

Neurosurgical Operations Using Visualization and 3D Printing

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Abstract

In planning of neurosurgical operations is very crucial the precision in drawing target structure and definition the near risk structures. Shape and location of the target structure before the operation can be previewed via visualization and 3D printing, which help in deciding which modality of surgical operation is the safest therapy for patient.

Planning of stereotactic surgery is performed by CT and MRI imaging, which are transferred after their merging into the virtual planning system called "TomoCon". Visualization and virtual planning greatly assist the subjectivity of hand drawing contour by the neurosurgeon for a 3D model of brain structures for optimization of treatment. For this reason, we proposed to use virtual reality in the planning of neurosurgical operations. Using the stereoscopic view of the CT and MRI slices in 3D model, we make better corrections in the segmentation phase of creating the 3D model of brain structures.

Visualization and 3D printing increase the focus on the precision of planning process. Particularly in the case of radiosurgery, the calculation of the lowest dose in the structure of the risk and the effectiveness of irradiation influences the preservation of the highest quality of life after surgery.

Keywords: neurosurgery, radiosurgery, visualization, virtual reality, 3D printing, neurosurgery planning.

Introduction

The history of Virtual Reality (VR) began in the 90s of the last century. Technology research company Gartner forecasted mass use of VR after 2010. Company Oculus Rift designed prototype Oculus Rift DK in 2010 and later in 2013 Oculus Rift VR. Company HTC with Valve Corporation announced their virtual reality headset HTC Vive in 2015 and was distributed in 2016, which is the second most widely used VR model today.

Both models Oculus Rift VR and HTC Vive we implemented in the projects focused on the mapping historical sites and natural curiosities [1, 2, 3] (See Figure 1). Training and methodological materials for teachers were created for modern approaches displaying information for education of history.



Figure 1: Images for left and right eye.ww

The experiences of these VR devices we applied also for neurosurgical planning system in which we use software system TomoCon and our VR-TomoCon system [4, 5].

Since the beginning of our millennium 3D printing is applied in medicine for creating individualized dental implants and prostheses. 3D printing technology helps in the production of prostheses, assistive devices, production of hearing aids, prostheses, nose, ears, eyes, teeth, breast reconstruction, of bone substitutes (See Figure 2).



Figure 2: Examples of 3D printing of prostheses.

The result of 3D printing object depends from the printed material as well as from the type of printer (e.g. printer speed and resolution). Printing technologies can form the desired templates for virtual models of objects (modeled needed shapes and textures). The 3D printer creates the base of object, moving of printer head and loading material in the x-y plane, and gradually creates layers of

printed object with respect to the vertical axis z. In recent years, 3D printing is applied in clinical practice but also in undergraduate and graduate education. [6-9].

3D printing uses the outputs of the various layers of 2D imaging methods such as X-ray, computed tomography (CT), magnetic resonance imaging (MRI) (example of MRI imaging of slices see on Figure 3). CT and MRI images of slices of the body will be transformed into 3D models with display of anatomical structures. Creating 3D models for printing is similar to creating 3D models for virtual reality. This creates the 3D virtual object according to the model.

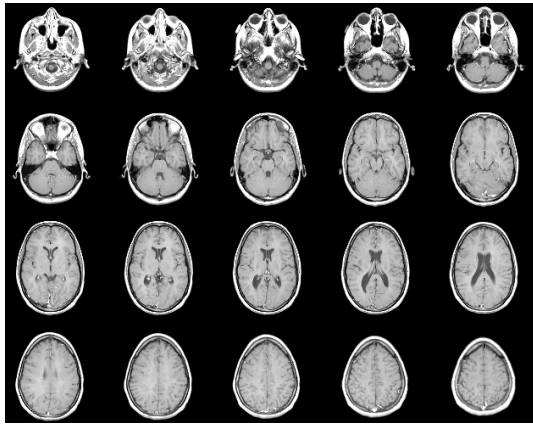


Figure 3: MRI imaging series of the brain.

The precision of stereotactic planning ensures fixation of the stereotactic frame, which determines the exact coordinates in the patient space (See Figure 4). By the one day session surgery the patient is examined by the CT and MRI with the condition that coordinates system is identical defined by the stereotactic frame. For multiple CT or MRI scans, it need to be made transformations based on consistent structures of the brain.

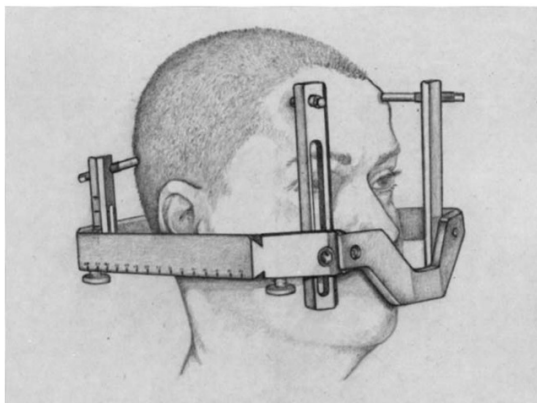


Figure 4: Fixation of the stereotactic frame.

In planning of neurosurgical operations is very crucial the precision in drawing target structures and definition of the risk structures. In terms of creating a scene in the virtual space, the neurosurgeon can see all important structures not only in 3D space but also in the different views of CT and MRI sections (sagittal and transversal).

Materials and methods

Neurosurgical planning is based on previous CT and MRI sections that were performed without a stereotactic framework. In some

cases, 3D printing of selected structures is performed, which the physician can see like real. Planning of stereotactic neurosurgery operation begins by CT and MRI sections with the stereotactic frame. These virtual combined slices from merged CT and MRI images are transferred to the planning software system VR-Tomocon, which allowed better definition of the edges of the target structure (e.g. the tumor) and identify necessary anatomical structures. Distinguish tumor from normal tissue, particularly of critical structures is done for reasons of protecting critical structures with the limit radiation doses in case radiosurgery.

Thanks to virtual reality (stereoscopic viewing of the brain) the neurosurgeon can better perceive quality of prepared segmentations in 2D sections and he may correct preformed segmented data of defined structures. By scrolling through the sections, you can choose a suitable view for the present brain structures. In combination with the volumetric model you can more precisely identify individual structures and may be closer to zoom this structure. Virtual reality systems today provide abilities to online tracking defined space. The user can bypass object of interest and see it from all sides. Through these methods, the neurosurgeon has better idea of the real state of various structures in the brain and through the interaction he may better perceive these 3D objects. This way he faster decides to determine proper actions for neurosurgery planning. VR-TomoCon system allows to transfer “objects of interest” back to the original system TomoCon.

In the planning radio surgery operation, it is critical accuracy of target and limit risk bearing structures. The shape of the tumor, its borders and localization before surgery can be visualized and using 3D printing to help in decision making radiation therapy. As example for radiosurgery decision-making is the irradiation modality which is safest for the patient, if it is radiation therapy by LINAC treatment or gamma knife or proton radiation [10]. In this case, critical risk structures such as lenses, optic nerves, optic chiasm, brain stem, pituitary, are outlined in the planning program. Drawing of the skin is used to calculate the penetration depth of the beam. Subjectivity of manual plotting that makes neurosurgeon using a 3D model, helps to visualize and optimize treatment. Precision plotting target structure and critical structures in real space is enhanced by the planning program.

Segmentation of data we used in planning program VR-TomoCon for better viewing of 3D objects and 3D printing. In this way we created a 3D virtual model of the object as well as the tumor visible anatomical structures of the brain to the press. Then we used the software TomoCon from TatraMed for 3D Printing necessary structures. This process 3D model structures and 3D printing we applied for one patient with a tumor of the optic nerve and the patient with two tumors, one situated near the weir and the other near the vessel, but at a safe distance from the optic structures (meningioma).

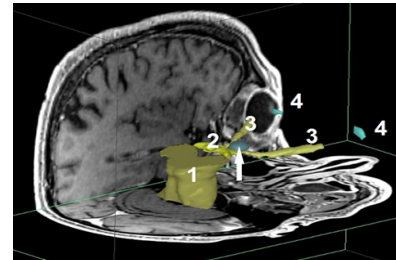


Figure 5: Virtual view on the brain structures with meningioma tumor on the optic nerve (see the arrow).

Before the stereotaxic radiosurgical treatment indication we made 3D model of the patient's brain with the tumors and critical structures (See Figure 5). Risk structures are numbered:

1. brain stem
2. optical chiazma
3. optic nerves
4. lens

The tumor is located directly on the optic nerve, so we decided to fractionated radiotherapy by stereotactic gamma knife brain surgery to not damage the eye of the patient.

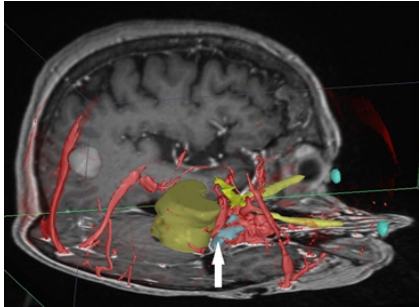


Figure 6: Virtual view of the brain with a 3D finding meningioma (two tumors near sluice and blood vessels).

In this case, the patient has two tumors, one lying near the sluice and other nearby vessels, but at a safe distance from the optic structures, so we decided to stereotactic radiosurgery operation (See Figure 6). In this case, one tumor is occipital behind, touches the occipital sluice. The tumor is light blue, indicated by the arrow. A second tumor is in a tangle of blood vessels in the jugular foramen the optic nerve several millimeters below it, also the same light gray color. Radiosurgery procedure must protect at-risk structures - lenses, optical chiazma, brainstem and blood vessels in the jugular foramen.

This patient was successfully operated in one radiosurgery session without damaging critical structures.

Discussion

In collaboration with Faculty of informatics Pan-European University we successfully implemented virtual reality devices into TomoCon system for planning treatment.

Likewise, in collaboration with Ophthalmologist clinic of the Faculty of Medicine in Bratislava we planned radiosurgery operations of the brain and eye using program TomoCon. Before the operation, we created 3D models of the necessary structures and printed to the 3D printer, which we use them for postgraduate teaching of physicians and medical students in stereotactic radiosurgery operation of the brain and eye tumors (See Figure 7).

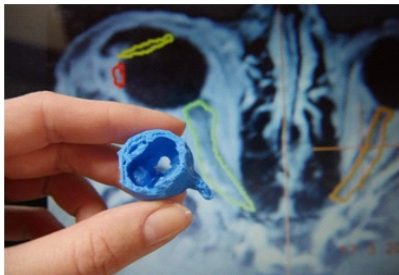


Figure 7: 3D model eye with stereotactic planning system in the background

At stereotactic radiosurgery treatment plays an important role in the formation of the layout plan, the shape of the tumor, as well as distances and bearings to critical structures. 3D tumor imaging with visible anatomical structures of the brain helps to determine the best modality of the therapy. These procedures ensure optimal treatment strategy for maintaining the highest quality of life after irradiation.

In stereotactic radiosurgery, virtual reality helps us for deciding which modality radiation is optimal for the patient. As an example we list treatment by these devices: Linac, Gamma knife, Cyber knife or proton therapy. We decide between them in order to preserve the highest quality of life after surgery.

The virtual reality and 3D printing helps in improving the vision of the tumor as well as in the actual planning process [1, 4, 5] The ability to see the 3D structure of the head with tumor process is beneficial to the whole team that creates the radiosurgery plan (clinical physicist, neurosurgeon, radiotherapist, ophthalmologist, radiologist and psychologist). 3D spatial perception contributes to a better understanding of the location and progression of tumors compared with the creation of perception from the series of 2D views only.

Objective is to optimize the health of each patient. Very important are personality determinants of patients from psychological point of view, which also affect patient's condition after postoperative treatment [11, 12]. The new phenomenon "Big Data analytics" helps towards this objective that active use of large amounts of data is changing the way of decision-making [13]. The related decisions must be in the future not only the experiment, but the right decision making.

Conclusion

Limitations of virtual reality may be in different resolution devices that could deform the space on the edge of the user field. For this reason, it is necessary to precisely calibrate the equipment for each single user. Another limitation of virtual reality is a necessity to use gestures for manipulating data in the virtual space, which due to long working hours with data may lead to user fatigue. This factor is very individual.

When planning radio surgery operation is crucial plotting precision target of bearing and limit risk structure. The above-mentioned shape and boundaries, we have succeeded to display through 3D printing. In this way, we have increased exactness targeting therapeutic dose during the planned intervention, and consequently affected the calculation of the lowest dose to risk structures.

Visualization and 3D Printing contributes to a better understanding of localization and progression of tumors with creating of imagination spatial arrangement through regular 2D slices that assist in undergraduate and postgraduate education.

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