



The Use of Augmented Reality and 3D Printing Technologies in Planning and Conducting Surgical Intervention in Orthopedics

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Abstract

Currently, the use of augmented reality and 3D printing technologies is becoming increasingly popular when planning and conducting surgical operations in patients with musculoskeletal pathology. In 2019-2021, more than 80 operations were performed on knee joints, ligaments and spine using new technology. We have developed a technique that allows for preoperative planning using original software and additional reality glasses (additional reality complex). During the operation, the additional reality complex performs assistance, providing access to the data of additional methods of examination of the patient and making an "overlay" on the operating field in glasses of the additional reality of normal anatomy or previously performed MRI or CT data. The new method of simulation and use of augmented reality glasses with the HoloDoctor program for implantological treatment demonstrated a good visualization of the anatomical features of the implant placement area, provided an opportunity for the surgeon to thoroughly study the intervention area before surgery, perform surgery in the conditions of the patient's real anatomy, including using the navigation in augmented reality.

Disciplinary: Medicine (Orthopedics, Traumatology).

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1 Introduction

Patients with complex pathology are prescribed examinations based on digital technologies for diagnosis. To date, these methods of examination include computer and magnetic resonance imaging. Modern software for processing images obtained during CT and MRI is supplied with these devices [1-3]. The functions of these programs are sometimes not enough to carry out more complex work with the obtained data, including for the differentiation of tumors in various diseases [4,5]. The creation of 3D models of organs in these programs is carried out quite successfully, however, it requires a few large time expenditures and additional resources [6,7]. In addition, the software used is not capable of creating 3D models of the internal structure of organs if the images were obtained without the use of contrast agents [8,9].

In addition, there is a very limited number of programs for viewing, describing and reconstructing DICOM images obtained from CT, and MRI, for diagnosis and treatment planning using neural networks (for example, Amira for Life Sciences (Germany), UNIM (Russia)). One such software is Myrian (Intrasense (France)) - a multimodal solution for viewing and post-processing medical images. Myrian includes easy-to-use but powerful specialized packages for colonoscopy, liver, lungs, blood vessels, orthopedics and others. Alternative software (3DViewer, RadiantDICOM, etc.) either does not have the necessary functionality or is too difficult to use in medical institutions – they do not have a single modular complex that could perform recognition, differentiation of tumors, viewing reconstructed 3D models on surgical monitors, intuitive and intuitive interface, there is no possibility of using augmented reality glasses for doctors of various specialties. In addition, there are practically no medical programs based on the use of holographic images superimposed on real objects (HoloLens mixed reality technology) for both diagnostic doctors and surgeons.

Recently, there are many high-tech methods of diagnosis and treatment of various diseases (X-ray, MRI, ultrasound, PACS server, patient monitoring devices and MIS). At the same time, if this equipment is not included in the unified information environment of the medical center, their work becomes less effective due to the inability to apply programs for planning, simulation and intraoperative navigation [10].

The HoloAnatomy training application for medical students allows you to study anatomical terms, see the structure and work of human internal organs (the movement of blood through the vessels, the passage of electrical impulses through various parts of the brain), adjust the scale of anatomical models (get closer to the heart and hear its beating, see its structure), recognize hand movements and the user's voice. The creation of realistic three-dimensional anatomical models contributes to the in-depth study of anatomy.

2 Literary Review

The Medsights Tech program, developed for augmented reality glasses, allows you to see the patient's internal organs through the skin in real time during surgery.

The navigation system "ARtomed Technology" (Republic of Belarus, Russia) is used in the surgical treatment of intraorbital tumors. A virtual volumetric model is built based on files in the Digital Imaging and Communications in Medicine (DICOM) format, taking into account that the quality of reconstruction depends on the quality of input data and the accuracy of the reconstruction system [11].

The structures and color rendering parameters necessary for inclusion in the model are selected taking into account the specific clinical situation. To simplify visualization, the model is processed and modified. The prepared and optimized model is loaded into Microsoft HoloLens2 augmented reality glasses. In the preoperative period, using the possibilities of increasing and rotating the 3D model, surgical intervention planning is carried out with the participation of all members of the surgical team. Intraoperatively, a 3D model of the skull is superimposed on the patient according to bone landmarks (the lower orbital edge and nasal bones). Surgical access and surgical reception are carried out in the projection of the visualized tumor. Thus, this technology allows you to visualize interactive individual anatomical models with high detail, which can be changed in real-time. System management does not require special skills. The same technology can perform many tasks related to the process of diagnosis, preoperative planning, intraoperative navigation, as well as surgical training [12,13].

Microsoft Hololens application developed by British doctors for augmented reality glasses, allowing surgeons to see the internal blood vessels or bones of the patient during surgery. The testing took place during five real operations and in the future, it is planned to automate the process of creating models from CT scans of patients [14,15].

Special software for Microsoft Hololens augmented reality glasses were developed and tested by scientists from Imperial College London under the leadership of Dimitri Amiras. This program displays models of internal organs directly on the body of patients, several other programs segment CT images of patients by types of objects: skin, muscles, bones and blood vessels [16]. Based on this data, a 3D model is built and loaded for display in glasses.

As a result of our research, a relatively small amount of research by scientists on the subject of planning and navigating the course of the operation in real-time, using combined CT and ultrasound systems, and using avatar technologies in telemedicine using mixed reality technologies was revealed [17]. The analysis of the literature allowed us to identify the main shortcomings in this direction:

- 1) lack of information about the use of AR technology and augmented reality holographic glasses to combine simulation and reconstruction on a real patient in real-time;
- 2) the lack of programs on the Russian market that allow you to plan and track the results of treatment according to objective indicators.

The solution to these problems is connected with the creation of a new type of simulator for planning and navigating surgical interventions. The purpose of this work was to explore the possibilities of using augmented reality and computer processing in the HoloDoctor program in

orthopedics (traumatology), as well as to test in practice the methodology developed by us for planning and conducting surgical interventions on the skeleton with the assisted technology of additional reality.

3 Method

In this paper, we consider a method developed by us that allows us to plan a surgical intervention on the human skeleton.

As a result of the work of the software, all or some of the incoming elements in augmented reality are placed on the human body or body parts (for example, a leg), providing the most convenient access to all downloaded information. The surgeon works with 3D models of bones in the form of holography with the ability to view the anatomical structure of the bone in the form of a 3D model obtained after CT. Thus, the surgeon plans the course of the operation and creates holography by combining simulations and reconstructions of clinical 3D models on a real patient in real time with the ability to view the medical history and Dicom images.

The method includes the stages of planning a surgical operation, surgical navigation in real-time using augmented reality, and at the stage of planning a surgical operation, a computer or magnetic resonance imaging is performed on the patient and 3-4 separate three-dimensional models (directly bone, its blood vessels, ligaments, pins, etc.) are formed based on DICOM files on a computer in the program. The resulting multilayer model is placed in a simulator program, with the addition of models of the body surface and large vessels. 3D images in the system are created by MRI scanning and computed tomography of internal organs, while the program itself selects a certain color for each of the organs (after Dicom reconstruction). The resulting image is transmitted to the HoloLens augmented reality glasses.

Preoperative planning begins with a CT scan of the patient, after which the exact structure of the organ appears for submission to the CT planning system. There is a combination of the CT image taken earlier (in 1 hour) and the CT received in real-time of the patient. For radiologists (radiologists), this module will reduce the time for processing and describing medical images [18].

With the help of the system, Microsoft imposes a layer of mixed reality on the patient during surgery. The surgeon can use it to track the position of organs, organ systems, and surgical instruments in real time.

The program simulates manipulations on the created 3D image of a real patient using surgical instruments in the relevant specialty. This system is fully adapted for the use of augmented reality glasses (HoloLens mixed reality glasses) for practicing, combining and modeling various manipulations in surgery, which will allow projecting virtual organs on the patient's body.

With the help of gestures, a medical specialist can point to the desired organ, and in addition, remove it from the illustration. Then the image is connected to mixed reality glasses, and the doctor can see a virtual 3D map of the internal organs of a person directly on his body. The

system interacts with a surgical dummy (special markers are pasted for the operation of a simulator program using mixed reality - holography) using pre-taken medical CT and MRI data.

When developing the real-time surgical intervention simulator module, the need for a cross-platform product was taken into account, in particular, the need to support the display in augmented reality glasses (HoloLens glasses), the use of infrared cameras, stereo sensors (TOF cameras) and pointers with sensors.

To simulate the navigation of surgical intervention in real-time (we have prepared a system with additional modules (a module for HoloLens glasses and a navigation module), which allows you to make an incision and stitch the tissues of a selected area on the human body or organ, select simulation modes for planning an operation using an alarm system (warning the system about the close distance of blood vessels if the surgeon is approaching the danger zone), the mode of intraoperative navigation of surgical intervention, the choice of surgical instruments - laser, scalpel, trocar, wound expander, etc. A special function of virtual angioscopy has also been developed, which allows you to virtually view the internally selected organ structures along a given trajectory. In the presented clinical case, we used this function in viewing the ureteral lumen and renal pelvis, exiting blood vessels before surgery (planning the course of surgical intervention).

A software module (for a simulation surgical system) has also been finalized with the function of importing 3D models of organs or organ systems in obj format for navigating surgical intervention, allowing you to download a multi-layered, highly polygonal, 3D model obtained, for example, a 3D model of bone and surrounding tissues with vessels or kidneys with vessels, neoplasm. Thus, the following functionality is obtained: loading a 3D model, overlaying a map of blood vessels, scrolling a 3D model, zooming in and out of an organ model, instrument setup mode, simulation mode and navigation of surgical intervention both in augmented reality and on a Windows PC.

4 Result and Discussion

In 2021, a surgical operation using augmented reality glasses was performed for the first time in the Stavropol Regional Clinical Hospital. Modern technologies have helped to speed up the implementation of autoplasty (surgery method).

We used a new technological chain with an Anatomical Atlas developed by us and a System of interaction with HoloLens augmented reality glasses, during which real patients with knee joint pathology were operated on, the patella of the knee joint was restored, conducted in the Trauma and Orthopedic Department of the Stavropol Regional Hospital.

We chose the first patient according to the degree of complexity of the operation, namely, the patient was injured while running.

The approbation of the developed methodology was carried out on the basis of the Stavropol Regional Clinical Hospital (Russia, Stavropol, Semashko str., 1). The approbation of the methodology in traumatology (osteology) using augmented reality was carried out in 2020-2021 (Figure 1).



Figure 1: Performing surgical interventions on the knee joint with the assisted technology of additional reality at the Stavropol Regional Clinical Hospital

4.1 Training of Medical Specialists and Students

The original software, together with additional reality glasses (additional reality complex), allows you to create models of various surgical pathologies based on DICOM files obtained during CT or MRI studies and stored in databases. This makes it possible to simulate an infinite variety of clinical cases and to conduct multi-sided training of doctors of surgical specialties.

Based on the obtained DICOM CT or MRI files, the original software allows us to simulate a specific clinical case. The teaching methodology consists of the use of a complex additional reality by the teacher and students. Students, being in a simulated clinical situation, perform surgical manipulation. The teacher monitors the implementation of a given case. This technique allows us to practice surgical interventions both individually and in groups of different levels of training without involving expensive models [19,20].

It is also possible to use an additional reality complex as the "eye of the surgeon" [21]. This technique allows students not to be in the surgical hall, which reduces the bacterial load on the

operating room and eliminates the possibility of a biological accident, observes the smallest nuances of surgical intervention and receives comments from the leading surgeon. The technique allows you to broadcast in real--time and record the most interesting clinical cases (Figure 2).

The additional reality complex can serve as a means of telemedicine, during patient consultation or surgical intervention.

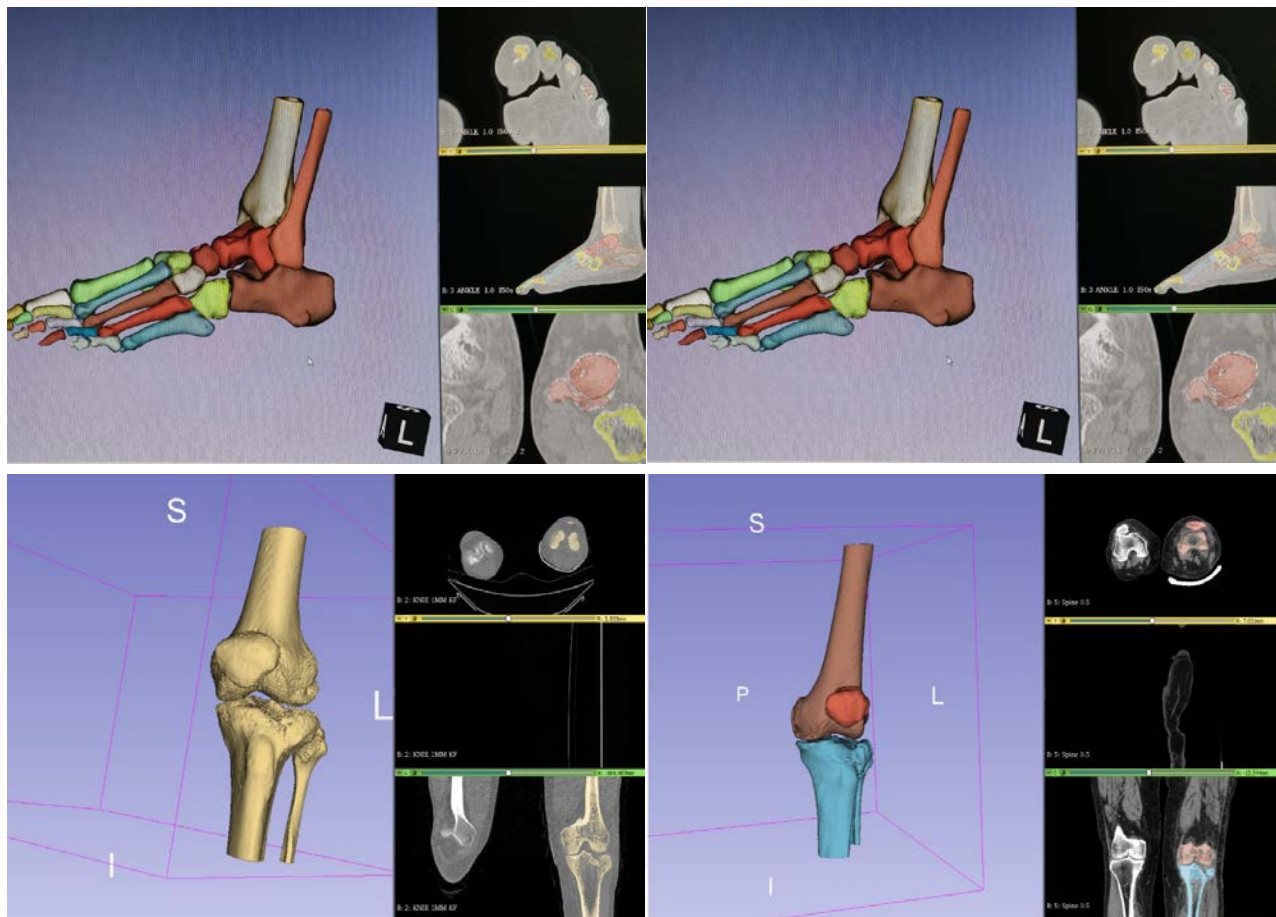


Figure 2: Screenshots taken while working with the software package

4.2 Clinical Case No. 1.

Diagnosis: Intra-articular fracture of the lateral condyle of the right tibia with displacement. Oblique fracture of the head of the right fibula (Figures 3, 4).

Local pain in the right knee joint, the upper third of the lower leg, increases with movement. Moderate swelling of the right knee joint, the upper third of the lower leg. Crepitation and pathological mobility in the area of the right knee joint. There are no active movements.

Under aseptic conditions, a surgical incision of the right knee joint was made. A rupture of the posterior horn of the inner meniscus was revealed. The posterior horn of the inner meniscus was resected. An aseptic dressing was applied.

Under general anesthesia, after the prior informed voluntary written consent of the patient, surgical treatment was performed: open osteosynthesis of the right condyle of the tibia with a plate.



Figure 3: Demonstration of 3D reconstruction of the fibula, tibia and patella, DICOM images of the knee joint in augmented reality glasses



Figure 4: 3D printing of femoral and tibial bone reconstruction to simulate the course of surgery and to demonstrate to the patient. Also, this 3D reconstruction was used to teach medical students

Operation progress: To navigate the surgical intervention, HoloLens augmented reality glasses were used, which made it possible to reduce the operation time by 28 minutes, instead of 2 hours, they spent 1 hour 32 minutes. This technology allows you to overlay computer-generated visual objects (in this case, a 3D model of the tibia, knee joint, pins, and blood vessels) and additions to the existing objective reality.

Also, the software made it possible to display everything that a surgeon needs in preoperative planning. Right during the operation, the surgeon received the results of all studies, pictures, MRI, CT data, with which he supplemented his knowledge.

New HoloDoctor software. Orto expands the boundaries for training, it shows the doctor's work through his own eyes and allows you to get a hint from a more experienced colleague in real-time right in the operating room.

Before that, they used HoloLens augmented reality glasses to describe medical images, practice, and combine 3D models.

Result: The additional reality glasses feature a 3D model of the knee joint with a small fracture of the tibia, a CT patient and a medical history in convenient sectors. Under aseptic conditions, an arthroscopic chamber with lower lateral access was inserted into the knee joint cavity under a tourniquet and an arthroscopic instrument through lower medial access. 25 ml of blood with an admixture of viscous synovial fluid was released.

The knee joint is abundantly washed with a sterile solution. During the examination of the joint cavity, it was found that the ligaments in the knee joint (cruciate ligaments of the knee joint) were damaged, and a small crack in the tibia was also revealed. The plateau was raised under arthroscopic control. An L-shaped incision was made on the outer surface 2 cm below the articular slit, made by a MOS plate with angular stability.

Stitches were applied to punctures and wounds, and an aseptic dressing. The limb is in an elevated position. Cold is temporarily applied to the area of the right knee joint. Plaster immobilization. Elastic bandaging of the lower extremities.

4.3 Clinical Case No.2

Diagnosis: Closed spiral fracture of the bones of the left tibia: tibia in the middle third with the displacement of the distal fragment posteriorly (Figure 5).



Figure 5: Viewing and navigation in augmented reality glasses HoloLens 3D reconstruction and Dicom images

The axis of the left shin is broken due to the valgus in the middle third. Moderate swelling of the left shin and foot. There is pathological mobility in the middle third of the lower leg. There are no active movements. Passive movements are sharply painful. Local pain at the fracture site, which increases when lifting the leg and trying to move the foot, pain at the fracture site with careful pounding on the heel. Deformation and shortening of the lower leg, pathological mobility, crepitation of fragments. The victim cannot lift his leg on his own.

The nature of the operation: Osteosynthesis of the external condyle of the left tibia under arthroscopic control using additional reality glasses.

Result: With the use of additional reality glasses, a 3D model of the fracture and a CT scan of the patient were placed in convenient sectors. Under aseptic conditions, an arthroscopic chamber with lower lateral access was inserted into the knee joint cavity under a tourniquet and an arthroscopic instrument through lower medial access. 70 ml of blood with an admixture of viscous synovial fluid was released.

The joint is abundantly washed with a sterile solution. During the examination of the joint cavity, it was found: an impression fracture of the lateral condyle of the femur. A trepanation window (1.5x1.5 cm in size) in the cortical layer is made on the inner surface of the lower leg 4 cm below the articular surface. The plateau was raised under X-ray and arthroscopic control. The congruence of the articular surface has been restored, fixation with 2 spokes. An L-shaped incision was made on the outer surface 2 cm below the articular slit, made by a Mosfet with angular stability. The spokes are removed, and the lateral condyle is stable under arthroscopic control. The bone defect is filled with an osteoplastic matrix, an extracellular collagen matrix is laid on the defects of the cartilage tissue.

Surgical intervention is carried out in compliance with asepsis with a sterile instrument.

Stitches were applied to punctures and wounds, and an aseptic dressing. To give an elevated position of the limb, cold on the area of the left knee joint. Plaster immobilization. Elastic bandaging of the lower extremities.

5 Conclusion

In 2019-2021, more than 80 operations were performed on knee joints, ligaments and spine. When exploring the possibilities of using augmented reality technologies in orthopedics and traumatology, all the tasks have been solved. Clinical cases were processed and integrated with HoloLens augmented reality glasses to describe medical images, and practice and combine 3D models.

The developed software package allows us to simulate surgical intervention on the created 3D image of a certain patient with the pathology of the musculoskeletal system. This system is fully adapted for the use of augmented reality glasses (HoloLens mixed reality glasses) and can project virtual organs on the patient's body, creating conditions for practicing, combining and simulating various surgical manipulations [22,23].

The methodology developed by us for planning and conducting surgical intervention in orthopedic practice allows us to reduce the time of the operation by optimizing the navigation system and accurately determining the place of surgical access with minimal tissue damage. As a result, the number of complications decreases and the period of postoperative recovery is shortened.

In the process of education, it is possible to use educational holographic simulators with reference to phantoms or mannequins, allowing not only to change the physiological parameters of the patient in manual mode but also to reproduce intraoperative endosurgical, angiographic and ultrasound images.

In this work, we investigated the possibilities of using augmented reality technologies and computer processing in the HoloDoctor program in orthopedics (traumatology), and also carried out the practical application of the methodology developed by us for planning and conducting surgical interventions on the skeleton with the assisted technology of additional reality.

Application of the methodology will be relevant even in the case of COVID-19 disease in the patient [24].

6 Availability of Data and Material

Data can be made available by contacting the corresponding author.

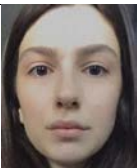
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