The possibility of rapid prototyping in the manufacture of 3-d models of cranial implants from CT-DATA

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ABSTRACT

The article is devoted to the development of a method for manufacturing models of cranial implants using full-scale prototyping by means of extrusion 3D printing.According to the results, specialized software was developed that allows building a geometric model of cranial implants with the maximum degree of automation, performing spatial visualization of the volume model of the implant and generating initial data to create the corresponding full-scale model.

Keywords: bone, skull, 3D printing, an implant, model.

1. INTRODUCTION

Defects of the bones of the vault and the base of the skull can be etiologically both congenital and acquired (post-traumatic, hypertensive, neoplastic)[1,2].At the same time, their pathogenetic mechanisms contribute to the disruption of conditions necessary for normal functioning and development of the brain, which leads to an increase in the dynamics of hemo-and liquorodynamic disorders[3,4]. Also, the cosmetic aspect is an additional disabling factor, which, in conjunction with the above disorders, leads to a significant reduction in the patient's quality of life, complete or partial disability. This causes the medical and social relevance of the problem of closing bone defects[4,5].

The restoration of the integrity of the skeleton of the skull is currently carried out using a significant amount of biological (for example, auto bone, cartilage, cadaver bone, brefotkan, bone chips) and non biological materials (titanium, tantalum, bioinertial ceramics, plastic, silicone)[2,3,4].The complex spatial configuration of cranial defects with significant changes in thickness, the volume of applied functional loads and the nature of the surface in the implantable area require the development of approaches for ultra-precise geometric modeling of the shape of implants. Modern technologies of rapid prototyping allow, through the acquisition of full-scale implant models using 3D printing, to improve the accuracy of reconstruction of cranial defects. Therefore, the aim of the work is to develop a method for manufacturing models of cranial implants using full-scale prototyping by means of extrusion 3D printing[5]. To determine the shape of cranial defects, data obtained using X-ray spiral computed tomography[6,7] are most often used, which allow visualizing bone structures with high contrast and spatial resolution and detecting corresponding abnormalities of the skull surface. The arising errors and errors of averaging data for reconstruction at the boundaries of tissues with different X-ray absorption characteristics can be ignored[8,9].

2. EXPERIMENT AND RESULTS

Patient head examinations were performed on a Siemens Somatom Emotioon + spiral computed tomograph with the following styling and scanning conditions:

- providing the possibility of adjusting the inclination of the head in the sagittal, horizontal and frontal planes,
- performance of topograms in the frontal and sagittal planes,
- conducting scanning parallel to the plane of the base of the skull with a step of 1 mm;

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- the possibility of refined visualization of areas with a complex geometric shape, the orbit and wings of the sphenoid bone.
- specifying the exact scale factors and sizes of image elements when imaging tomographic slices.
- To create an implant model, the initial data were sets of tomographic slices (DataSets), performed with a fixed pitch of 1 mm (see Fig. 1)[10,11,12].
- The task of creating an implant model using rapid prototyping tools according to spiral computed tomography consists of 6 main stages:
- segmentation - the selection on the images of tomographic sections of bone structures;
- determine the location and selection of the bone defect replacement method;
- creation of a large implant reconstruction;
- preparation of data for prototyping in stl format;
- creating a layer-by-layer model of the implant in the G-code format for 3D printing on specific equipment.
- 3D printing of full-scale model.

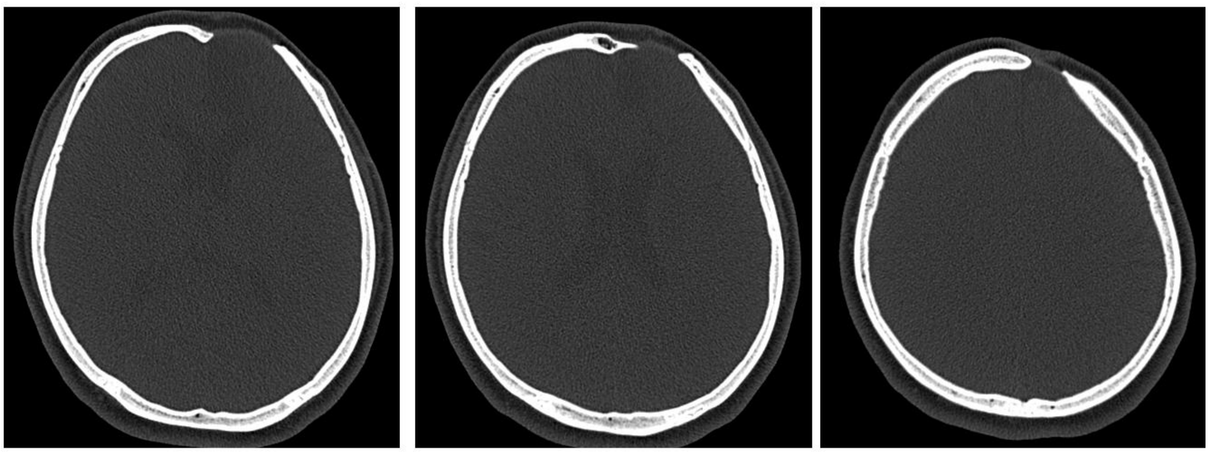

Figure 1. Images of characteristic tomographic slices with a defect in the skull in the left frontoorbital area.

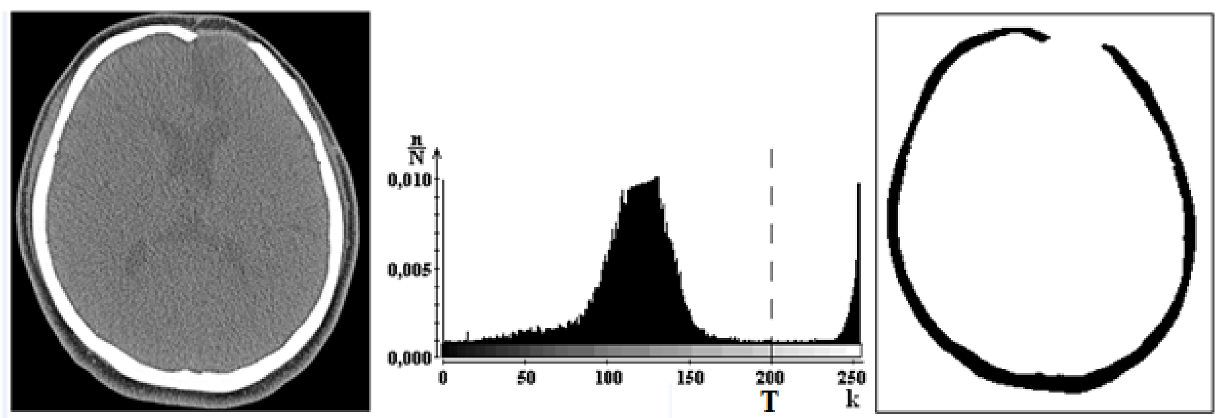

Figure 2. Threshold segmentation of a tomographic image: a) source image; b) image histogram; c) segmented image of the skull (T is the segmentation threshold).

At the stage of image segmentation, the procedure was carried out, consisting in the selection of image elements belonging to bone structures. When imaging tomographic slices, the correspondence between the intensity of the image element and the Hounsfield numbers, which determine the density of the tissue, was set. At the same time, the characteristic bone window was selected, which most closely corresponded to the dynamic range of the display of bone structures[12,13,14]. Based on a priori information, the procedure for segmentation of bone fragments in tomographic images was performed by a threshold method[13,15,16], based on an analysis of the image brightness histogram, which is a discrete function that shows what number n of image elements has intensity *k*. Figure 2 shows images of a tomographic slice with a bone defect (Fig. 2, a) and its corresponding brightness histogram (see Figure 2, b), which has 3 maxima. The average value between the two main maxima in the light region corresponds to the segmentation threshold T = 200 (indicated by the dotted line in Figure 2, b).The result of segmentation of bone structures is shown in Figure 2b.

At the second stage of the procedure for determining the geometric characteristics of the implant, the method of bone defect reconstruction is implemented by calculating the implant parameters on a symmetrically located intact part of the skull. When using symmetrically located areas of the skull, the main problem in determining the exact configuration of the implant is the need to observe strict compliance of the defect area and the intact part of the skull surface, which is determined not so much by anatomical asymmetry, but by errors in geometric constructions, inaccuracies of the surface reflection procedure and difficulty (and sometimes a) provide the necessary styling.For example in[17,18,19], methods are proposed for calculating the implant configuration over a symmetrically located part of the skull surface, which allows minimizing the errors associated with laying. At the third stage, the construction of a volume reconstruction of the implant and the construction of a polygonal model of its surface takes place. Triangulation and rendering of a polygonal model of the implant surface is performed. When this occurs, the determination of the geometric characteristics of the model and the correction of its shape taking into account the possibilities of fixing the implant[20]. At the fourth stage, the data are prepared for prototyping and the implant surface model is converted into the standard stereolithographic format stl. At the fifth stage, the creation of a layer-by-layer model of the implant in the G-code format, taking into account the capabilities of 3D printing on specific equipment[14], setting print speeds, layer thickness, additional supports, etc. (see fig. 3, a)[20]. The final stage was the printing of the implant model surface (see Figure 3b).

a) b)

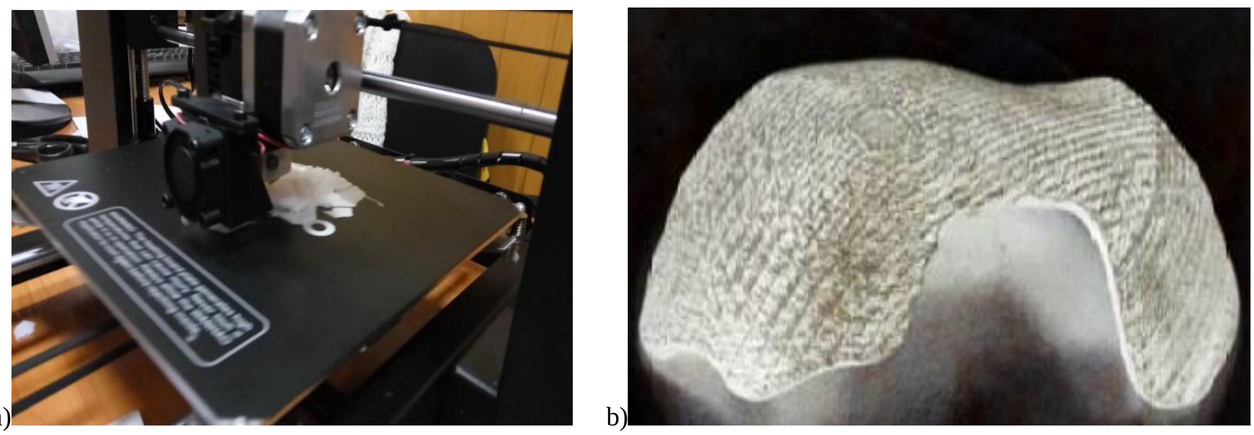

Figure 3. The final stage of creating a full-scale model of a cranial implant on a 3D printer: a) illustration of the printing process of the implant model layer, b) the finished model of a cranial implant

3. CONCLUSIONS

Implant models are made of PLA-plastic, which does not allow to install them directly to close the defect in the skull. But such models allow a specialist at the planning stage of an operation to assess the amount of surgical intervention[14,15], and also based on the model, it is possible to form parameters and create molds for the manufacture of an implant that directly reconstructs a bone defect.According to the results, specialized software was developed that allows building a geometric model of cranial implants with the maximum degree of automation, performing spatial visualization of the volume model of the implant and generating initial data to create the corresponding full-scale model[20].

The complex architectonics of cranial defects, in particular, those moving from the skull vault to the upper region of the face, imposes increased requirements on the shape of the implants used, which geometrically exactly correspond to the reconstructed defects. The perspective of the work is to study the possibilities of 3D printing technology for the reconstruction of bone defects solely by means of rapid prototyping.

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