# Patient-Specific Actual-Size Three-Dimensional Printed Models for Patient Education in Glioma Treatment: First Experiences

***Tom H. van de Belt[1], Hugo Nijmeijer[1], David Grim[1], Lucien J.L.P.G. Engelen[1], Rinaldo Vreeken[2,3], Marleen M.H.J. van Gelder[1,4], Mark ter Laan[5]***

■ BACKGROUND: **Patients with cancer need high-quality information about disease stage, treatment options, and side effects. High-quality information can also improve health literacy, shared decision making, and satisfaction. We created patient-specific three-dimensional (3D) models of tumors including surrounding functional areas and assessed what patients with glioma value (or fear) about the models when they are used to educate them about the relationship between their tumor and specific brain parts, the surgical procedure, and risks.**

■ METHODS: **This exploratory study included adult patients with glioma who underwent functional magnetic resonance imaging and diffusion tensor imaging as part of preoperative work-up. All participants received an actual-size 3D model printed based on functional magnetic resonance imaging and diffusion tensor imaging. Semi-structured interviews were conducted to identify facilitators and barriers for using the model and perceived effects.**

■ RESULTS: **Models were successfully created for all 11 participants. There were 18 facilitators and 8 barriers identified. The model improved patients' understanding about their situation; patients reported that it was easier to ask their neurosurgeon questions based on their model and that it supported their decision about preferred treatment. A perceived barrier for using the 3D model was that it could be emotionally confronting, particularly in an early phase of the disease. Positive effects were related to psychological domains, including coping, learning effects, and communication.**

■ CONCLUSIONS: **Patient-specific 3D models are promising and simple tools that could help patients with glioma better understand their situation, treatment options, and risks. These models have the potential to improve shared decision making.**

## INTRODUCTION

Patient information and shared decision making are crucial for high-quality care.[1-3] For shared decision making, it is essential that the patient understands health information to enable her or him to make well-considered health-related decisions.[4-6] Patients with cancer who have poor health literacy are more dissatisfied about their care, and poor health literacy is considered as an independent risk factor for poor health outcomes.[7] In addition, research shows that patients have a great desire to receive information about their disease and treatment options and complications.[8-11] However, it can be challenging for health care providers to explain complex conditions and risks in layman's terms,[11] especially when making use of two-dimensional (2D) imagery.[11,12] Of all information provided by a health care provider, patients instantly forget approximately 40%–80%.[13] Often there is a discrepancy between patients' perceived and actual understanding of their condition. The topics most frequently misunderstood are risks and complications of treatment.[14]

**Key words**
- 3D printing
- Glioma
- Patient education
- Surgery
- Treatment and risks

**Abbreviations and Acronyms**
**2D**: Two-dimensional
**3D**: Three-dimensional
**DTi**: Diffusion tensor imaging
**fMRI**: Functional magnetic resonance imaging

*From the [1]Radboudumc REshape Innovation Center, [2]Radboudumc 3D Lab, [3]Department of Oral and Maxillofacial Surgery, [4]Department for Health Evidence, Radboud Institute for Health Sciences, and [5]Department of Neurosurgery, Radboud University Medical Center, Nijmegen, The Netherlands*

*To whom correspondence should be addressed: Tom H. van de Belt, Ph.D. [E-mail: tom.vandebelt@radboudumc.nl]*

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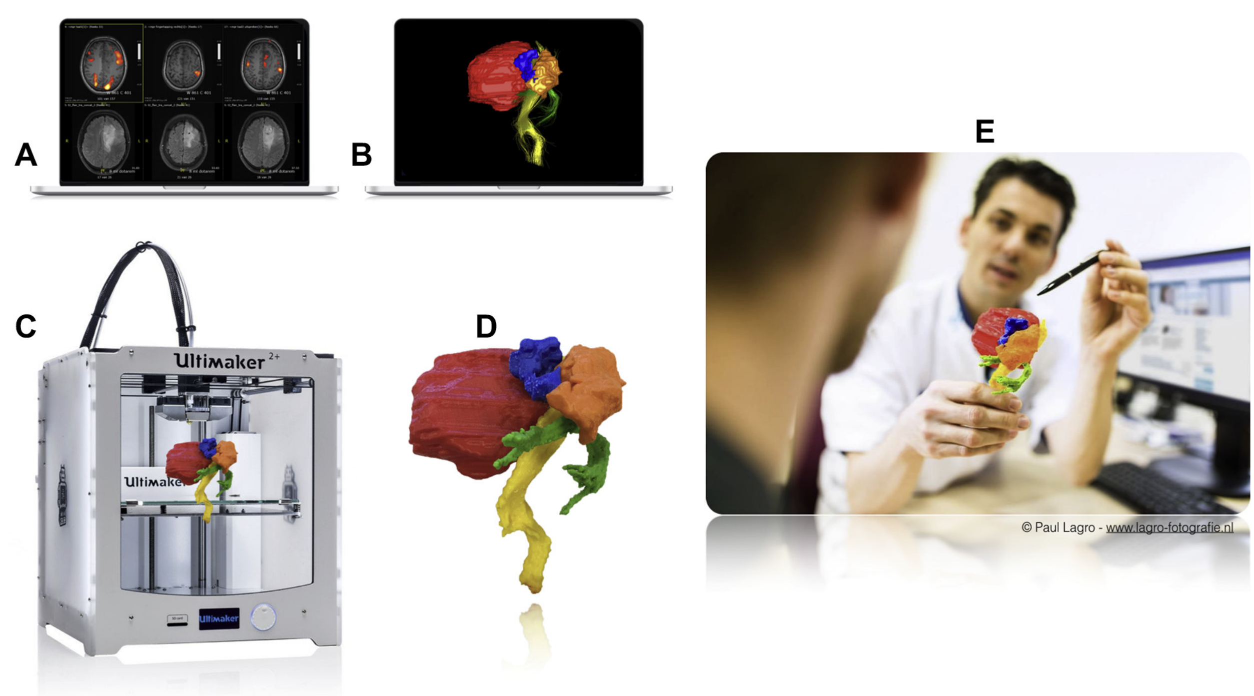


**Figure 1.** Process and application of creating a patient-specific three-dimensional (3D) model of a brain tumor. (**A**) Functional magnetic resonance imaging and diffusion tensor imaging. (**B**) Visualization as 3D model. (**C**) 3D printer. (**D**) Printed 3D model. (**E**) Use of the 3D model.

In glioma surgery, extensive imaging (functional magnetic resonance imaging [fMRI], diffusion tensor imaging [DTi]) is often used to create a three-dimensional (3D) computer image to guide the surgeon in decision making. These images often are also used to explain the procedure and risks to patients during preoperative consultation. As options can vary from biopsy only (low risk) to gross total resection (increased risk) with extensive monitoring (awake), patients are invited to participate and discuss their options based on their preferences. We think the use of patient-specific 3D models could help to reduce the communication gap between health care providers and patients. Especially in the case of glioma surgery, these patient-specific models might add substantial value when explaining procedures and associated risks to patients. In these cases, it is not just the anatomy that is valuable in decision making, but also the location of eloquent areas. In this case, general anatomic models do not suffice in explaining the specifics.

3D printing technology facilitates the creation of patient-specific 3D models.[15] Although 3D models are increasingly used in the field of surgery, such as for surgical planning and implants,[16,17] studies in which they are used for patient education are rare.[18,19] As a result, little is known about patients' preferences regarding use of this new tool for patient education. Previous work focused on assessing health literacy and general appreciation of the use of 3D models by means of surveys.[18,19] To develop a better understanding of what patients actually value (or fear) in the application of 3D models in patient education, we employed a qualitative, in-depth approach. This also allowed us to identify what facilitators and barriers actually exist for the use of the models during consultation and the positive and negative effects patients perceive.

## MATERIALS AND METHODS

### Design and Setting

The ethics committee of the Radboud University Medical Center reviewed the study protocol and approved the study (number 2015-1631). All participants were mentally competent and provided written informed consent. Between January 2015 and June 2016, we invited patients with brain tumors who underwent fMRI and DTi as part of preoperative work-up to participate in the study and offered them a 3D-printed model of their functional imaging. For anatomic reference, the neurosurgeon used regular magnetic resonance imaging. After discussing surgery options and involved risks, plenty of time was reserved for the patients to ask questions. All participants were interviewed about expectations and experiences with these 3D models before and after the consultation. These qualitative results could be used to create a survey to further quantify results.

### Patient-Specific 3D Models

The creation and application of the 3D models are shown in Figures 1 and 2. The entire process is further explained in the Appendix.

### Semistructured Interviews

To identify expectations and experiences with the model, semistructured interviews were conducted with all participants before and after consultation with their neurosurgeon. Based on participants' preferences, close relatives attended these interviews and were allowed to assist patients during the interviews. An interview guide was used based on the model for change by Grol and Wensing[20] including individuals, social context, and organizational or economic content. The interviews conducted before the consultation consisted of 5 topics: 1) general/ demographics, 2) characteristics related to the model (patient), 3) characteristics related to the model (professional), 4) the 3D model, and 5) context (friends, family, and work). The interview guide used after each consultation consisted of 3 major topics: 1) experiences, 2) the value of using 3D prints during consultation, and 3) additional experiences and needs. Based on the first interviews, we enriched the interview guide to obtain additional relevant information from upcoming interviews, aiming for data saturation. All interviews were recorded and transcribed verbatim. Subsequently, 2 authors (H.N. and D.G. or T.H.B.) analyzed each interview individually. The goal of this text analysis was to identify 1) perceived barriers and facilitators that could influence the use of the 3D model and 2) perceived positive and negative effects of using the model, as shown in **Figure S1**. Furthermore, any other relevant (as determined by the researcher) factor or quote was collected. Disagreements were discussed until consensus was reached.

As no framework to classify barriers and facilitators specifically for 3D printing is available, they were classified according to the framework for information and communication technologies in health care, developed by Gagnon et al.[21] and further enriched by Archambault et al.[22] In some cases, 3D model—specific factors were added to the existing framework. Effects (positive and negative) were classified using the Donabedian model for quality of care, which consists of 3 dimensions, including the structure, processes, and outcome of health care.[23]

## RESULTS

Of 13 patients invited, 11 (85%) participated in the study. A patient-specific 3D model was successfully created for every participant, and all patients were interviewed. Regarding the qualitative analysis, data saturation was reached, and no additional patients were included. One patient refused to be interviewed before the consultation with the neurosurgeon, and another patient refused to be interviewed after the consultation with the neurosurgeon, both for unspecified personal reasons. The characteristics of the study population are listed in **Table 1**.

### Barriers and Facilitators

All participants mentioned at least 1 facilitator using the patient-specific 3D model, resulting in 18 different facilitators. Only 6 participants mentioned at least 1 barrier, accounting for 8 different barriers. An overview of the barriers and facilitators is provided in **Table 2**. All factors that were mentioned are discussed here, according to the framework of Gagnon et al.[24]

***Knowledge.*** On one hand, participants told us they thought the model would help them better understand their clinical situation.

**Figure 2.** Illustration of how the model was used for patient education (actress acting as patient).

Factors mentioned were the superiority of 3D over 2D, 1:1 scale model, and use of color. Some participants indicated that the 3D model could help them better explain their situation to relatives and better recollect information. On the other hand, several patients mentioned that the use of a 1:1 scale model with bright colors might act as a barrier as well.

***Risks and Treatment.*** On one hand, patients thought the model would help them understand risks better. They also stated that a model would facilitate better understanding of the surgical procedure itself. On the other hand, it was mentioned that the model could not be detailed enough to fully appreciate the situation.

***Coping and Acceptance.*** The participants believed that a 3D model facilitated coping and acceptance of the situation. In particular, it was mentioned that the model could help in raising awareness among relatives.

***Communication.*** Participants mentioned that the 3D model help them better understand the surgeon and help them ask questions. Patients thought that the use of a patient-specific 3D model might also be valuable for surgeons because it made it easier to explain their situation. However, 1 participant found that it was not easier for the surgeon to explain their situation with the model.

***Emotional Confrontation.*** Patients mentioned confronting the model might be an emotional experience, especially in the early phase of treatment.

***Patients' Needs.*** It was mentioned by 1 participant that there was simply no need for a 3D model.

***Perceived Positive and Negative Effects.*** Eight participants mentioned at least 1 perceived positive effect of using patient-specific 3D models, and 4 participants mentioned negative effects. The main domains, according to the framework of Donabedian,[23] are also shown in **Table 2**.

***Psychological Domain.*** The main themes that were identified were coping, acceptance, and confidence. On one hand, 1 patient mentioned that the 3D model helped in making a decision about

**Table 1.** Study Population (N = 11)

| Variable | Value |
|---|---|
| Age, years, mean ± SD | 43.2 ± 11 |
| Female sex | 5 (45%) |
| Education | |
| No/lower education | 2 (18%) |
| Intermediate vocational education | 7 (64%) |
| Higher vocational education | 2 (18%) |
| Academic | 0 (0%) |
| Medical background* | 2 (18%) |
| Glioma grade | |
| 2 | 8 (73%) |
| 3 | 2 (18%) |
| Unknown (not operated) | 1 (9%) |

Values are reported as number (%) except for age.
*Working experience in health care (eg, nurse).

**Table 2.** Facilitators and Barriers for Using a Three-Dimensional Model and Positive and Negative Effects

| Factors | Facilitators | Barriers |
|---|---|---|
| Factors related to 3D print | | |
| Knowledge about current situation | | |
| Patients' understanding* | 6 | 3 |
| Understanding of family and friends* | 1 | 0 |
| Risk and treatment* | | |
| Patients' understanding | 1 | 1 |
| Supports decision about treatment | 1 | |
| Risk and treatment NFS | 1 | |
| Coping and acceptance* | 1 | |
| Support by family and friends* | 1 | |
| Communication | 3 | 1 |
| Emotional confrontation* | | 2 |
| Individual factors or health care professionals' characteristics (knowledge and attitude) | | |
| Patients' needs* | | 1 |
| | **Positive Effects** | **Negative Effects** |
| Effects on psychological domain | 3 | 3 |
| Learning effects | 4 | 0 |
| Communication | 2 | 0 |

3D, three-dimensional; NFS, not further specified.
*Newly added factor to taxonomy.

the preferred treatment, even though this treatment was the most unpleasant one. Another patient stated that the model helped her to accept the tumor as part of herself, instead of something frightening. The model also increased confidence and trust in their neurosurgeons.

On the other hand, it was mentioned that confronting the model was an emotional experience. One participant described this as follows:

"It [the 3D model] makes it very realistic. This is really inside your own head. With a picture you can think 'aah it's just a picture,' but now you can really see it in front of you. It is uncomfortable seeing something like this, since it is so tangible" [translated from Dutch].

Also, anger and fear were mentioned as negative effects of use of the 3D model. It was mentioned that this was less so with regular 2D magnetic resonance imaging, as the images looked less "real."

***Learning Effects.*** According to patients, the 3D model helped them better understand their situation, treatment options, and risks. The 3D model particularly helped patients to understand the location and size of the tumor, and it provided them with a clearer image than the 2D images they were used to seeing on their neurosurgeon's screen. A patient stated:

"I think the model is very clear. You can see how it is positioned in the head. It could not get clearer than this" [translated from Dutch].

Other patients stated that the situation became even clearer when the 3D model was used in combination with radiologic images on the computer screen.

***Communication.*** Participants mentioned that the 3D model improved communication with their neurosurgeon, and others perceived the use of the model during the consultation as pleasant. One patient stated that the model enabled him to ask more questions, which would have been hard to ask otherwise. Several patients asked to take the model home to show to their friends and family and to explain it to them.

## DISCUSSION

### General Findings

We successfully created patient-specific 3D models to inform patients with glioma about their situation, treatment options, and risks. The models were highly appreciated by patients. Our study resulted in a comprehensive overview of experiences and perceived effects of using 3D models by patients with glioma. Their experiences were predominantly positive, particularly regarding understanding their medical situation, psychological aspects, and communication. Although these findings indicate that the use of such models could contribute to fully informing patients, participants also mentioned that confronting the models could be an emotional experience. Future projects should take the later comment into account.

### Other Research

The few previous studies on this matter concur with our findings.[18] A pilot study by Silberstein et al.[24] used questionnaires to evaluate the potential value of using physical 3D-printed models of renal malignancies for patients, trainees, and clinicians.[24] Their study showed that use of the model could influence both patients' and trainees' understanding of renal malignancies. An earlier study by Spiegle et al.[25] that focused on decision aids for better assisting patients with cancer in making decisions about their procedure proposed that 3D models could be considered as valuable communication aids. This corresponds to a recent study among adolescents with congenital heart disease in which personalized 3D models were used to inform them about their situation[19] and a similar study in kidney patients.[20]

The use of 3D models has increased tremendously since these 3D printers became widely available. However, research on the effectiveness and efficacy of the use of these models in health care is scarce.[16] When evaluating the effects of using 3D models in patient education, a challenge lies in finding objective criteria. Because physicians and other health care workers might not always be able to judge what is important to patients, we have take the first step by detecting barriers, facilitators, and positive and negative effects as perceived by patients.

### Strengths and Limitations

An important strength of our study is that we found a relatively simple way to print personalized actual-size 3D models of the tumor and surrounding functional areas. The relationship between tumor and function especially can be demonstrated this way, which was valued by patients because it helps them to better understand the suggested procedures and risks, and it facilitates coping. Another strength compared with other studies is the qualitative approach.[18,19] The identification of the wide spectrum of barriers, facilitators, and positive and negative effects as perceived by individual participants allows us to address barriers and further improve the use of these models. In this way, we have created a sound basis to further quantitatively study the effects of 3D model use. In follow-up studies, we will be able to determine whether the use of these models truly contributes to patients' understanding of their disease, the procedure, and risks compared with the use of 2D imaging alone. Although additional factors could have been found, we believe data saturation was reached in the present study, as in the last 6 interviews, only 4 new factors were identified. A potential limitation relates to the timing of the interviews, which were conducted immediately before and after the preoperative consultation with the neurosurgeon, and thus we cannot make conclusions about long-term experiences or experiences of relatives. We hope to address long-term experiences in forthcoming work.

## CONCLUSIONS

Patient-specific 3D models are promising and simple tools that can help patients with a brain tumor better understand their current situation, treatment options, and risks. We have identified the facilitators, barriers, and perceived positive and negative effects of use of these models in patients with gliomas in eloquent areas during patient consultation. Future projects should address the barriers and negative effects mentioned and evaluate the extent to which the use of 3D models could positively influence the quality of health care, including in the longer term. Stratification based on kind of pathology and location of the tumor is recommended.

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## APPENDIX

### Process of Creating Patient-Specific 3D Models

For this study, 3D models were printed using a consumer market—aimed Ultimaker 3D printer (Ultimaker BV, Geldermalsen, The Netherlands). After fMRI and DTi images were imported, they were fused with the anatomic magnetic resonance imaging scans, using StealthViz software (Medtronic, Minneapolis, Minnesota, USA). The tumor was segmented based on T2 fluid attenuated inversion recovery signal or contrast enhancement on T1 postgadolinium scans. Relevant areas of elevated blood oxygen—level dependent signal in fMRI scans (representing functional areas) were segmented, and tractography was performed based on DTi scans. Segmentations and tractography were visualized as 3D models, which were exported as Digital Imaging and Communications in Medicine (DICOM) image sequence. MeVisLab (MeVis Medical Solutions AG, Bremen, Germany) was used to import the DICOM imaging, and 3D model reconstructions were made of the segmented parts. The 3D model reconstructions were exported as STL files. Preparation of the STL files for printing was done in 3DS Max 2015 (Autodesk Inc., San Rafael, California, USA). The files were imported, cleaned, and checked for errors, and small changes were made to fit the segmentations to each other as a puzzle. Finally, the models were exported as STL files and imported in Cura version 2.1.2 64 bit (Ultimaker B.V., Geldermalsen, The Netherlands) and sent to the 3D printer. Each part was printed in a specific and consistent color (red for tumor, blue for cortical speech and language areas, orange for cortical motor areas, yellow for corticospinal tract, green for superior longitudinal fascicle or arcuate fascicle, white for optic radiation). Separate parts were glued together.

### Costs

The 3D printer used in this study cost €1500 ($1740.68). Additional costs, including materials and electricity, were estimated at €5 ($5.80) per 3D model. Furthermore, a technician spent 1—2 hours per print on editing imported images.

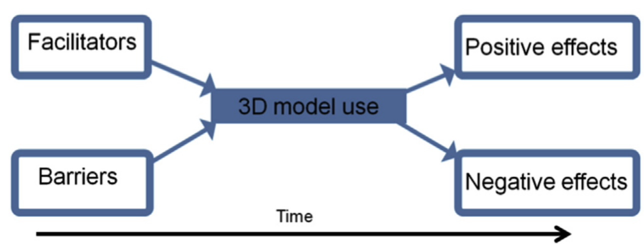


**Figure S1.** Perceived barriers and facilitators that could influence the use of the three-dimensional model and perceived positive and negative effects of using the model.