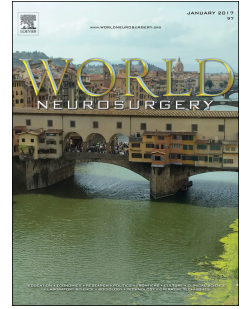


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Credit author statement

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

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

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

Short title: Patient-Neurosurgeon communication

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2 **procedures.**

3

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23 *Keywords:* 3D Printing, Communication, Informed Consent, Intracranial Aneurysm, Neurosurgery,

24 Patient Education

25 *Short title:* Patient-Neurosurgeon communication

26 **ABSTRACT**

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

33 *Methods:* A 3D-printed model of a middle cerebral artery aneurysm was created for use during
34 patient consultations to discuss microsurgical treatment of unruptured cerebral aneurysms. In total,
35 38 patients and 5 neurosurgeons were included in the study. After the consultation, the patients
36 and neurosurgeons received a questionnaire to assess the effectiveness of the 3D-printed model as
37 an educational tool.

38 *Results:* The 3D model improved the patients' understanding of the diagnosis, the aneurysm's
39 relationship to the parent artery; the treatment process as well as the risks if left untreated. The
40 patients found the 3D model to be an interesting tool (97%). The neurosurgeons were satisfied
41 with the 3D-printed model as a patient encounter tool, they found the model effective during
42 consultation (87%) and better than the conventional education tools used during consultations
43 (97%).

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

47
48 *Keywords:* 3D Printing, Communication, Informed Consent, Intracranial Aneurysm, Neurosurgery,
49 Patient Education

51 **INTRODUCTION**

52 Surgeons' communication with their patients is pivotal in establishing a patient-surgeon
53 relationship¹. Surgeons must communicate the medical problem to the patient with grace and
54 humility so they can visualize the clinical condition and understand the potential complications if
55 left untreated. The patients' understanding of their treatment and post-surgical complications are

56 integral to clinical and ethical compliance². Increased knowledge of the procedure yields improved
57 medical outcomes and quality of life following treatment³.

58 Current patient education materials have shortcomings leading to low patient
59 comprehension of neurological treatments⁴. In the past, it was noted that during neurosurgical
60 consultations for cerebral aneurysm treatment, patients had a poor understanding of the treatment
61 plan and incorrectly estimated the risks without or with treatment⁵. State-of-the-art tools, like
62 patient imaging datasets, clinical textbooks, anatomical charts, and hand-drawn images, have
63 helped neurosurgeons during consultations⁶. However, not all patients can visually interpret their
64 medical problems before providing informed consent, leading to low patient comprehension.
65 Different approaches exist to address the shortcomings of current patient education materials.
66 Virtual reality (VR) has been used to educate patients during their neurological consultations⁷.
67 Custom interactive 360° VR models are a powerful tool for enhancing patient education; however,
68 the studied patient groups have included people of all ages who were highly educated. In the
69 current study, we used a 3D-printed model as these models are possibly more suitable and
70 convenient for lower-educated patients. In the last decade, 3D printing has helped surgeons in
71 other specialties improve patient communication and satisfaction^{8,9}, and it is currently used as a
72 patient education tool for neurosurgical interventions¹⁰. Studies on 3D-printed models report
73 improved patient understanding, greater patient satisfaction, and an environment that promotes
74 comfort and reduces anxiety¹⁰. A potential disadvantage of these models is that it can be
75 emotionally confronting for the patient to visualize the problem and treatment options in a realistic
76 way¹⁰. Combining these 3D models with other modalities like medical images is the most effective
77 for patient education, and it shortens the time needed for patients to understand the disease, its
78 treatment, and risks¹⁰.

79 Patient education and discussion of treatment options is crucial when treating unruptured
80 cerebral aneurysms, because patients are mostly asymptomatic¹¹. The detection of unruptured
81 cerebral aneurysms has increased as the use of magnetic resonance imaging (MRI) and computed
82 tomography (CT) angiography has increased^{12,13}. Patient education tools are necessary in cases of
83 unruptured cerebral aneurysms before obtaining informed consent to clearly demonstrate the risks
84 of leaving the aneurysm untreated, to describe the best treatment options and because patients are
85 usually asymptomatic¹⁴. Furthermore, these tools are necessary to improve the patients'
86 understanding of the relationship of the aneurysm to the parent and branching arteries as well as

87 neighboring anatomical structures, which is essential when deciding on the treatment but also in
88 the understanding of the risk of treatment¹⁵. 3D-printed models can be used as a patient education
89 tool as they potentially provide a better view of the surgical procedure and accompanying
90 craniotomy and then improve the informed consent process.

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

95

96 **METHODS**

97 *Patient background*

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

106

107 *Neurosurgeon background*

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

110

111 *3D printing of the aneurysm model*

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

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

125

126 *Patient consultation with the 3D-printed model*

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

133

134 *Questionnaire*

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

143

144 *Ethical Disclosure*

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

147

148 **RESULTS**

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

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

168

169 **DISCUSSION**

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

178 In most cases, the surgeons found the model effective during the consultation. They
179 reported that, in a few cases, the model had only a limited effect. These cases corresponded to

180 patients who did not find the model helpful in understanding the disease, its risks, and the
181 relationship to the aneurysm's parent artery. Therefore, the surgeons had a reasonable estimation
182 of the patients' understanding. To improve the effectiveness of the 3D model in the future, a
183 patient-specific vessel could be printed that can be easily inserted into the skull model.

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

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

197

198 *Limitations*

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

205

206 **CONCLUSION**

207 3D models are helpful as patient education tools and can improve the informed consent
208 process. The use of a 3D model improved the patients' understanding of their medical condition
209 and their treatment. 3D models can be considered a useful armamentarium during single patient-
210 surgeons interaction, facilitating a single patient's decision process.

211
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215
216 **Declarations of interest:** none

217
218 **Conflict of interest:** none

219
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261

262 **FIGURE LEGEND**

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

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

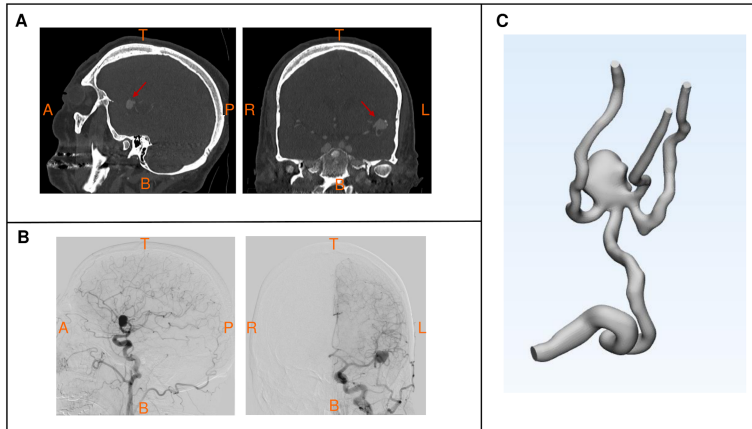
268 **Figure 2.** Neurosurgeon interacting with a patient using the 3D reconstructed image-dataset and
269 3D printed models

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

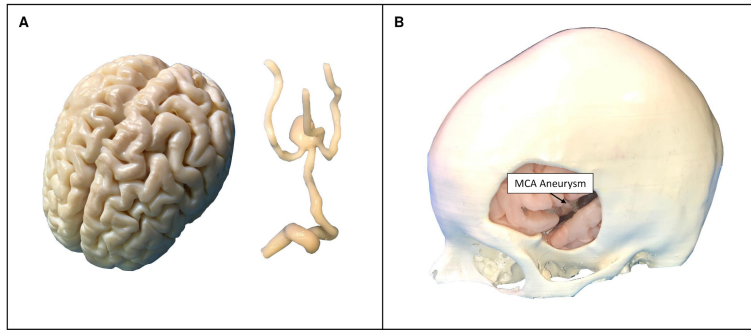
271 **Figure 4.** Results of the surgeon questionnaire about the 3D-printed model

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

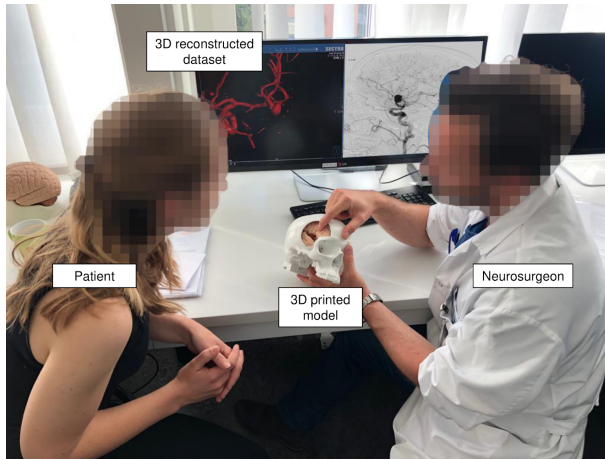
Table 1. Questionnaire to assess the effectiveness of 3D-printed models



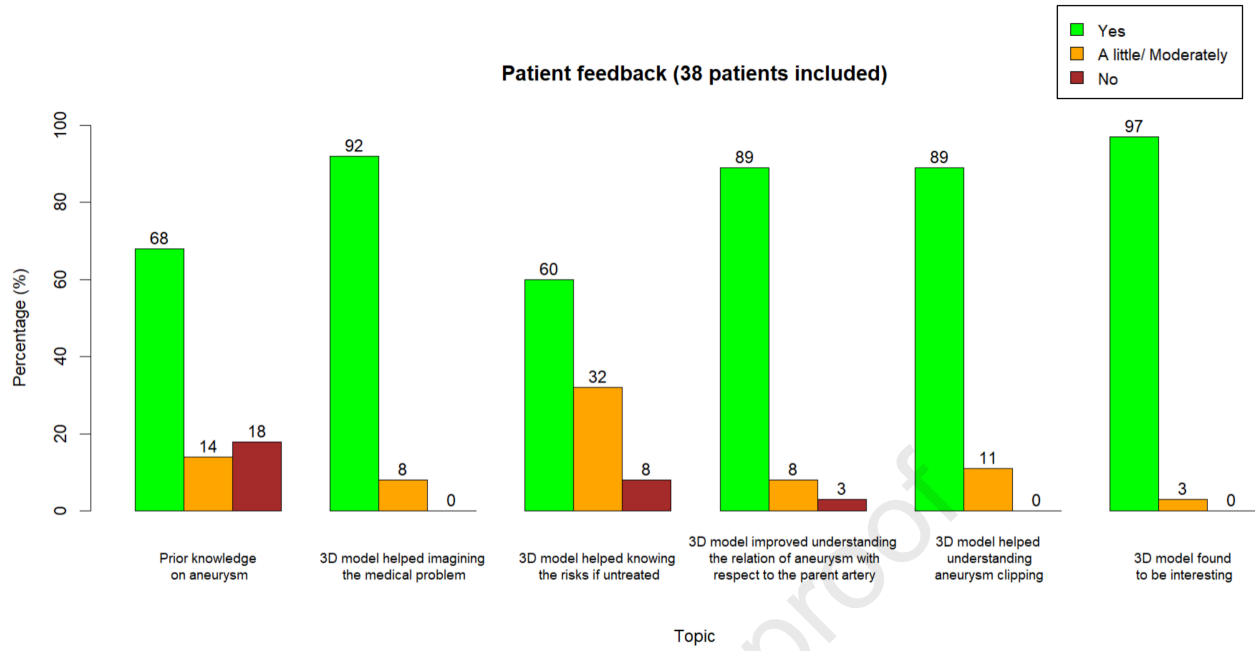
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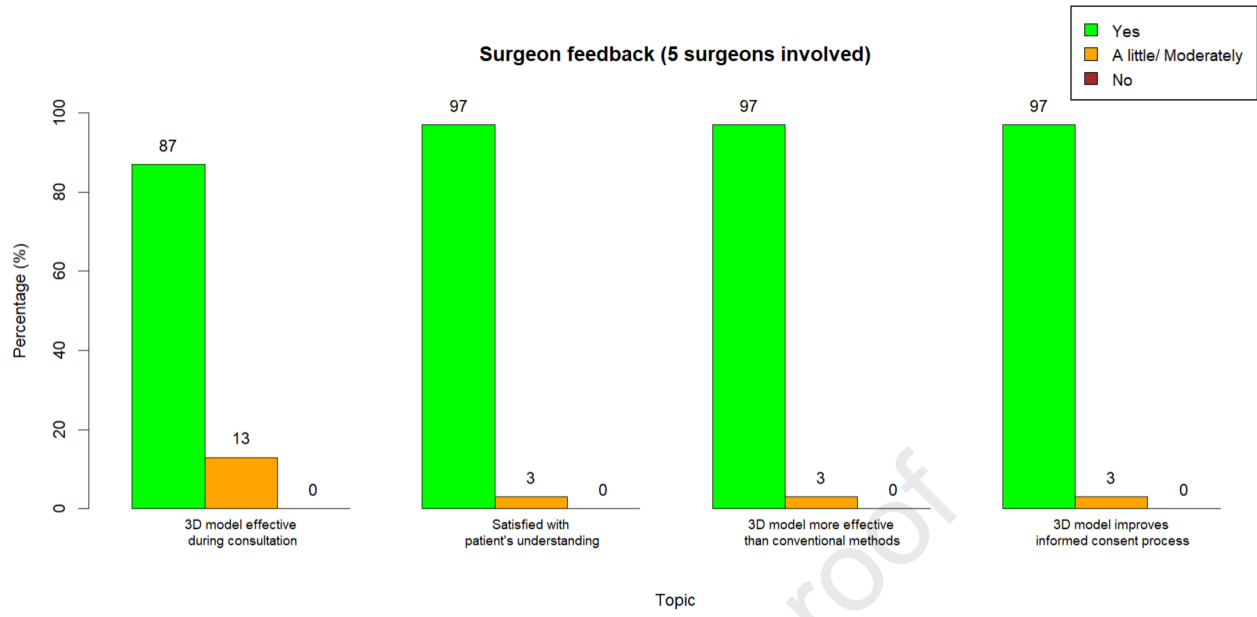


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Abbreviations:

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

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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:

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