were used alongside the 3D models, as shown in Figure 3. As a result, the patients could visualize and feel the size of the aneurysm and the branching arteries, and they had a better understanding of the surgical process and post-operatively recovery phases.

Questionnaire

The patients received a questionnaire in the local language, German, at the end of the consultation to evaluate the usefulness of the 3D-printed model in terms of patient education, patient satisfaction, patient knowledge, and patient consent. The questionnaire contained six questions. In addition, for each patient, the corresponding surgeon received a questionnaire about the effectiveness of the 3D-printed model during the consultation, their satisfaction regarding patient education, a comparison with conventional methods, and whether using the model improved the informed consent process. The English version of the questionnaire is presented in Table 1.

Ethical Disclosure

The study was approved by the Ethics committee KEK Bern-2019-01335 for the use of patients' dataset.

RESULTS

The results of the questionnaire that the patients received after the consultation with the 3D model are shown in Figure 4. Most (68%) patients had previous knowledge of what aneurysms were prior to the consultation; nevertheless, for 92% of the patients, the model provided added value as it helped them to visualize the problem in the brain and provided a better visual understanding of intracranial aneurysms. For 89% of the patients, the 3D model helped them understand the aneurysm's relationship to the parent artery and to comprehend the treatment process. 60% of the patients considered the 3D model to be useful in better understanding the risks associated with leaving the aneurysm untreated. 8% of the patients reported no improved understanding of the possible risks. Overall, the patients were satisfied with the 3D-printed model, as 97% reported that it added value to the consultation.

Figure 5 shows the responses to the surgeons' questionnaire. Overall, the surgeons were satisfied with the use of the 3D model. In 97% of the cases, the surgeons were satisfied with how the patients understood the treatment explanation. Furthermore, in 97% of the cases, the surgeon reported that the 3D model was more effective than conventional methods, like 2D and 3D images, drawings, and oral communication. No surgeons reported no added value from the 3D model compared with these conventional methods. According to the surgeons, the 3D model improved the informed consent process; in 97% of the cases, this was a significant improvement, and in 3% of cases, the improvement was only limited. In 13% of the cases, the surgeons were not convinced about the model's effectiveness.

DISCUSSION

Patients found the 3D model interesting as it helped them to understand their condition and the aneurysm's relationship to the parent artery, which helped them to realize the possible treatments. The understanding and interpretation of the diagnosis and its implications vary among patients. On the other hand, the ability to inform and educate patients varies among surgeons. However, overall, the present study shows how a 3D model could help in building a constructive interaction between surgeons and patients. The surgeons were satisfied with the use of the 3D model and its ability to improve the patients’ understanding. They reported that the 3D model was more effective than conventional descriptive methods, which led to improved informed consent.

In most cases, the surgeons found the model effective during the consultation. They reported that, in a few cases, the model had only a limited effect. These cases corresponded to patients who did not find the model helpful in understanding the disease, its risks, and the relationship to the aneurysm's parent artery. Therefore, the surgeons had a reasonable estimation of the patients' understanding. To improve the effectiveness of the 3D model in the future, a patient-specific vessel could be printed that can be easily inserted into the skull model.

The 3D model helped to convince patients to undergo treatment as it allowed for a clear representation of the aneurysm treatment. The discussion of the size of the cranial opening was critical as patients often refuse treatment due to aesthetic reasons or prefer endovascular treatment, even when clipping is the better option. The 3D model helped the patients visualize the size of the cranial opening and the skin incision, which made them realize that the aesthetic impact was limited as the surgeons aim to make the opening as small as possible.

In this study, the 3D model was not evaluated regarding its effectiveness in improving patient-surgeon communication outcomes and explaining patient-specific pathology, and future studies should validate the valuable improvements in patient-neurosurgeon communication. 3D-printed models can help educate patients on neurosurgical procedures and minimally invasive interventions prior to obtaining informed consent. In the future, patient-specific 3D-printed models can be used as an armamentarium to enhance personalized information processes and patients' education.

Limitations

This study has several limitations. The studied population was small, which did not allow for group comparison to statistically identify the significance of this consultation method. The different educational backgrounds of the patients were not compared, and this variable likely influenced the patients' understanding. Finally, no follow-up was conducted; therefore, the long-term impact, the integration of 3D-printed models in future neurosurgical aneurysm consultations and improved societal understanding cannot be derived from this study.

CONCLUSION

3D models are helpful as patient education tools and can improve the informed consent process. The use of a 3D model improved the patients' understanding of their medical condition and their treatment. 3D models can be considered a useful armamentarium during single patient-surgeons interaction, facilitating a single patient's decision process.

Funding: This work was supported by funding Innosuisse 51144.1 IP-LS under the title ‘Training and Patient Education in Cerebrovascular Procedures’; and by the Swiss Heart Foundation Grant FF20061 under the title “Novel patient-specific cerebrovascular 4D surgical simulator”.

Declarations of interest: none

Conflict of interest: none

REFERENCES

1. Tung YC, Chang GM. Patient satisfaction with and recommendation of a primary care provider: associations of perceived quality and patient education. *Int J Qual Health Care*. Jun 2009;21(3):206-13. doi:10.1093/intqhc/mzp006
2. Broekman MLD. *Ethics of Innovation in Neurosurgery*. 1 ed. Springer Cham; 2019:167.
3. Sander IM, Liepert TT, Doney EL, Leevy WM, Liepert DR. Patient Education for Endoscopic Sinus Surgery: Preliminary Experience Using 3D-Printed Clinical Imaging Data. *J Funct Biomater*. Apr 7 2017;8(2)doi:10.3390/jfb8020013
4. Shlobin NA, Clark JR, Hoffman SC, Hopkins BS, Kesavabhotla K, Dahdaleh NS. Patient Education in Neurosurgery: Part 1 of a Systematic Review. *World Neurosurg*. Mar 2021;147:202-214.e1. doi:10.1016/j.wneu.2020.11.168
5. King JT, Jr., Yonas H, Horowitz MB, Kassam AB, Roberts MS. A failure to communicate: patients with cerebral aneurysms and vascular neurosurgeons. *J Neurol Neurosurg Psychiatry*. Apr 2005;76(4):550-4. doi:10.1136/jnnp.2004.051649
6. Barrow DL. Communication skills in the physician-patient relationship. *World Neurosurg*. Nov 2013;80(5):e107-8. doi:10.1016/j.wneu.2011.10.016
7. Louis R, Cagigas J, Brant-Zawadzki M, Ricks M. Impact of Neurosurgical Consultation With 360-Degree Virtual Reality Technology on Patient Engagement and Satisfaction. *Neurosurgery Open*. 2020;1(3):okaa004. doi:10.1093/neuopn/okaa004
8. Biglino G, Koniordou D, Gasparini M, et al. Piloting the Use of Patient-Specific Cardiac Models as a Novel Tool to Facilitate Communication During Cinical Consultations. *Pediatr Cardiol*. Apr 2017;38(4):813-818. doi:10.1007/s00246-017-1586-9

9. Chou PY, Hallac RR, Shih E, et al. 3D-Printed Models of Cleft Lip and Palate for Surgical Training and Patient Education. *Cleft Palate Craniofac J*. Mar 2018;55(3):323-327. doi:10.1177/1055665617738998

10. Shlobin NA, Clark JR, Hoffman SC, Hopkins BS, Kesavabhotla K, Dahdaleh NS. Patient Education in Neurosurgery: Part 2 of a Systematic Review. *World Neurosurg*. Mar 2021;147:190-201.e1. doi:10.1016/j.wneu.2020.11.169

11. Cianfoni A, Pravatà E, De Blasi R, Tschuor CS, Bonaldi G. Clinical presentation of cerebral aneurysms. *Eur J Radiol*. Oct 2013;82(10):1618-22. doi:10.1016/j.ejrad.2012.11.019

12. Dandurand C, Zhou L, Fitzmaurice G, et al. Quality of life scores in patients with unruptured cerebral aneurysm: Prospective cohort study. *J Clin Neurosci*. Sep 2021;91:350-353. doi:10.1016/j.jocn.2021.07.024

13. Vernooij MW, Ikram MA, Tanghe HL, et al. Incidental findings on brain MRI in the general population. *N Engl J Med*. Nov 1 2007;357(18):1821-8. doi:10.1056/NEJMoa070972

14. Park J, Son W, Park KS, et al. Educational and interactive informed consent process for treatment of unruptured intracranial aneurysms. *J Neurosurg*. Mar 2017;126(3):825-830. doi:10.3171/2016.2.Jns151830

15. Kim PS, Choi CH, Han IH, Lee JH, Choi HJ, Lee JI. Obtaining Informed Consent Using Patient Specific 3D Printing Cerebral Aneurysm Model. *J Korean Neurosurg Soc*. Jul 2019;62(4):398-404. doi:10.3340/jkns.2019.0092

FIGURE LEGEND

Figure 1. CT (A) and DSA (B) images of a patient with an MCA aneurysm, 3D reconstruction of the aneurysm and surrounding vessels (C)

Figure 1. Solid 3D printed brain model and intracranial aneurysm with a portion of the branching arteries and the carotid artery (A), 3D printed model where different anatomical parts exist out of different flexible materials (B)

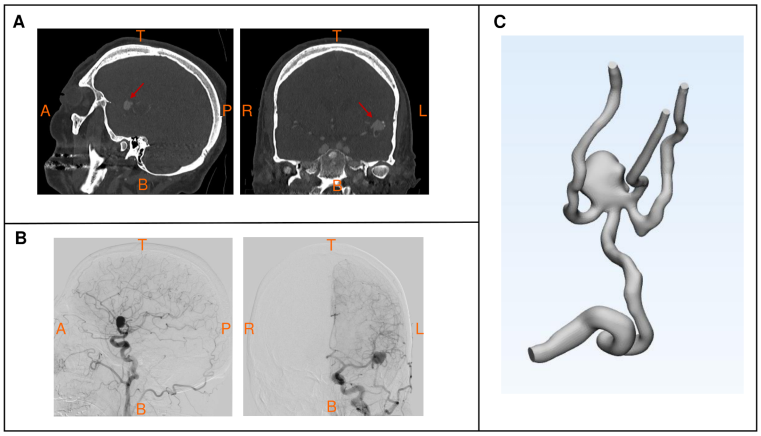
Figure 2. Neurosurgeon interacting with a patient using the 3D reconstructed image-dataset and 3D printed models

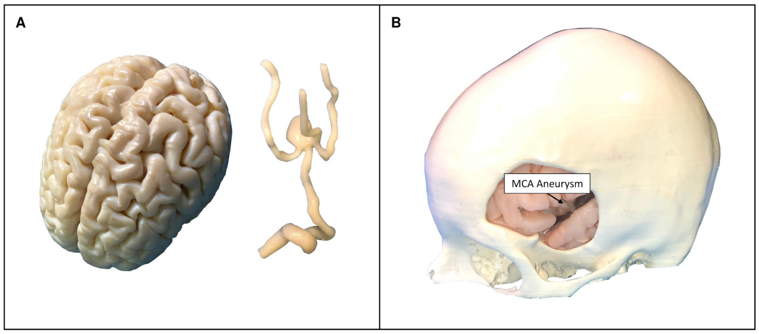
Figure 3. Results of the patient questionnaire about the 3D-printed model

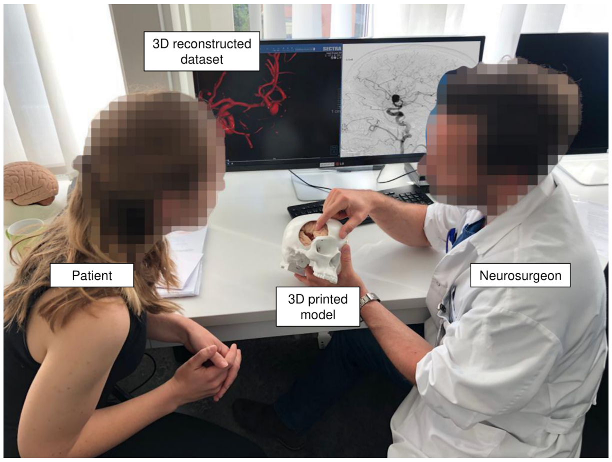
Figure 4. Results of the surgeon questionnaire about the 3D-printed model

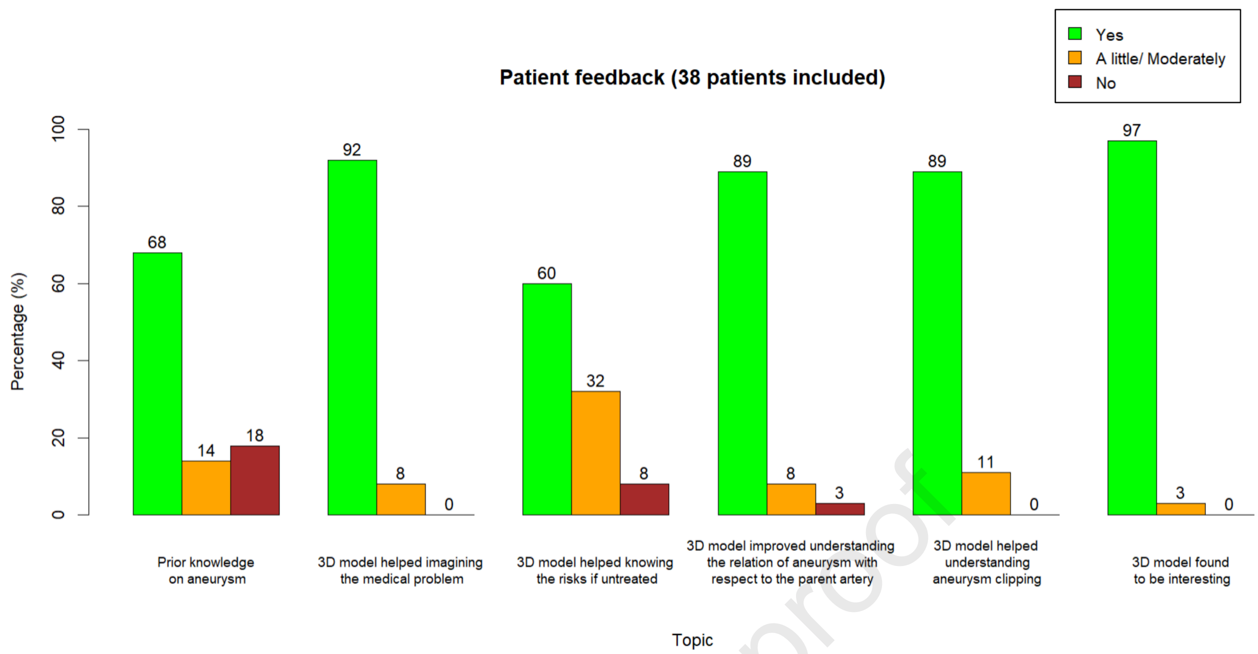
Patient Questionnaire			
Did you know about aneurysms before? Did you read about it, or you knew it already?	Not at all	Heard slightly	Yes
How did the 3D model help you imagine the problem in your brain and about the intracranial aneurysm?	Did not help	Moderately helpful	Helped a lot
How much did the 3D printed model help you to know the risks if untreated?	Did not help	Moderately helpful	Helped a lot
How much did the 3D-printed model improve your understanding of the aneurysm's relationship to the parent artery?	Did not improve	Moderately improved	Improved a lot
Did the models help you understand the aneurysm clipping surgery or planned treatment?	Not at all	Yes, a little	Yes, a lot
Was the 3D-printed model interesting to you?	Not at all	Yes, a little	Yes, a lot
Surgeon questionnaire			
Was the 3D-printed model effective in the consultation?	Not at all	Moderate	Yes, a lot
Are you satisfied with the patient understanding of the diagnosis and the treatment?	Not at all	Moderate	Yes, a lot
I am convinced I use 3D models more effectively than conventional methods like scan images, drawings, and oral communication.	Not convinced	Moderately convinced	Yes, greatly true
Can the 3D model improve the informed consent process?	Not helpful	Moderately helpful	Will be greatly helpful

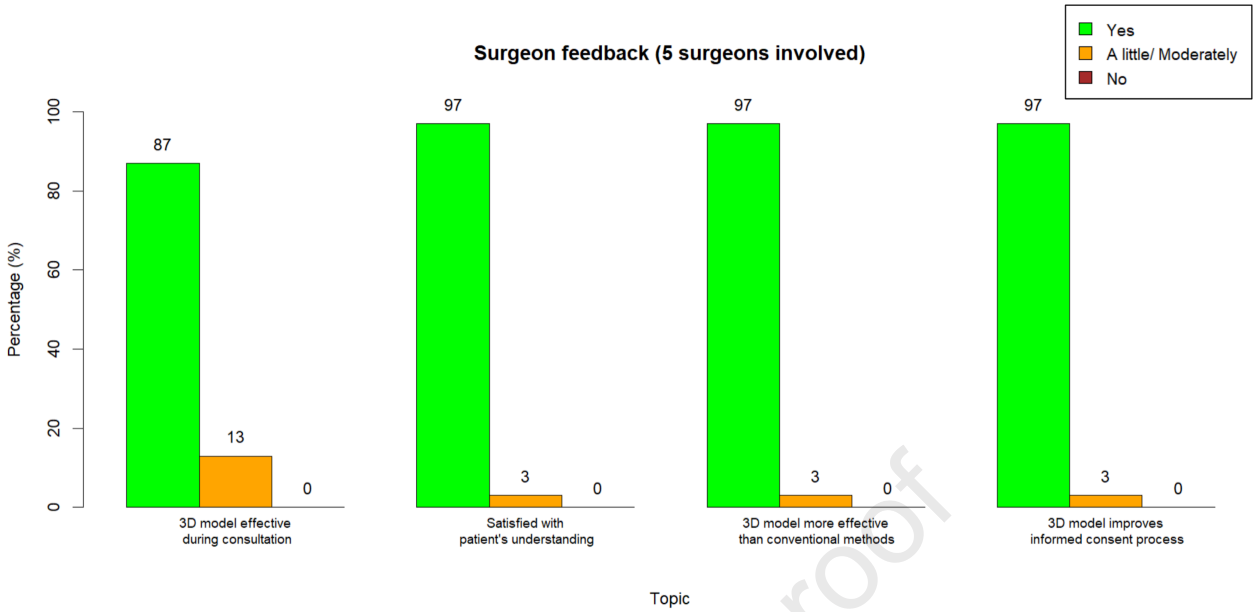
Table 1. Questionnaire to assess the effectiveness of 3D-printed models


A
T
A
P
B
T
R
L
B
B
T
A
P
B
T
R
L
B
C


A
B
MCA Aneurysm


3D reconstructed dataset
Patient
3D printed model
Neurosurgeon


Patient feedback (38 patients included)
Yes
A little/ Moderately
No
Percentage (%)
0
20
40
60
80
100
68
14
18
92
8
0
60
32
8
89
8
3
89
11
0
97
3
0
Prior knowledge on aneurysm
3D model helped imagining the medical problem
3D model helped knowing the risks if untreated
3D model improved understanding the relation of aneurysm with respect to the parent artery
3D model helped understanding aneurysm clipping
3D model found to be interesting
Topic


Surgeon feedback (5 surgeons involved)
Yes
A little/ Moderately
No
Percentage (%)
0
20
40
60
80
100
87
13
0
97
3
0
97
3
0
97
3
0
3D model effective during consultation
Satisfied with patient's understanding
3D model more effective than conventional methods
3D model improves informed consent process
Topic

Abbreviations:

ACOM	anterior communicating artery
CT	computed tomography
DSA	digital subtraction angiography
ICA	internal carotid artery
MCA	middle cerebral artery
MRI	magnetic resonance imaging
SAH	subarachnoid hemorrhage
VR	virtual reality

Declaration of interests

☐ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☒ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Fredrick Johnson Joseph reports financial support was provided by Innosuisse Swiss Innovation Agency. Fredrick Johnson Joseph reports financial support was provided by Swiss Heart Foundation.