Application of a Simulation System Using Augmented Reality to Practice the Skills of Minimally Invasive Spine Surgery

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Authors’ contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The developed HoloDoctor software package allows performing surgical operations in real time. It should be emphasized that the operation time on the HoloDoctor PC is reduced by 20-30% compared to traditional methods. The performance of HoloLens glasses with our program is high, while allowing the doctor to save time. The complex provides diagnostics, therapy planning, treatment adjustment as needed and minimizes the risk of medical error. HoloDoctor can be used in educational practice by integrating it into educational programs for medical specialties.

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1. INTRODUCTION

In modern neurosurgery, for a qualitative approach to the treatment of patients with brain and spinal cord tumors, as well as spinal injuries in general, it is necessary to solve many issues related to the peculiarities of such a narrowly focused specialty. This kind of diagnosis requires a certain range of knowledge and skills [1,2]. In addition, there are virtually no medical programs based on the use of holographic images superimposed on real objects (HoloLens mixed reality technology) for both diagnostic doctors and surgeons [3,4].

The solution of these problems is associated with the creation of a new type of simulator for planning and navigating surgical interventions. This work is already being carried out on the basis of software modules and equipment developed earlier by our team of authors, combined into software complexes and using augmented reality technologies [5-7].

Patients with complex pathology are prescribed examinations based on digital technologies for the purpose of diagnosis [8-11]. To date, these methods of examination include computer and magnetic resonance imaging, ultrasound with three-dimensional image reconstruction, atomic force microscopy, etc. [12-15].

Today, Russia has a rather limited supply of intelligent technologies for medicine [16-18].

Modern humanity has accumulated a huge amount of medical knowledge, which, unfortunately, is not fully used in the clinical practice of a doctor [19-21]. Effective implementation of knowledge is accompanied by the need to process huge amounts of information, which goes beyond the capabilities of a person. For example, there is a problem of differentiation of tumors during CT or MRI. This is the main reason for medical errors and delays in the transition of medicine to a qualitatively new level – personalized medicine [22-27].

In this regard, in order to move the quality of medical services at the Stavropol Regional Clinical Hospital (Stavropol, Russia) to a new level, we conducted a study of the possibility of using augmented reality in performing spinal surgery.

2. MATERIALS AND METHODS

To plan the course of a surgical operation, it is necessary to work out the operation scenario. To do this, the patient is carried out a standard CT or MRI procedure. Next, the radiologist builds a 3D model of the internal organs and tissues of the operating field zone from the Dicom images obtained. The developed software module for viewing Dicom images allows you to identify pathological neoplasms in order to assess the severity and dynamics of pathological processes (diseases). The next step is for the surgeon to plan an operation scenario based on the resulting 3D model.

Before starting the operation, the doctor puts on augmented reality glasses. The visualization system projects a 3D model onto the skin. The surgeon begins the operation.

Throughout the entire operation, the navigation system monitors the position of the instruments, the access trajectory in accordance with the planned scenario.

Full access to the field of surgery: scaling the model of an organ or organ systems, image detailing, which allows you to study every centimeter of the body and each of its inner layers-files obtained on CT and MRI (Fig. 1).

As part of this work, we used the software of our partners from the company “Hologroup” to study the possibilities of software data (MR Guide and MR Builder) in medicine. With the help of MR Guide, we created holographic guides (excursions) of the chest, its vessels, heart and lungs obtained with CT, and also used them for an anatomical atlas.

The MR Guide and MR Builder programs allow you to make tours without writing additional program code. Working with the application takes place directly in Microsoft HoloLens glasses. The user interacts with the interface and the holographic content by looking, gestures and voice commands. Functional capabilities were studied at the Stavropol State Medical University and the Stavropol Diagnostic Center.

After researching the technical capabilities of the MR Guide and MR Builder programs in HoloLens glasses, we applied several algorithms in our software package that allow viewing images obtained from CT, MRI (Dicom images and 3D reconstructions).
2.1 Methodology of the Procedure

Stage 1: Access. In the operating room, under multicomponent intubation anesthesia, in the patient's position on the stomach, a linear incision of the skin and subcutaneous tissue along the midline is performed. X-ray monitoring of the level of surgical intervention is carried out. Skeletonized bone structures. Decompressive laminectomy is performed, and its size depends on the localization and nature of the formation. When the pathological formation is localized on the anterior surface of the spinal cord or vertebral body: opening the canal of the vertebral artery, its mobilization with resection of the articular processes, and, if necessary, the vertebral body.

Stage 2: Removal of the tumor formation/resection of bone fragments (in case of injury or developmental abnormality). Surgical manipulations are carried out: with the use of an intraoperative microscope and (or) an endoscope, and microsurgical instruments with maximum magnification; very carefully with maximum immobilization of neurovascular formations with the exception of traction moments and under the control of intraoperative neuromonitoring.

Stage 3: Stabilization of vertebral-motor segment (VMS). VMS stabilization is carried out using an intraoperative navigation system. The choice of the stabilization method is determined by the degree of destructive changes in the spine.

Methods of stabilization of VMS: posterior stabilization (transpedicular, transarticular) of the segments of the spine (with damage/damage and instability of the posterior support complex of the spine); stabilization (fixation with neck plates, cages, cannulated screw, mesh mesh) of the anterior structures of the spine (with damage/damage and instability of the anterior support complex); stabilization of the anterior and posterior support complexes of the spine (with total damage/damage).

Stage 4: Suturing the wound. Layer-by-layer stitches are applied to the wound with the drainage tube left for 24 hours. Indicators of the effectiveness of the procedure: regression of neurological symptoms; stabilization of VMS (lack of mobility in VMS).

3. RESULTS AND DISCUSSION

The module for glasses developed by us is controlled by gestures, i.e. a medical specialist can point to the desired organ or instrument and remove it from the illustration. The software module interacts with a surgical dummy using pre-taken medical data from CT and MRI.
With the technical implementation of the simulation module for planning surgical intervention, all the tasks have been solved. The interface is fully functional and can be used to demonstrate and conduct simulations of static surgical interventions on three-dimensional models of human organs for educational and practical purposes.

The technical implementation of the modules and additional components of the prototype of the software package for simulating the planning of surgical intervention in real time was carried out, which allows importing bulk data in DICOM format of different modalities (CT, MRI, PET, X-ray angiography) and combining it with CT images taken earlier.

3.1 Clinical Analysis

The clinical case presented in this paper was treated in the department of radiation diagnostics of the Stavropol Regional Clinical Consultative and Diagnostic Center. We used HoloLens augmented reality glasses to describe medical images, practice, and combine 3D models (Fig. 2).

On a series of tomograms and multiplanar reconstructions of segments of the LI-SI spine, the posterior spinal fusion is determined by metal plates with transpedicular fixation with screws in the vertebral bodies ThII-L3.

3.2 Results of Clinical Analysis

The standing of the metal structure is correct. In the anamnesis, surgical treatment is the removal of semi-vertebrae Trb, ThII, ThII2. The left transverse process of the L5 vertebra is expanded, forms an articulation with the adjacent sections of the sacrum. The shape and proportions of the vertebrae are not changed. The height of the disks is reduced. The tissues of the disks L2-L3, L3-L4, L4-L5 circularly stand beyond the bone boundaries of the vertebral bodies until 3,4-3,5-5, Mm, respectively, moderately compressing the epidural sac. The closing plates of the bodies are sealed, with smooth contours. At the edges of the adjacent closing sites of the vertebral bodies, marginal bone growths are determined. The facets of the articular processes are sclerosed, with marginal bone growths. The lumen of the spinal canal is not changed. The dural sac and epidural tissue are differentiated. The result of CT and MRI image processing using HoloDoctor software and HoloLens augmented reality glasses is shown in Fig. 3.

Fig. 2. Viewing a series of tomograms on the study and description of the case with glasses in augmented reality glasses
The result of the study: In the anamnesis, surgical treatment is posterior fusion with transpedicular fixation. CT scan shows signs of dystrophic changes in the lumbar spine. Circular protrusion of L2-L3, L3 - L4, L4-L5 discs. Left-sided sacralisation of the L5 vertebra.

3.3 Discussion of Results of Clinical Analysis

A neurologist together with a radiologist in the Department of radiation diagnostics and the Department of Neurology of the Stavropol Regional Clinical Hospital (Stavropol, Russia) were able to examine in detail the pathological signs - the closing sites of the vertebral bodies with marginal bone growths in HoloLens augmented reality glasses and on a PC. The doctors worked with medical data in the form of Dicom images, medical histories, a 3D model of the spine with a straightening plate. The radiologist conducted a description of the clinical case with glasses using Dicom images, measuring the size of marginal bone growths,
vertebral bodies, damaged intervertebral discs, and the doctor also uploaded images with a history to the PACS server. Then all the described studies on the patient were transferred to the neurologist and surgeon for further treatment. The radiologist and neurologist are satisfied with the result of using HoloLens glasses with the developed HoloDoctor program, in addition, this clinical case was described and worked out on a PC using our program. The time spent by the radiologist to describe the clinical case was less than 15 minutes in HoloLens glasses, and 20 minutes on a computer (We describe the time spent on the computer and in augmented reality glasses. It varies. The radiologist managed to describe the clinical case with glasses faster, since he used voice input and typing.).

4. CONCLUSION

The use of the HoloDoctor software package with modules for viewing Dicom images, a simulator of surgical intervention using sensors, allowed to reduce the time of this operation from 5 hours to 2 hours, and also made it less traumatic for the patient. According to the results of the work, the HoloDoctor software package with modules for viewing Dicom images was implemented in Stavropol Regional Clinical Hospital (Stavropol, Russia).

The radiologist and neurologist are satisfied with the result of using HoloLens glasses with the developed HoloDoctor program, in addition, this clinical case was described and worked out on a PC using our program. The time spent by the radiologist to describe the clinical case was less than 15 minutes in HoloLens glasses, and 20 minutes on a computer. We describe the time spent on the computer and in augmented reality glasses. It varies. The radiologist managed to describe the clinical case with glasses faster, since he used voice input and typing.

The new software complex HoloDoctor was also patented, a certificate of registration of software for a computer was obtained.

The new method of performing spinal surgeries using HoloLens glasses expands the surgeon's operating field, makes it possible to see the medical history, 3D models of the vertebral bodies and pin attachments, as well as compare with the anatomical 3D model of the spine from the atlas.

CONSENT AND ETHICAL APPROVAL

It is not applicable.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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