

Ukr Neurosurg J. 2023;29(3):58-65
doi: 10.25305/unj.284245

Own experience of using holographic neuronavigation using an augmented reality helmet in neurosurgery

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Received: 10 July 2023

Accepted: 07 August 2023

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Objective: to optimize surgical access to intracranial lesions (tumors, arteriovenous malformations, cysts, etc.) by using a holographic neuronavigation system with augmented reality helmet.

Materials and methods: The study included thirty-four patients who underwent cerebral neurosurgical interventions. Creation and clinical use of mixed reality neuronavigation (MRN) system holograms was possible in all cases, which allowed accurate localization of lesions. The additional time required for synchronizing the MRN system with the clinical environment was estimated, which decreased with the number of MRN system uses. Operators evaluated the effectiveness of the technology and in most cases provided positive evaluations after use.

Results: A semi-automatic MRN-recording system on HoloLens smart glasses has been developed and tested for accuracy and performance. 34 patients with intracranial lesions were prospectively included in the study. Three-dimensional holograms of lesions, markers, and surrounding anatomical landmarks based on multimodal imaging were generated for each patient and then imported into the MRN system in AR helmet. After point recording, holograms were projected onto the patient's head and observed through the AR helmet during the planning and conducting of surgical interventions.

Conclusions: In this small pilot study, the authors found that mixed reality neuronavigation system MRN can be applied in the workflow of a neurosurgical operating room and is a possible method of preoperative identification of lesion boundaries for surgical access planning. Future studies are needed to identify strategies to improve and optimize the accuracy of MRN system.

Keywords: *mixed reality; neuronavigation; preoperative planning*

Introduction

Preoperative planning in neurosurgery requires a thorough understanding of anatomical relationships to ensure optimal outcomes. However, determining the precise localization of intracranial lesions relies greatly on medical imaging due to the highly protected nature of the brain and complex anatomy. With the advent of the concept of navigation-guided surgery, commercial neuronavigation systems have been developed that can accurately determine the location and boundaries of lesions during neurosurgical procedures. Preoperative accurate projection of localization of the target lesion on the patient's scalp is of considerable importance for neuronavigation systems. However, visual coordination between the operating field and the navigation monitor can be distracting for the surgeon [1]. It also requires the imaginative transformation of 2D images into 3D physical space depending on the surgeon's experience. In addition, a standard neuronavigation system has bulky equipment, including an infrared camera, a navigation workstation and accessories. Typically, a neuronavigation system costs more than \$300,000.

Recently, new image processing technologies have been created that combine real and virtual environments for interactive human-computer interaction [2,3]. In virtual reality, users observe objects in a fully virtual environment, whereas in augmented reality - virtual objects in the physical environment that surrounds them. Mixed reality, a derivative of augmented reality, enables interactive digital data to be displayed and interacted with in a physical environment. Commercial augmented reality (AR) helmets, such as "HoloLens" (Microsoft Corp., USA), facilitate the application of these imaging technologies in many fields, including healthcare and education. Augmented reality helmets have three key features: 1) a holographic display provides a better perception of 3D virtual objects by superimposing holograms on the user's visual field, 2) spatial mapping allows the designed holograms to maintain their physical position in space even if the user is moving, 3) hands-free interactive interface allows the user to control the device using gestures, gaze and voice.

The use of AR helmet in neurosurgery is considered a promising method. There have been studies evaluating



the utility of AR helmets for neuronavigation, but their registration accuracy remains debatable. In addition, the relatively long, time-consuming, and complex workflow discourages surgeons from using AR helmets for navigation. We conducted a prospective pilot study to develop a less expensive, easy-to-use mixed-reality neuronavigation system using AR helmets and determine its clinical efficacy and accuracy during neurosurgery.

Objective: to optimize surgical access to intracranial lesions (tumors, arteriovenous malformations, cysts, etc.) by using a holographic neuronavigation system with augmented reality helmet.

The objectives of the study consisted in determining the feasibility of using holographic navigation for planning neurosurgical interventions, determining the time required to operate the system, and subjectively assessing the benefit of the technique for clinical practice.

Materials and methods

Study participants

From November 2022 to May 2023, 80 patients with intracranial brain pathology were examined at Kharkiv Regional Clinical Hospital, of which 34 met the criteria for inclusion in the study.

Written informed consent was obtained from all patients or their legal representatives. The bioethics

commissions of Kharkiv National Medical University and the MNE of KRC "Regional Clinical Hospital" approved the conduct of this study.

Inclusion criteria

Patients were involved in the study based on the possibility of creating three-dimensional models of affected brain areas.

Limits of the lesion were defined as follows:

1. In case of homogeneously expanded lesions (meningioma, glioblastoma and metastases) - by the expanded part of the lesion.

2. In case of heterogeneous enhanced lesions (cavernous malformation and diffuse gliomas) - by the edge of the abnormal signal on T2-mode FLAIR.

3. In case of intracerebral hematomas and hematomas of the ventricular system - according to the data of computer tomography (CT).

Patients with intracranial lesions with highly diffuse borders that are difficult to define were not included in the study.

Characteristics of the group

The patients were predominantly female (19 (55.88%)). The mean age of the patients was (39±12) years. Data on the pathology diagnosed in patients are given in **Table. 1**.

Study design

Overall study design is shown in **Fig.1**

Table 1. Main pathologies and localization of the lesion

Indicator	Abs.	%
<i>Pathology</i>		
Intracerebral tumors	5	14,71
Extracerebral tumors	4	11,76
Intracerebral hematomas	8	23,53
Metastases	2	5,88
Arteriovenous malformations	4	11,76
Cavernous malformations	3	8,82
Hydrocephalus	8	23,53
<i>Localization</i>		
Frontal lobe	4	11,76
Parietal lobe	6	17,65
Temporal lobe	4	11,76
Occipital lobe	3	8,82
Basal ganglia	3	8,82
Ventricular system	9	26,47
Cerebellum	3	8,82
Brain stem	2	5,88

This article contains some figures that are displayed in color online but in black and white in the print edition.

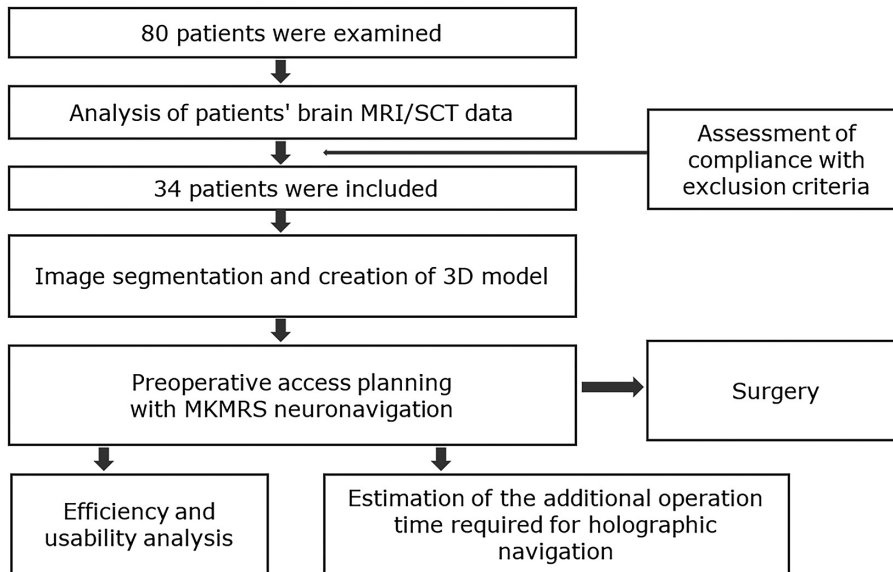


Fig. 1. Overall study design: MRI - magnetic resonance imaging; SCT - spiral computed tomography

Results and their discussion

Data post-processing and holographic visualization

All preoperative CT or magnetic resonance imaging (MRI) data were available in DICOM format. The type of imaging sequence is chosen based on radiological characteristics of the lesion and surgical requirements. After importing the data into 3D-Builder (Microsoft Corp., USA), segmentation and 3D modeling of the lesion were performed. The depth of the lesion was defined as the distance from the nearest border to the brain surface. Lesions were classified by hemisphere (left/right), lobe (frontal, parietal, temporal, occipital, cerebellum, trunk, basal ganglia), volume. Modeling was performed for the target lesion, position markers, and natural anatomic landmarks on the patient's head. All virtual models were created in OBJ format and imported into Unity version 2022.2.9 (Unity Technologies, USA) for compatibility with holographic navigation. We developed a Unity module for uploading processed 3D holograms online to a dedicated server based on Microsoft Azure (Microsoft Corp., USA) using the "HoloLens" (Microsoft Corp., USA) AR helmet. Based on the HoloLens Mixed Reality Toolkit, we have also developed the "MKMRS" application for downloading holograms and registering them in the physical environment for navigation. Wireless data access using the Remote Rendering service of the Microsoft Azure cloud platform made it possible to visualize high-definition holograms through transparent lenses in front of the neurosurgeon's eyes. **Fig. 2** demonstrates the workflow view of DICOM data post-processing, **Fig. 3** – preoperative access planning using AR helmet.

Hologram registration

The augmented reality helmet was comfortably and firmly fixed on the operator's head by adjusting the headband and the top strap to avoid slipping during movement. The AR helmet was calibrated before each registration using a system-provided

calibration programme. The operator was asked to use the index finger to "air pressing" 6 holographic targets so that the device could align the actual finger position with the virtually displayed pressing cursor. This took about 1 min, improved the clarity of the holograms, and facilitated interaction with them once the correct pupillary distance was established. Manual registration was performed with rigid head fixation, using landmarks on the patient's skull. The developed MKMRS software running on the HoloLens glasses, recognizes hand gestures for manual registration and is used to move and manipulate the hologram until it matches the patient's face and head anatomy. Registration on the patient's head can be performed manually automatically using an algorithm that matches the holographic surface area with the physical surface area, or a combination of manual and automatic registration (**Figures. 4 and 5**).

This pilot study demonstrates that the use of a head-worn mixed reality neuronavigation system during operative neurosurgery is technically feasible. The feasibility of clinical application of holographic neuronavigation using AR helmet in neurosurgery has been proven.

A mixed reality neuronavigation system can provide advantages in a real clinical environment because it enables additional visual holographic information [4]. Without turning the head towards other monitors, the operator can visualize a hologram of the target lesion and surrounding important structures "mapped" onto the patient's head. Holograms are visible through a projection display in front of the user's eyes. Thus, the user can gain an intuitive understanding of the location and shape of the target lesion. The system has ergonomic advantages and reduces distraction and improves the workflow efficiency [5,6]. The operator can control the device using gestures or voice, without requiring members of the surgical team to operate the workstation. Compared to commercial neuronavigation

systems, the cost of this system is much lower (without a computer - about 4,000 USD) [7].

The user can perform image data processing and holographic visualization using only AR helmet and a computer, anytime, anywhere, without requiring a bulky workstation hardware system. Compared to standard optical neuronavigation systems, the holographic neuronavigation system is not tied to an infrared camera. Lesion localization and simple navigation can be achieved by holding a 3D-printed positioning tool, or manual registration can be performed. Team members can share real-time information from the operator with another "HoloLens" device via a local network, which is important for training young doctors, interns and students. An important point of this holographic localization method is to register the hologram on the patient. For this purpose, we have developed a semi-automatic co-registration procedure. Compared to placing the hologram manually, this registration has the potential advantage of reducing visual misinterpretation, so the operator does not need to adjust the position of the hologram from different points in space. To maximize these benefits, we have created an intuitive system based on the Microsoft Mixed Reality Tool Kit (MRTK) that is easy to set up for individuals with minimal augmented reality experience. Although augmented reality in the operating room was also used by other authors, we

created a program based on MRTK for downloading and manipulating holograms created on the basis of DICOM data, as well as software for clinical use, because existing systems are either not available in Ukraine, or their use is very expensive.

The neurosurgeon or his assistant recorded the time required for holographic navigation, i.e., the duration of the period from setting up the system to creating the lesion contour on the patient's head (data post-processing, holographic visualization and holographic registration). This time is important for evaluating the effectiveness of using the holographic navigation method in the operating room. Additional time of surgical intervention averaged (39.2±7.9) minutes. The time decreased as the frequency of use and surgeon mastery of the technique increased (**Fig. 6**). Data post-processing accounts for most of the time required for holographic navigation, which decreases with increasing experience in using the system and AR helmet.

A questionnaire was used to assess the effectiveness and usability, with the help of which information was collected in the postoperative period. Neurosurgeons were asked to rate the following statements on a scale from 1 to 5 (1 - "completely disagree", 5 - "completely agree"):

1. It was easy for me to operate the hologram and map it to anatomic surfaces.

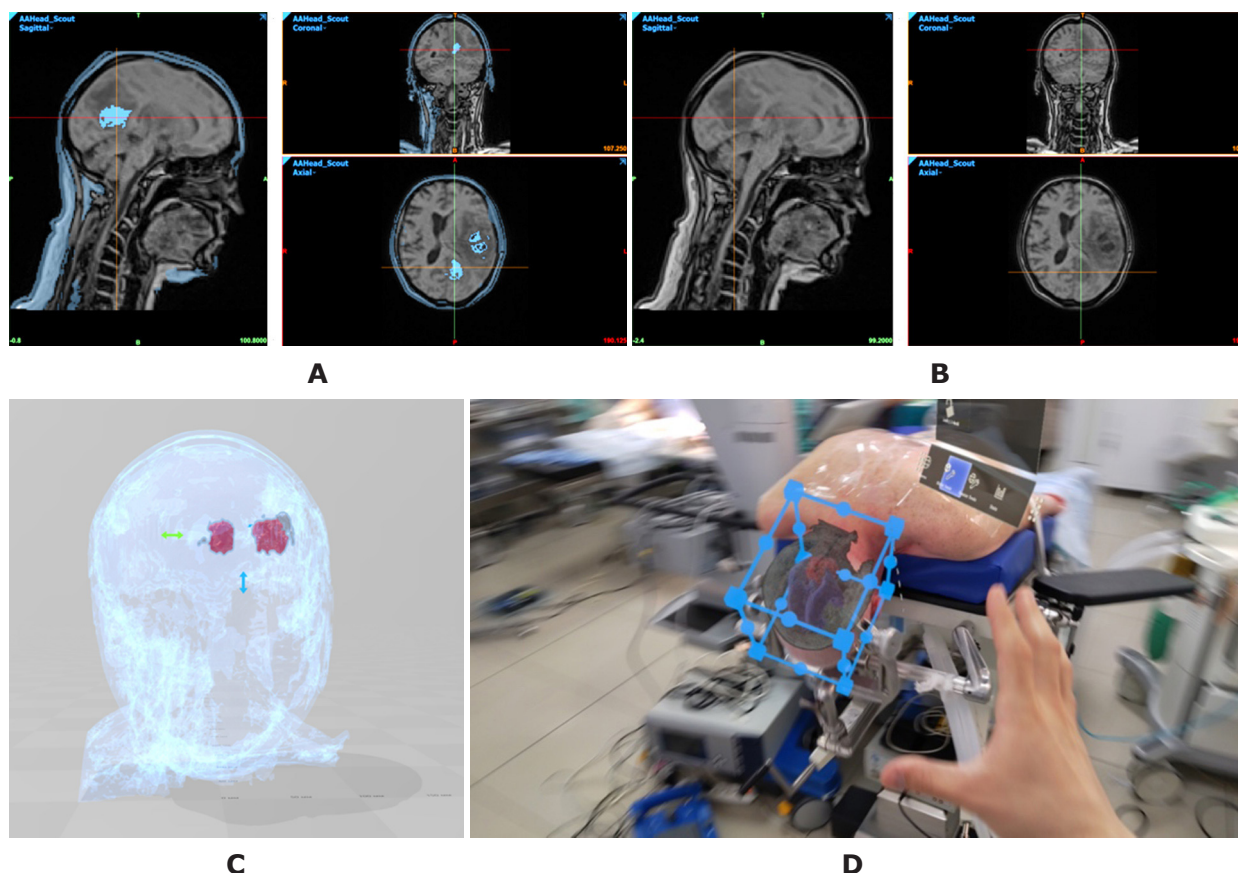


Fig. 2. Step-by-step process of using DICOM images for holographic navigation: A - MRI view of the brain of a patient with neoplasms; B - segmentation of neoplasms; C - view of 3D model after reconstruction; D - view of holographic model mapped to the patient's head through an augmented reality helmet

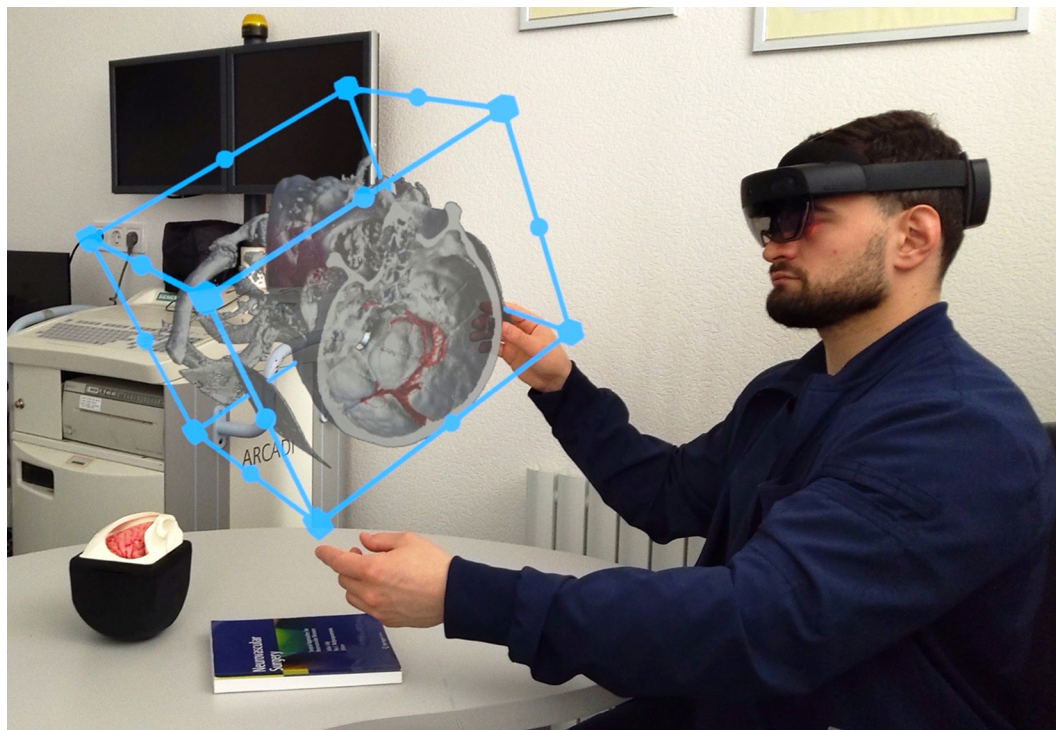


Fig. 3. Preoperative planning using 3D model

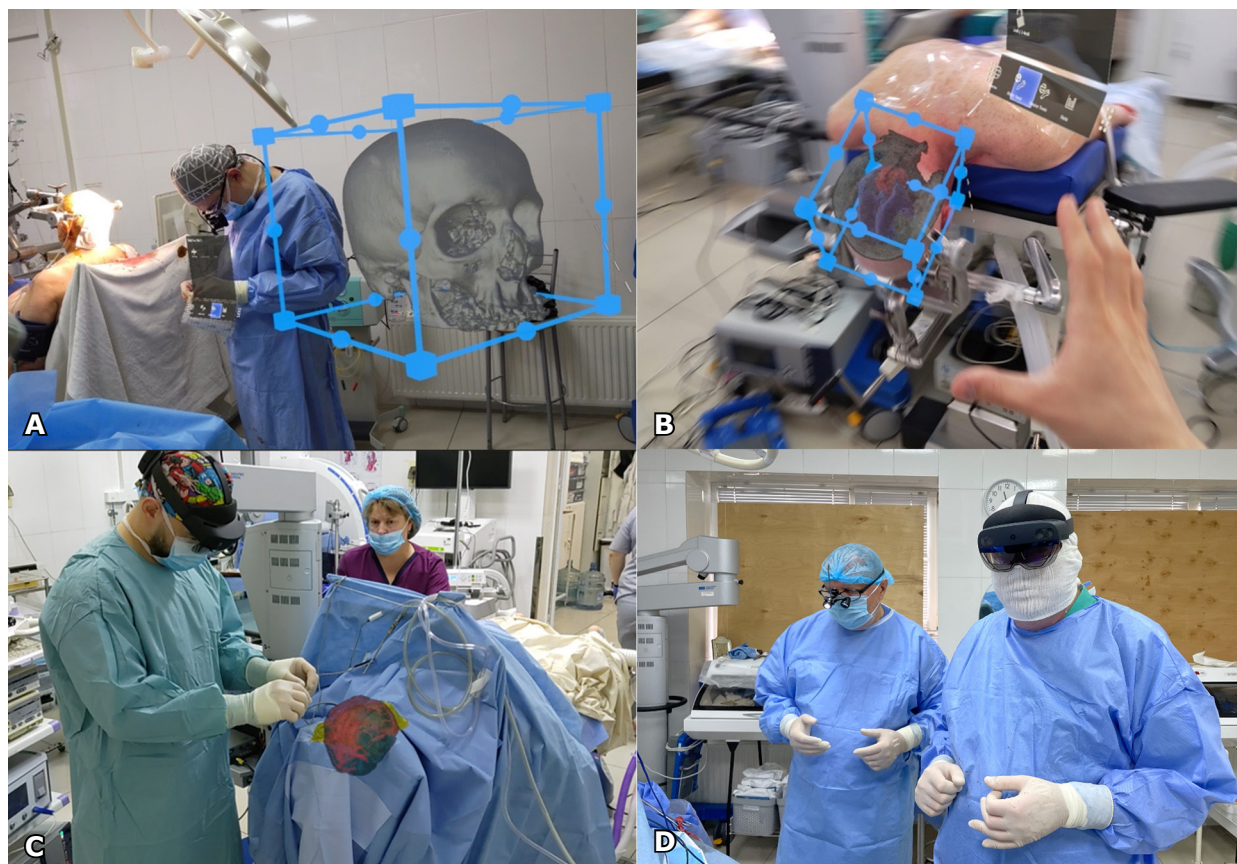
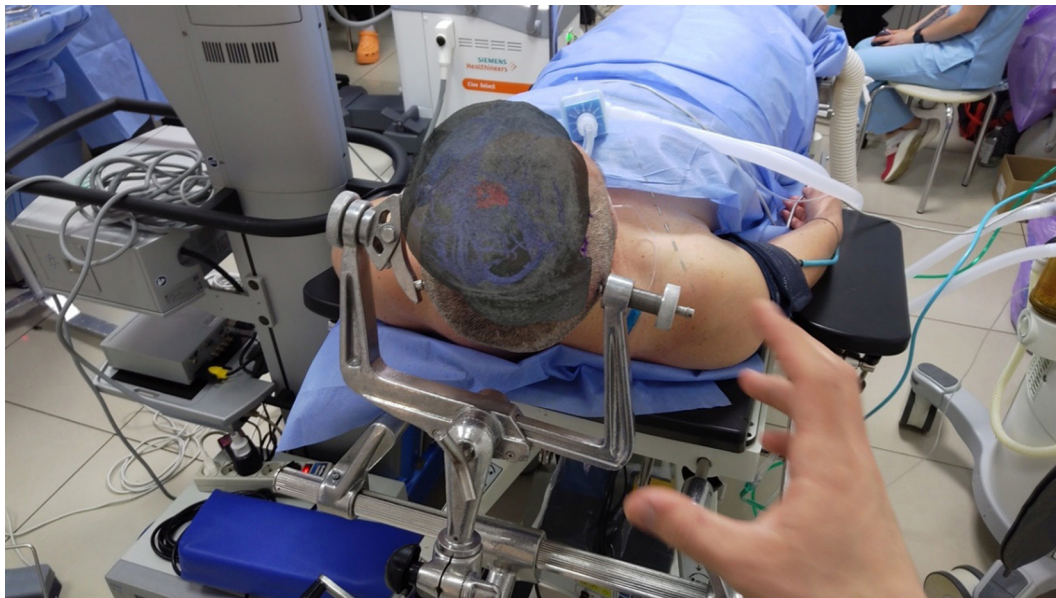


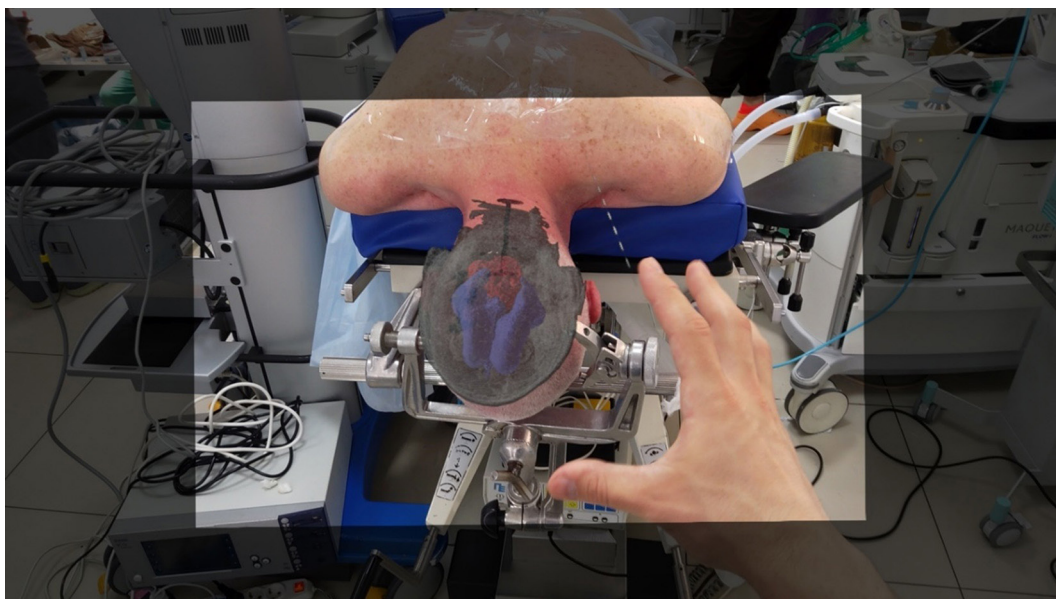
Fig. 4. Use of augmented reality during the planning of surgical access and surgical intervention: A – view of the 3D skull model before mapping; B – mapping of the 3D model to the patient's skull; C – view of holographic navigation after processing the surgical field; D - surgical team during access planning



A



B



C

Fig. 5. Preoperative view of holographic navigation for: A - cerebellar hematoma; B – cavernous malformation of the precentral gyrus; C - a neoplasm of the IV ventricle

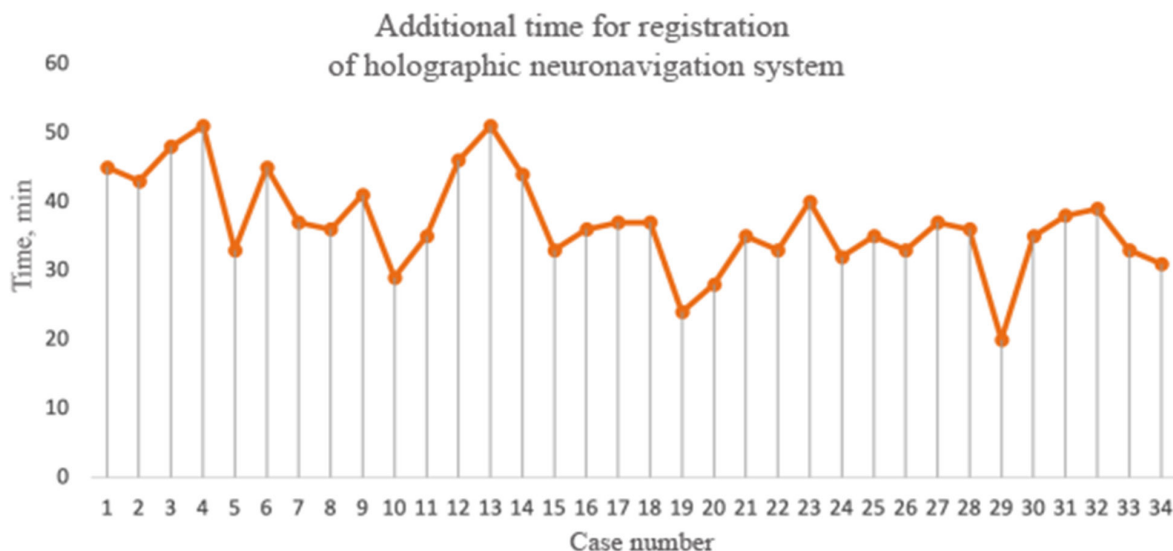


Fig. 6. Dynamics of changes in the duration of the period from the hologram creation to the final registration on the patient's head

2. The boundaries of the hologram coincided with the real boundaries of the lesion.

3. I did not feel any discomfort when using the augmented reality glasses.

4. The use of MKMRS software for AR helmet facilitated preoperative planning.

In general, the use of augmented reality technology for navigation, as well as the operation of the application in the "Hololens" helmet, was evaluated favourably. Neurosurgeons reported positional accuracy, image quality, and clinical effectiveness of holographic navigation. This contributed to reducing the duration of surgical intervention and craniotomy size, as the spatial representation of the pathological process and its relationship with normal structures improved when using the system. The lack of discomfort and the benefit of these technologies during preoperative planning are also noted. The surgeons' evaluation changed to positive after several uses with adaptation to the mixed reality concept (**Table 2**).

When using holographic neuronavigation in the study some limitations of the system were revealed.

Firstly, hologram drift (displacement) was observed, which did not greatly affect the accuracy of the system and arose due to a certain error in the tracking data and information displayed using the "HoloLens" glasses. The visual effect of holographic drift occurred mainly during movements around the hologram and was not noticeable when approaching or moving away from it.

Secondly, observing holograms can distract the operator's attention from the physical space, which can reduce the visibility of the operating area. In addition, the operator may feel uncomfortable trying to perform technical maneuvers with AR helmet, for example, to mark boundaries or perform cuts. This problem is solved by the built-in capabilities of the AR helmet, as the "HoloLens" screen brightness and hologram opacity can be easily adjusted using the settings on the device, so that the operator can clearly see both the hologram and the patient.

Thirdly, data post-processing takes up most of the holographic neuronavigation setup time. One of the challenges is to provide a sufficient number of well-trained personnel to segment DICOM images and create holograms. Many clinics around the world have 3D technology centers that are directly involved in segmenting medical images, as well as creating three-dimensional models based on them. In addition, the continuous development of MKMRS software contributes to the simplification of the process, so the holographic neuronavigation system becomes easier to use.

Despite the promising preliminary results, the system should be improved. Any movement of the patient's head after registration will result in a strong deviation of the hologram. In this case, re-registration should be performed to ensure that the hologram is matched correctly. We are developing markers for placement in the surgical area, which will be continuously tracked by the AR helmet to accurately keep the hologram on the patient's head. Future research should focus on automating the mapping of the 3D model to real physical objects. A comparative study with neuronavigation stations and hologram position adjustments followed by calibration of the AR helmet and software should be performed to assess the accuracy of using holographic neuronavigation in the operating room.

Conclusions

The conducted study has shown the technical feasibility of applying the mixed reality neuronavigation system with the use of the augmented reality helmet in the treatment process and the accuracy of obtained data. We are convinced that this technology has great potential for implementation in clinical practice, educational process and simplifies the preoperative planning of complex minimally invasive surgical interventions. It is necessary to conduct additional research and testing to improve the accuracy and efficiency of the system.

Table 2. Surgeons' questionnaire results after using the mixed reality neuronavigation system on the augmented reality helmet

Questionnaire	Rating				
	1 (completely disagree)	2 (more disagree than agree)	3 (difficult to answer)	4 (more agree than disagree)	5 (completely agree)
It was easy to operate the hologram and map it to anatomic surfaces	0 (0%)	3 (8,1%)	8 (21,6%)	16 (43,2%)	10 (27,0%)
The boundaries of the hologram coincided with the real boundaries of the lesion	0 (0%)	1 (2,7%)	0 (0%)	13 (35,1%)	23 (62,2%)
I did not feel any discomfort when using the augmented reality glasses	1 (2,7%)	3 (8,1%)	2 (5,4%)	20 (54,0%)	11 (29,7%)
The use of MKMRS software for AR helmets facilitated preoperative planning	0 (0%)	1 (2,7%)	4 (10,8%)	12 (32,4%)	20 (54,0%)

Disclosure*Conflict of interest*

The authors declare no conflict of interest.

Ethical approval

All procedures performed on patients comply with the ethical standards of institutional and national ethics committees, the 1964 Declaration of Helsinki and its amendments or similar ethical standards.

Informed consent

Informed consent was obtained from each of the patients.

Funding

The study was conducted without sponsorship.

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