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Research Article

Individualized Intracranial Tumor Models Created with 3D Printer, an Early Clinical Experience

3B Yazıcı ile Kişiye Özel Beyin Tümörü Modelleri; Erken Klinik Deneyim

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Abstract: Intracranial tumors located at an eloquent cortical site have challenges during a radical resection and may cause serious morbidity. Several techniques are used to prevent such morbidity and recently addition of 3D printer technology provides the surgeon to plan the surgery on a model preoperatively, thus helps lowering morbidity. 9 patients with cortically located tumors were operated in our institutions planned preoperatively on a 3D printed model. Individualized 3D printed models for preoperative planning in patients with cortically located tumors were created successfully throughout this study. Most of the previous studies regarding utilization of 3D printers in neurosurgery focused on cranial deformities and intracranial aneurysm models. Tumors invading normal glial tissue set a challenge for creating 3D printed models for the disease. Future prospective studies are essential to prove the efficiency of the model in terms of reduced morbidity and better surgical outcome.
Keywords: Intracranial tumor, 3D printer, Neurosurgery education

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Özet: Değerli ve fonksiyonel kortikal bölgelerde yer alan intrakranial tümörlerin radikal rezeksiyonu esnasında çeşitli güçlüklerle karşılaşılabilir ve bu ciddi morbiditeye sebep olabilir. Bu tarz bir morbiditenin önüne geçmek için farklı yöntemler kullanılabilir. Yakın bir geçmişte 3 boyutlu yazıcı teknolojisinin eklenmesi ile cerrah, preoperatif olarak model üzerinde planlama yapabilir. Böylece morbiditenin azaltılmasına yardımcı olunabilir. Kliniklerimizde kortikal yerleşimli tümörleri olan 9 hasta, 3 boyutlu (3B) model üzerinde preoperatif hazırlık yapılarak opere edildiler. Nöroşirurjide 3B yazıcılarla ilgili bundan önceki çalışmaların birçoğunda kranial deformite cerrahileri ve anevrizmal modelleri üzerinde durulmuştu. Normal glial dokulara invazyon gösteren tümörlerin modellenmesi görece zor olup, bu tarz modellemelerin daha iyi cerrahi sonuçlar sağlayabileceğinin değerlendirilmesi açısından prospektif çalışmalara ihtiyaç duyulmaktadır.
Anahtar Kelimeler: İntrakranial tümör, 3 boyutlu yazıcı, Nöroşirurji eğitimi

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1. Introduction

Intracranial tumors account for 1,4 % of the newly diagnosed malignancies and 2,6 % of the mortality due to the malignancies annually (1). Meningiomas are the most common type of adult intracranial tumors mostly have a benign course. The treatment and surgical resection are affected by the location of the tumor. 24% of the adult tumors are gliomas (1). Low-grade gliomas account for 30 % of all gliomas (2). The ones located at an eloquent site have challenges during a radical resection and may cause serious morbidity.

3D printer technology has been started to be used in neurosurgery field since last several years. It has a wide variety of applications such as patient informal, preoperative surgical planning and preparation of surgical guides (3–5). The individualized implants perfected the cosmetic result of the surgery especially in cranioplasty. Planning preoperatively by not only evaluating the imaging but also by seeing and touching the model improved the surgical outcomes (6).

Some intracranial tumors may be located on or adjacent to the eloquent areas. Techniques such as awake craniotomy or intraoperative neuromonitoring are used to determine the extent of resection during the surgery (7). The use of those techniques aims to lower the surgical morbidity and improve the surgical results. Addition of 3D printer technology provides the surgeon to plan the surgery on a model.

The scope of this study is to investigate the effect of surgical planning and application of 3D printed preoperative models among patients operated due to cortically located tumors.

2. Material and Methods

9 patients with cortically located tumors operated between January 2019-January 2020 in our clinics were included to this study. Approval from the ethical committee were granted. Information regarding demographics of the patients, location of the tumor, the symptoms on admission, pathology results, duration of the operation, duration of the stay, presence of complications and Karnofsky Performance Score (KPS) were evaluated.

3D Model Creation

The computed tomography (CT) data was obtained in Digital Images and Communications in Medicine (DICOM) format, enabling formation of an interface between devices in favor of creating a solid model. RadiAnt DICOM Viewer (Medixant, Poznan) application was used in order to differentiate between the tumoral tissue and remaining soft tissue using the differences in Hounsfield Unit (HU) (Figure 1). Both the tumoral tissue and the remaining brain tissue images converted into a 3D model and exported as ".stl" files.

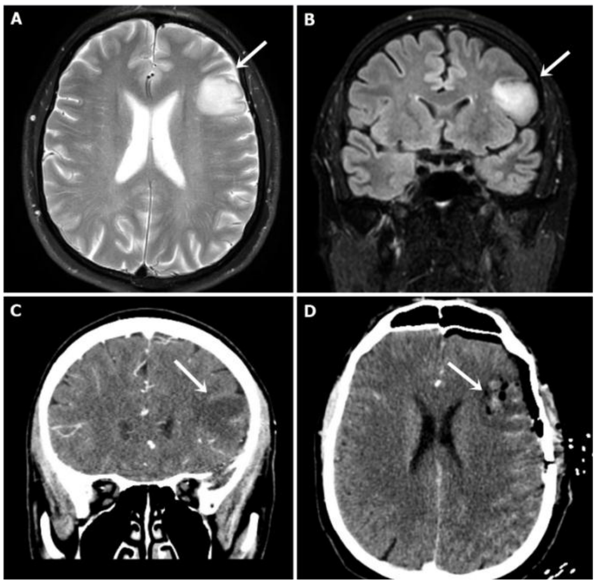

Figure 1. The tumoral component and normal brain tissue determined according to the MRI findings were highlighted on different shades (A, B). The tumor is extracted from the normal brain (C, D).

3D STL models obtained from Radiant DICOM Viewer, meshed again using Meshmixer ™ (Autodesk, San Rafael, U.S.A.) software. Both models overlapped on the coordinate system. The tumor model was then extracted from the brain model. The models prepared for 3D printing was exported and sliced using Cura (Ultimaker, Geldermalsen, The Netherlands) software then Gcode's were created (Figure 2). PLA filament of 2,85milimeters was used during printing process in which the recommendations of manufacturer were followed.

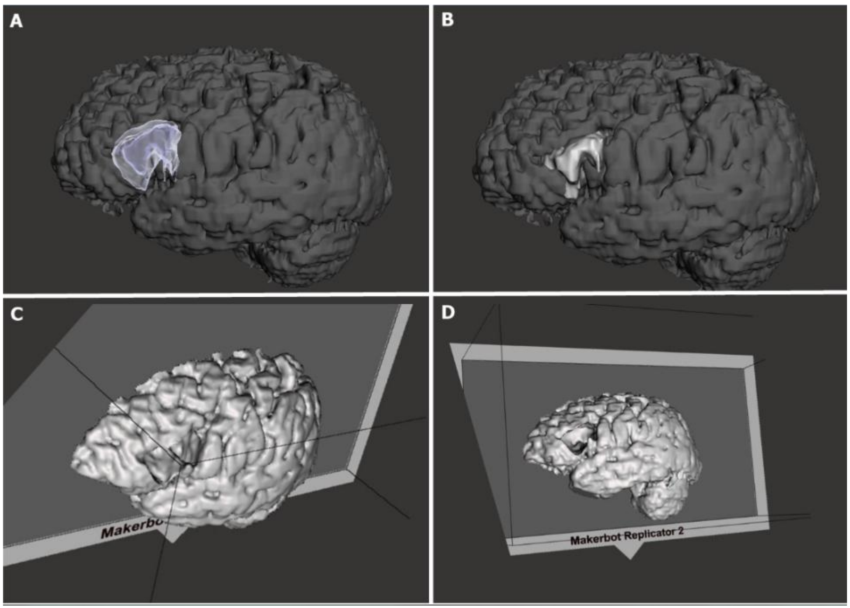

Figure 2. The successfully created 3D printed model (A, the normal brain tissue compartment is shown). Intraoperative images before (B) and after (C) the safe maximal resection.

The preoperative planning was done using the patient history and imaging, additionally the individualized 3D printed tumor and brain models. The models were sterilized and taken to the operation theatre for intraoperative navigational purpose. After the operations performed, the material quality, the potential benefits on the preoperative planning, the impact on prediction of complications and the usefulness for educational purposes of the 3D printed models were evaluated.

Statistical Package for Social Sciences Version 22.0 (SPSS, Chicago, IL, USA) was used for statistical analysis. The mean, median and standard deviation values were obtained.

3. Results

The mean age of 9 patients was 56,44±11,94 (range 36-74). 44,4 % (n=4) of the patients were female and 55,6 % (n=5) were males. Mean duration of hospital stay was 14,67±12,92 (range 4-75) days. The presenting symptoms were headache (55,6 %), seizures (22,2 %) and recent neurological deficits (22,2 %). 5 patient had tumor located on the frontal lobe (Table 1).

Table 1. Demographic data, as well as location and pathology of the tumors and complications were shown on the table.

No	Age	Gender	Location	Symptom	Resection	Surgery Time (min.)	Pathology	Complication	Hospital Stay (day)	KPS on Discharge
1	46	Male	Frontal	Headache	Subtotal Resection	120	Diffuse Astrocytoma	-	5	90
2	74	Male	Temporal	Seizure	Gross Total Resection	160	Glioblastoma	Wound infection	10	70
3	36	Female	Frontal	Headache	Gross Total Resection	170	Meningioma	-	6	90
4	48	Female	Occipital	Headache	Gross Total Resection	130	Glioblastoma	--	7	80
5	55	Male	Temporal	Neurological Deficit	Gross Total Resection	130	Carcinoma		4	80
6	59	Female	Frontal	Headache	Gross Total Resection	190	Glioblastoma	-	8	90
7	70	Male	Frontal	Headache	Gross Total Resection	170	Meningioma	CSF fistula	12	80
8	63	Male	Parietal	Neurological Deficit	Subtotal Resection	200	Glioblastoma	--	6	90
9	57	Female	Frontal	Seizure	Gross Total Resection	190	Carsinoma		9	80

7 patients (77,8 %) undergone gross total resection. The mean duration of operation was 162,22±29,48 minutes. The pathology results were as follows; 4 (44,4 %) glioblastoma, 2 (22,2 %) meningioma, 2 (22,2 %) carcinoma metastasis, 1 (11,1 %) diffuse astrocytoma.

Mean duration of hospital stay was 7,44±2,55 (4-12) days. 1 patient experienced surgical wound site infection whom treated with I.V. antibiotics for 10 days, received additional oral antibiotics after discharge. In 1 patient CSF fistula was observed. Lumbar drainage and dressing with pressure were applied. He discharged on postoperative 12th day without any signs of CSF leak. KPS of the patients at the time of discharge were as follows; 90 (44,4 %, n=4), 80 (44,4 %, n=4) and 70 (11,1 %, n=1).

4. Discussion

Most of the studies regarding utilization of 3D printers in neurosurgery focused on cranial deformities and intracranial aneurysm models. Tumors invading normal glial tissue set a challenge for creating 3D printed models for that disease. Individualized 3D printed models for preoperative planning in patients with cortically located tumors were created successfully throughout this study (Figure 3).

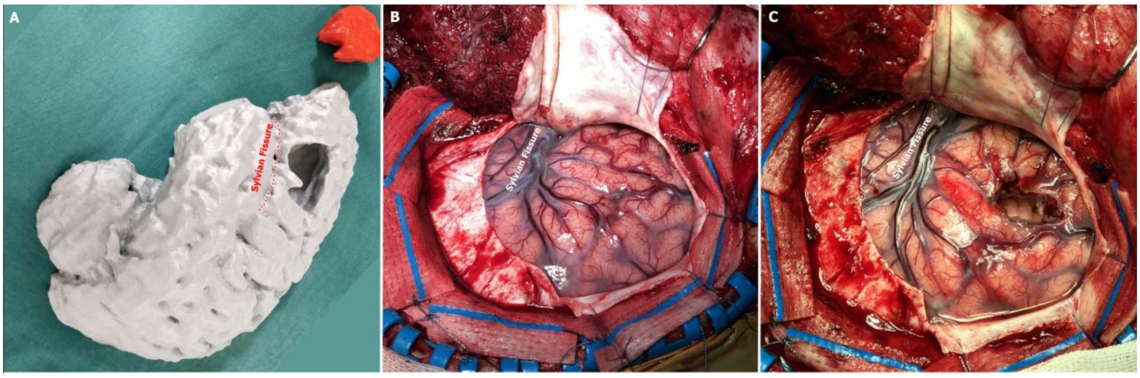

Figure 3. Preoperative MRI (A, B) and contrast CT (C) of a left frontal opercular lesion. It appeared as a hyperintense lesion on T2-weighted images. There was no evidence of contrast enhancement. Postoperative contrast CT (D) demonstrates total resection of the lesion. The lesion turned up to be a Diffuse Astrocytoma (WHO Grade 2).

Okonogi et. al. created 3D printed anterior clinoidectomy models in patients with sphenoid wing meningiomas and giant ophthalmic segment aneurysms. They drilled the anterior clinoid preoperatively on the model and reported that it was beneficial for surgical training (8). Our residents found 3D printed models for tumors located cortically beneficial especially for navigation during the operation.

Oishi et. al. simulated deep intracranial tumors (meningioma, schwannoma, epidermoid tumor etc.) in a 3D virtual environment in 12 patients. They decided the surgical strategies on those complex 3D anatomical models (9). In our study, determination and evaluation of arterial supply of meningiomas appeared to be shorten the duration of surgery.

Okonogi used binder jet type 3D printer. This system created the models with Powder Lamination method thus enabling the models themselves for drilling (8). We use Fused Deposition Modelling (FDM) technique. With this technique the bony anatomy can be studied however while drilling the models won't feel realistic. FDM technology is cheaper and uses an easily accessible raw material when compared with binder jet technology. Consumer products of FDM type can be used anywhere with ease.

Lan et. al. created preoperative models for aneurysms and highly vascular tumors. They discussed optimal surgical approach preoperatively and the relation of the aneurysm or tumor with the calvarium. They emphasized that young neurosurgeons would benefit from the models especially in cases with a complex anatomy (10). In our institution, firstly cranioplasty modelling then vascular and bony modelling were done and used for preoperative planning.

Van de Belt used 3D printed models of glial tumors to inform the patients with more understanding. They stated that the patients comprehended their disease better with the 3D printed models (11). Additionally, the patients being more decisive with the treatment options they're given was also remarked.

Lin et. al. modelled 2 sellar tumors and 1 acoustic neurinoma with 3D printer and compared with the shape of the tumors intraoperatively. Sphenoid sinus, hypophyseal fossa, cerebellopontine angle, the tumors and the relation with major arteries were demonstrated on the 3D printed models. However, it is stated that cranial nerves could be modelled poorly. The potential benefits for neurosurgical education were emphasized (12). In our study, cortically located tumors were modelled, we don't have any experience regarding cranial nerve modelling. Moreover, imaging of the cranial nerves and conversion from DICOM format to STL format is somewhat difficult.

Damon described 3D modelling of tumors and printing with FDM technique in detail with a technical note. They used T1-weighted images for contrast-enhancing extra axial tumors and high-grade glial tumors, and T2-weighted images for low-grade glial tumors (13). We also followed same the procedure for modelling.

Thawani demonstrated the relation between low-grade glial tumors and white matter fibers (14). Especially used FLAIR and DTI sequences and completed the resection of those low-grade gliomas successfully.

The technical limitation of this study was that the printing time with FDM technique is relatively long (12-24 hours). Additionally, arachnoid system, invasion of the tumor to the surrounding tissue and vascular hemodynamics cannot be modelled on 3D printed models.

5. Conclusion

In the future, hemodynamics, relation and invasion with the normal tissue may be shown appropriately with 3D printed models. Individualized 3D printed models enable preoperative surgical planning. Future prospective studies are essential to prove the efficiency of the model in terms of reduced morbidity and better surgical outcome.

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