The application of additive technologies in creation a medical simulator-trainer of the human head operating field

L N Kashapov\textsuperscript{1}, N F Kashapov\textsuperscript{1} R N Kashapov\textsuperscript{1,2,3} and B.Y. Pashaev\textsuperscript{3}

\textsuperscript{1}Engineering Institute, Kazan Federal University, Kazan, 420008, Russia
\textsuperscript{2}Laboratory of Radiation Physics, Kazan Physical-Technical Institute of the Kazan Scientific Center of the Russian Academy of Sciences, Kazan, 420029, Russia
\textsuperscript{3}Kazan State Medical University, Kazan, 420012, Russia

E-mail: kashramin@gmail.com

Abstract. The aim of the work was to determine the possible application of additive manufacturing technology during the manufacturing process as close as possible to reality of medical simulator-trainers. In work were used some additive manufacturing technologies: selective laser sintering (SLS), fused deposition modeling (FDM), binder Jetting. As a result, a prototype of simulator-trainer of the human head operating field, which based on the CT real patient, was manufactured and conducted its tests. It was found that structure, which is obtained with the use of 3D-printers ProJet 160, most appropriate and closest to the real properties of the bone.

1. Introduction

Education and improvement of professional skill surgeons is one of the major health problems. One method of training is to practice the skills on phantoms and simulator-trainers. A simulation training improves the quality of manipulation in normal and stressful situations in anesthesiology, it allows to achieve high quality of nursing manipulation, enhances the quality of care for patient, increases the frequency of successful small surgical interventions, reduces the number of complications. Particularly important the application of simulators-trainers in the field of neurosurgery at the practice skills, as part of learning new methods of access to the brain area. Cadaver heads are the best on the realism of the existing objects at the moment. Earlier, unidentified and unclaimed bodies can be sent to medical institutions, but now prohibited their use. The body of a deceased person can be use in educational and research purposes only if his identity is established, but do not have people who are willing to bury him. To get that body, the organization shall send a corresponding request. At the moment, there is an acute demand in cadaver material. Supply of cadaver material in Russia is carried out from the United States, and it is very expensive, for example, the cadaver's head is worth 1,000. Also cadaver heads do not reproduce the desired clinical case for practicing quite difficult operations to remove tumors. One of the existing problems is the necessity to create a phantom-simulators for practicing methods of treatment endonasal endosurgical skull base surgery diseases, transcranial surgery of brain tumors. A special feature of generated simulators is the necessity to recreate realistic anatomy, similar mechanical and strength properties, individuality in the tumor location. The solution to this problem can be found in the application of additive technologies with the use computed tomography of real patients. The aim of the work was to determine the possible application of additive technologies in creating a medical simulator-trainer of the human head operating field.
manufacturing technology in the manufacturing process as close as possible to the reality of the human head phantom to simulate the surgical field.

2. Main part

For creation of real anatomic form simulator-trainer used data from computer tomography of a young healthy man aged 21 years, obtained by X-ray tomograph SkyViev. This scanner is equipped with a conical X-ray source, wherein the slice thickness is 0.1 mm and the minimum step of longitudinal sections is 0.05 mm. The resolution of the device, a digital matrix 1000 by 1000, pixel size is 7.4 microns. The data obtained are DICOM extension. With program Slicer was designed the three-dimensional model of a human head.

After creating a virtual model of the main problem is the reconstruction of the object in a material form. It is necessary to choose the method of manufacturing and the materials that most closely coinciding with the mechanical properties of human tissues. In [1] describes a method for the manufacture of neurosurgical simulator using 3D printer Objet 500 Connex (Stratasys) that is highly effective and allows the layers to create simulators having a gradient composition and density of the material. The resulting model is very realistic, but it has a serious drawback - the high cost $ 2,600. It is very expensive and this method does not satisfy us. We have selected an approach to individual fabrication of each part and assembly.

The developed simulator-trainer should consist of several main parts: brain, tumor, dura, skull, subcutaneous tissue and skin. The skull is the main constructional support element simulator trainer, in which located brain, tumor and the dura mater covering the skull inside. And on the outside of the skull is attached to the subcutaneous tissue with the skin. Since the CT data obtained by Z-axis have a layer thickness of 100 microns, then it does not make sense to use in the manufacture of additive simulator technology to better than 100 microns. Beneath this criterion very well suited FDM-technology. For the manufacture of the skull was used 3D printer Fortus 400 mc [2,3], the construction materials produced ABS-plastic and polycarbonate. The skull was split into two parts to allow the application of the dura mater and the installation the brain with tumor. The resulting sample of skull is shown in Figure 1.

![Figure 1.](image)

The next stage is the manufacturing brain. MRI data used, which obtained by scanner General Electric Signa HDe 1.5 T. Then, using a BIOMODROID CB-MTI UM program it three-dimensional model of the brain was made in the STL format. As the mechanical properties of the brain coincides with the silicone rubber companies Bredent [3]. Shape for pouring the silicone manufactured in two parts, as shown in Figure 2.
The inner side of these forms is a cast of the external shape of the three-dimensional virtual model of the brain. Virtual model of forms were designed in the Geomagic software and printed on the installation of selective laser sintering SLS sPro 60 HD, from material nylon 12. This material has the following mechanical properties: tensile strength - 43 MPa; tensile modulus - 1586 MPa; relative elongation at break - 14%; strength in bending - 48 MPa; flexural modulus - 1387 MPa; Shore hardness D - 73. This material is well suited for manufacturing of forms for pouring silicone models. The tumor at the base of the skull was made similarly. The dura mater has a thickness of 0.5 to 1 mm. Liquid silicone was used for its production, which is applied to the inside of a plastic skull model, the silicone surplus flowed by gravity, and on the surface remained the silicone layer thickness of 0.8 mm, which is during 15 hours solidified.

Since in learning methods of treatment endosurgical endonasal skull base surgery diseases and transcranial surgery of brain tumors is supposed to be accessed through the nose, then the role of the subcutaneous tissue, the skin does not play a significant role and need only for fixing simulator trainer in the fixing device of the operating table. Subcutaneous tissue and skin replaced by polyurethane model shown in Figure 3.

While teaching on the simulator trainer surgical access should be carried out through nose, which is necessary to make a realistic, at the level of the biological prosthetics. Realized nasal region simulator trainer should have a high accuracy of fit to the skull and was made as follows. With the help of optical 3D-Scanner Range Vision, the principle of operation is based on structured illumination of the object of scanning by safe white light, and received a three-dimensional model of the nose in STL format. Further scan results of the skull and the file has been imported in the CAD-program PowerShape Pro. This program produced the combination of the nose to the skull, providing a snug fit to the skull. Virtual model of the nose has been obtained, which repeats the shape of the skull in the place of its fit. At the next stage was made master-model of the nose by using stereolithographic installation ProX 800, then master-model filled with silicone ProtoSiC RTV 245, and silicone mold manufactured for vacuum casting. Further, silicone rubber ProtoFlex 150-05 was filled in this form and obtained silicone nose for installation on the simulator-trainer (Figure 3).
Tests of a model were conducted using a high-speed motor multi-functional system UNIDRIVE SIII NEURO of STORTZ company with rotational speed 60000 rpm and DRILCUT-X II Shaver Handpice. Table 1 shows the results of the evaluation of the developed simulator-trainer by neurosurgeons of the human head operating field.

| Area of model               | The test property                  | evaluation       | disadvantages                                                                 |
|-----------------------------|------------------------------------|------------------|-------------------------------------------------------------------------------|
| Skull                       | Anatomy                            | Good             | It is necessary to make the removable an insertion in the skull for multiple use |
|                             | Mechanical properties of ABS material | Unsatisfactorily satisfactorily |                                                                              |
|                             | Mechanical properties of polycarbonate |                 |                                                                                |
| Dura mater                  | The possibility of cutting         | Good             |                                                                               |
| The brain and tumor         | formal resemblance                 | satisfactorily   | Necessary to make vessels of the head with the ability to injection the pressurized fluid |
|                             | The possibility of cutting         |                  |                                                                               |
| Subcutaneous tissue and skin| The outward similarity with the head of the patient, the possibility of mounting the device of the head fixation | Good             |                                                                               |
| Nose                        | outward similarity                 | Good             | It is necessary to create mucosa inside of the nasal cavity                  |

In general, the simulator-trainer of the head of the surgical field is ideally suited for training of neurosurgeons to methods of treatment endonasal endosurgical skull base surgery transcranial diseases and surgery of brain tumors. During the tests revealed several disadvantages: necessity of creation the mucous membrane of the nasal cavity, the skull from ABS-plastic does not correspond to the real properties and melts during drilling holes, no possibility of re-manipulation of operating drilling field. These problems were solved as follows: as a material was tested polycarbonate, which has a higher melting point and strength, but this plastic wound onto surface of bur and obstructed drilling procedure while using a diamond burs. On this basis, it was decided to use thermosetting plastics instead of thermoplastics. For the possibility of reusable application the part of the skull, which is prone to destruction in the process of practice skills, was made removable, as shown in Figure 4. Because of the need to use thermosetting plastics this replacement part manufactured on ProJet printer. The carcass of insertion impregnated by special binder based on polyester resins after receiving.

Figure 4.

3. Conclusions
The developed method of manufacturing simulator-trainers of the head surgical field with the individual characteristics (location of the tumor, the individual size, etc.) is very convenient and economically feasible in the manufacture of small quantities up to 20 pieces. This is due with the fact that on average, a trained team to practice manual skills consists of no more than 20 people. Interchangeable insertion of allow on the same simulation increasing the number of cycles of repetition thereby achieve the transition effect of "quantity" to "quality".

Existing at the moment 3D-printed simulators worth $ 2600 [1], produced by our method was $200. In the future we plan to improve simulator-trainers and to develop a method of manufacturing the circulatory system to filing fluid under pressure.

This work was funded by the subsidy allocated to Kazan Federal University for the state assignment in the sphere of scientific activities.

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