ALGORITHM OF PROCESSING MICROSPIRAL CT-SCAN RESULTS FOR CONSTRUCTING A THREE-DIMENSIONAL MODEL OF ORBIT THIN BONES

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Abstract. We developed the algorithm for preparation of DICOM images for the construction of a three-dimensional model of the bones of the facial skull. The DICOM image-processing algorithm reduced the data loss level about the thin bones of the orbit during building a three-dimensional model of the bones of the facial skull from 22–31% to 3–5%. The developed software automatically changes the color of the pixels of the thin bones of the orbit from gray to white. Thin bones of the orbit were expanded over one pixel using the DICOM image-processing algorithm. The analysis of the image processing results by the developed software was carried out using 3D Slicer software.

1. Introduction

Post-traumatic defects and deformities disrupt the habitual geometry of the face, lead to the development of functional disorders, the formation of cosmetic defects and, as a consequence, the violation of social adaptation of patients. The main place in the rehabilitation system for patients with posttraumatic changes in the bones of the facial skeleton is occupied by reconstructive and restorative operations, whose goal is to restore normal anatomy of the damaged area in order to achieve good functional and aesthetic results.

To eliminate posttraumatic defects of the bones of the skull, various materials of both biological and synthetic origin are used. However, the main problem with the use of the majority of existing materials is the need for intraoperative implant modeling that not only increases the duration of the intervention but, with extensive damage, does not allow the surgeon to accurately reconstruct the three-dimensional shape of the eye socket and achieve the desired cosmetic result when eliminating posttraumatic enophthalmos and hypophthalmia [1].

Currently, medical practice is introducing modern computer technologies for the production of personalized implants to remove defects in the bones of the skull [2, 3]. The

use of personalized implants in reconstructive and reconstructive surgery of the face has demonstrated their undeniable advantages, which, in high accuracy, reduce trauma, shorten the duration of the operation and ultimately achieve a predictable stable functional and cosmetic result [4].

To create such high-precision personalized implants, the quality of microspiral computed tomography (MSCT) is of decisive importance.

The analysis of the images obtained in the MSCT [5 – 7] in the DICOM [8] format and the three-dimensional reconstruction of the skull allows the surgeon to more reliably estimate the anatomical features of the individual patient, localization, boundaries and prevalence of the pathological process, and plan the scope of the surgery [9, 10].

However, among all bones of the facial skeleton, the lower and medial walls of the orbit are very thin structures (thickness ~ 0.1-0.3 mm), which is less than the resolving power of the existing apparatus (up to 0.625 mm). In this connection, the construction of a 3D model using the tomography software does not provide complete information about the state of the lower and medial walls of the orbit, they look like a cellular structure, have pores (Figure 1).

As a result of converting DICOM files to a 3D model, some of the information about the thin and small bones of the orbit is lost.

These losses lead to difficulties in determining the geometry of the damaged bones. It should also be noted that the software of existing MSCT does not allow you to edit the resulting 2D images, 3D models of the result of reconstruction, which leads to the use of additional software.

A software processing [11] and image analysis [12] get a great importance in medicine in general and in traumatology in particular.
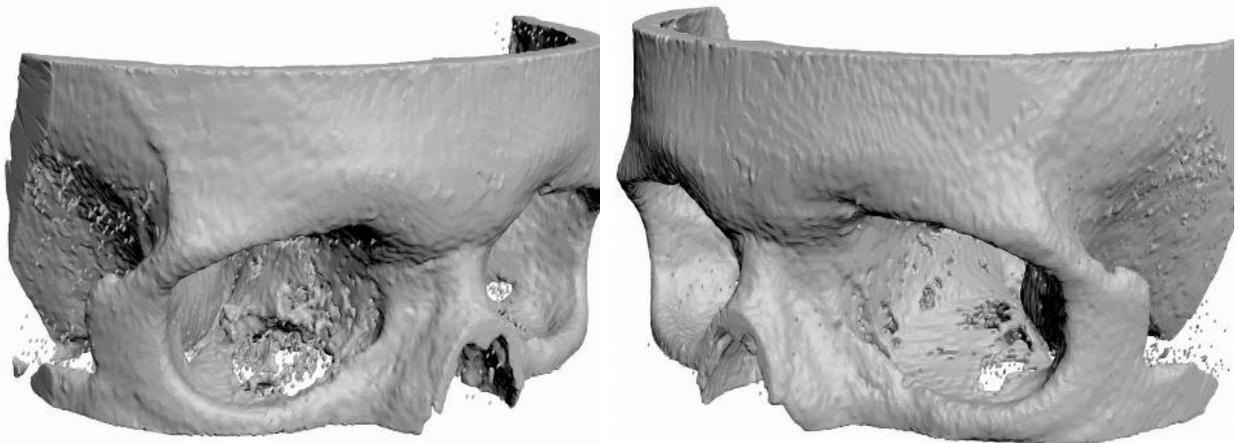

Figure 1. Type of three-dimensional model of bones of the facial skull: the result of the construction of a 3D editor.

The target of the work is to develop a technology for constructing a 3D model of the lower and medial bones of the facial skull while retaining complete information about their geometry based on the results of microspiral computed tomography (DICOM files).

2. Materials and Methods

During research, we analyzed DICOM images of several patients. The DICOM images contained data of MSCT scan of patients head including damaged eye socket bone. The DICOM images were received with device Siemens Emotion 6. We analyzed data of different patients of both genders aged between 20 and 40 with damage of eye socket bone.

DICOM images show slices of human head using density of body parts. The more the density the more intensive white color on the DICOM image. Soft parts colored as gray color, and voids colored as black color.

Analysis of the images of three projections using 3D Slicer software showed that in some places the thin eye socket bones absorbed X-ray beam less than the bones should absorb. As a result thin eye socket bones have a color that differs from white on the DICOM image. This is true for other slice orientations (Figure 2). Figure 2A shows axial slice of head where distance from MSCT starting point is -172.8 mm. Figure 2B shows sagittal slice of head where distance from MSCT starting point is -15.7 mm. Figure 2C shows coronal slice of head where distance from MSCT starting point is 213.2 mm. Figures 2B and 2C are the result of approximation built with 3D Slicer software.

The 3D Slicer software uses white pixels as input for building a 3D model of skull. As a result, 3D Slicer software loses a data about thin eye socket bones while generating the 3D model. We determined amount of data loss through the ratio between the area of eye socket bones and the area of defects.
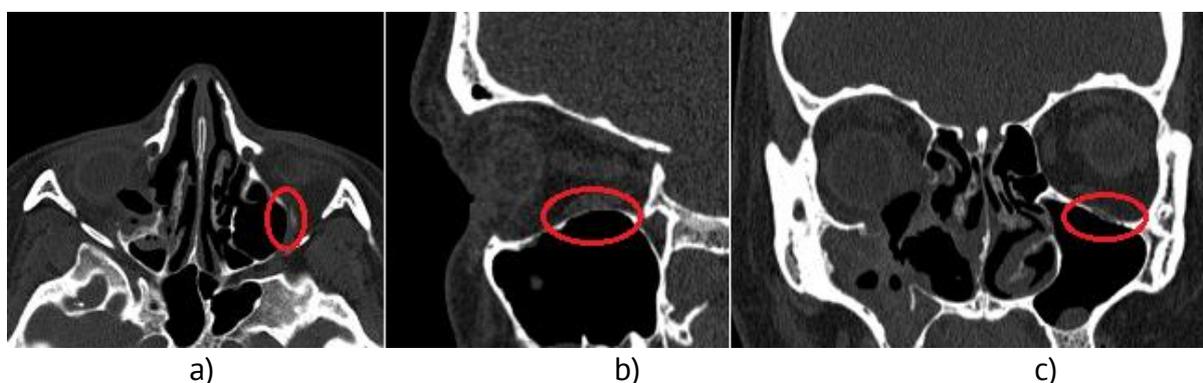

a)   b)   c)

Figure 2. Images of the three projections of the patient's head: a – axial orientation;
b – sagittal orientation; c – coronal orientation.

Therefore, it is necessary to make additions to the original DICOM images. We need to make thin bones visible to 3D Slicer software algorithms and do not distort the result of building a 3D model of the bones of the patient's head skull. The geometry of damage to the orbital bones should be preserved. Additions should only applied to the bones of a healthy orbit.

The analysis of three plane projections showed that the thin bones of the orbit border on the voids in the skull. At the same time, if the orbital bone is damaged, these voids are filled with biological cells, mostly fat cells. This leads to a change in the level of X-ray absorption and a change in the DICOM image of a healthy orbit bone. We need to note these circumstances while developing software that modifies the original DICOM files.

We propose the following technological chain to achieve the goal.

1) Process the original DICOM images with the developed special software. The flowchart of developed algorithm is presented in Figure 3. We implemented developed algorithm as software using C# programming language in the integrated development environment Visual Studio 2017 Community.

2) View the results of processing DICOM images in software 3D Slicer.

3) Set up 3D Slicer to build a 3D model of the bones of the facial skull by doing the following:

– Select the module "Volume Rendering". Select the DICOM image set in the "Volume" column.

– Select the display format "CT-AAA" in the "Preset" column. If the model is not displayed in the work area, center it with the function "Center the 3D view on the scene".

– Select the "Editor" module and confirm the model display properties.

– go to the "Edit Selected Label Map" tab and select the "ThresholdEffect" function; set the "Threshold Range" parameter to a filter value of 230 (this value can vary from 100 to 300); confirm the selected band with the "Apply" button.

4) Start the construction of the 3D model of the facial skull bones in the 3D Slicer software by selecting the "MakeModelEffect" function and pressing the "Apply" button.

The format of DICOM files pixel data is gray16 [13]. We analyzed color spectrum of the gray16 format to determine black, white and gray colors in RGB format in purpose of developing special software. The color spectrum of gray16 format is presented in Figure 4. We chose the average number of black pixels, white pixels and gray pixels as a basis of spectrum analysis, and were determining them visually. The black pixels match to voids, the white color pixels match to bone tissue, and gray pixels match to other body tissues and fluids. We checked results of analysis by processing DICOM images with the developed software. The size of an array of pixel data, which is [n; n], depends on the resolution of the source DICOM files: the height and width of the image.
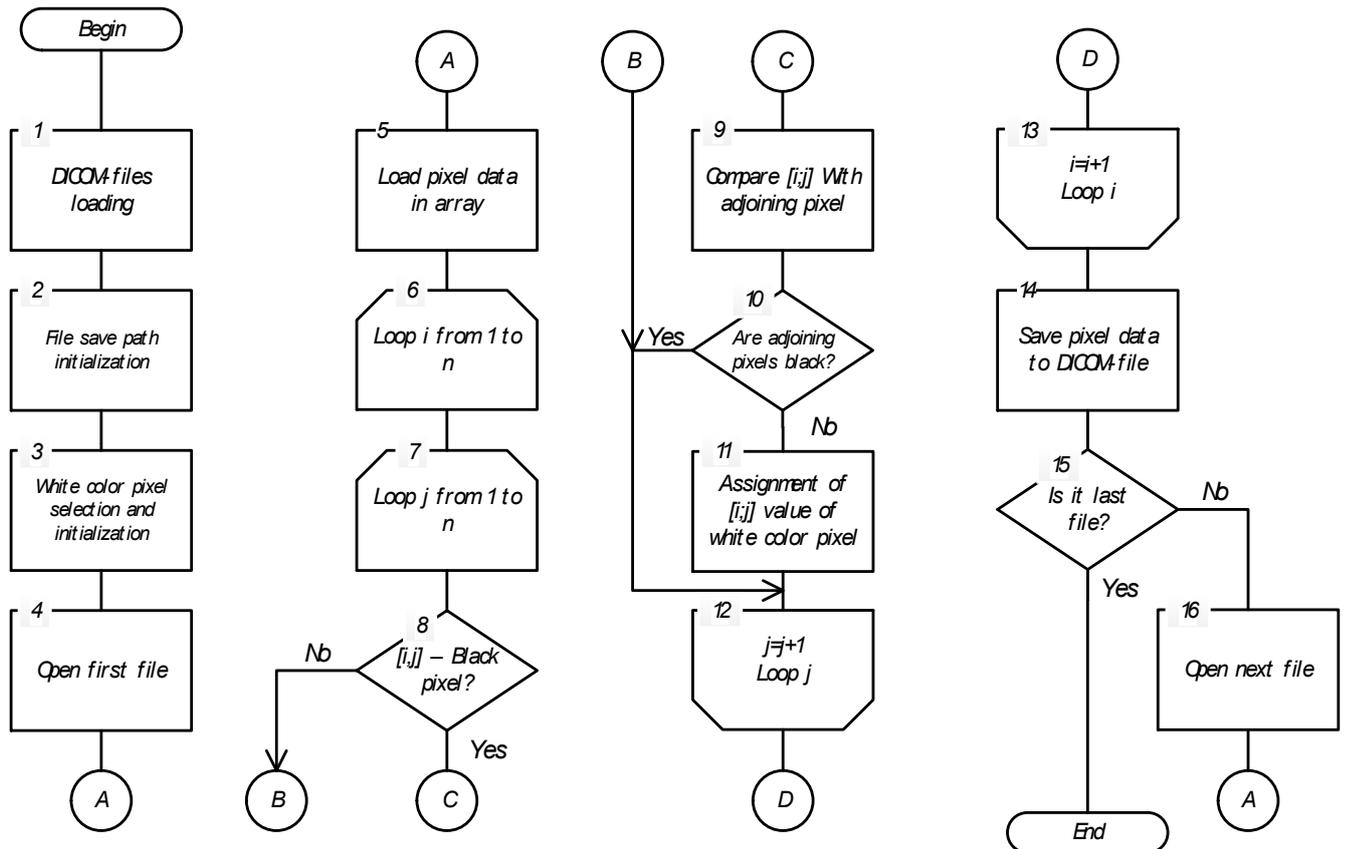
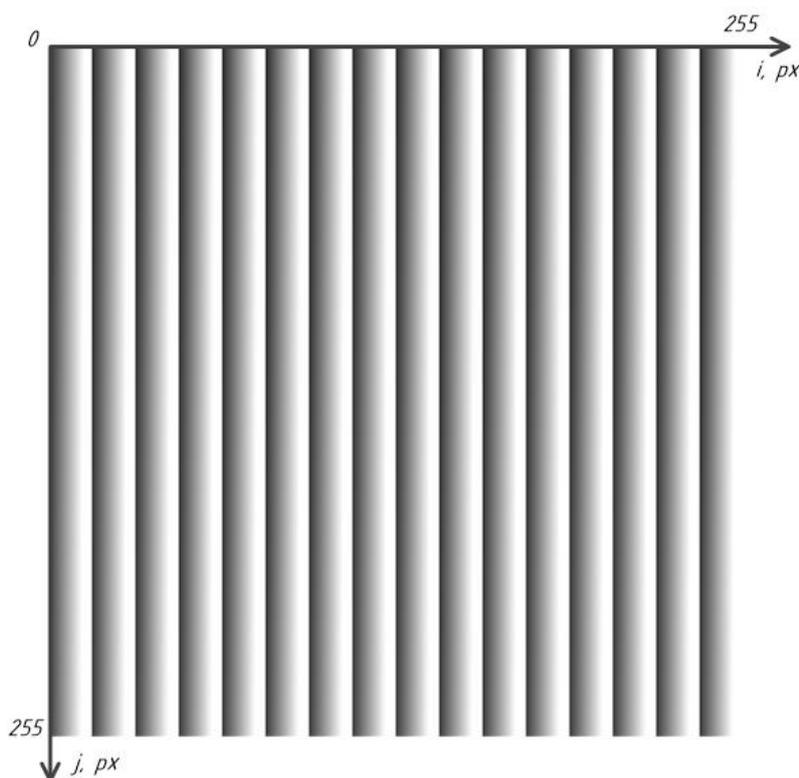**Figure 3.** DICOM images processing flowchart.

Figure 4. Color spectrum of DICOM images: i – the value low byte of the gray16 format pixel, $i = \overline{0,\,255}$, j – the value of high byte of the gray16 format pixel, $j = \overline{0,\,255}$.

The spectrum analysis of the DICOM file led to the next results. Black pixels of gray16 format have the following values of low byte and high byte:

$$i = 16 \cdot n, \; n = \overline{0,\,15},$$
$$j = \overline{0,\,255},$$

where n is an whole number.

White pixels of gray16 format have the following values of low byte and high byte:

$$i = 12 + 16 \cdot n, \; n = \overline{0,\,15};$$
$$j = \overline{144,\,255};$$
$$i = \overline{13,\,15} + 16 \cdot n, \; n = \overline{0,\,15};$$
$$j = \overline{0,\,255}.$$

The remaining values of low byte and high byte correspond to gray pixels of gray16 format.

3. Results and its discussion

The result of processing DICOM images by special software is another set of DICOM images with expanded white color. Figure 5 contains three projections of resulting DICOM images. In comparison with Figure 2, we can see the next result. The marked places in Figure 2, fragments with an implicit bone, are transformed into an explicit white color, characterizing the presence of bone tissue. Figure 5A shows axial slice of head where distance from MSCT starting point is -172.8 mm. Figure 5B shows sagittal slice of head where distance from MSCT starting point is -15.7 mm. Figure 5C shows coronal slice of head where distance from MSCT starting point is 213.2 mm. Figures 2B and 2C are the result of approximation

built with 3D Slicer software. The thin orbit bone became visibly better on axial orientation (figure 5A).
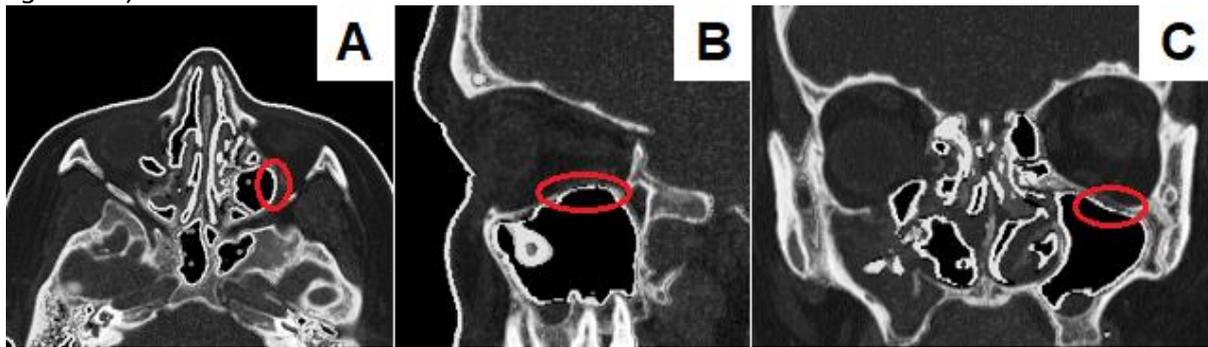

Figure 5. Three projections of the patient's head, constructed on the basis of the original DICOM images converted by special software: a – axial orientation; b – sagittal orientation; c – coronal orientation.

Results of approximation with 3D Slicer became visibly better too: sagittal orientation (figure 5B) and coronal orientation (figure 5C).

However, there is a significant weakness of algorithm of DICOM image processing within the developed software. The algorithm converts the skin on the patient's face into bone (Figure 5).

This complicates viewing and further work on the analysis and construction of the geometry of damage, for the manufacture of an individual implant. In order to eliminate this weakness, we modified the algorithm of processing the DICOM images: additional actions were added after block 13 of the algorithm (Figure 3) to correct the array of pixel data (Figure 6).
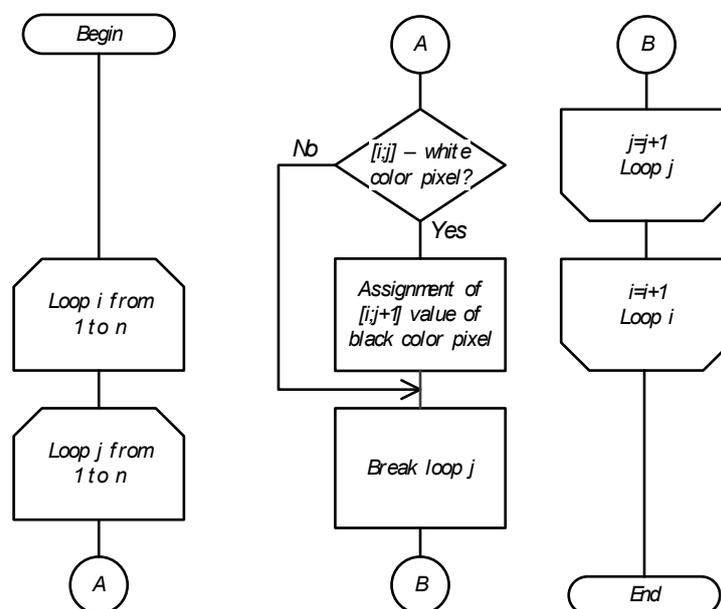

Figure 6. Modified flowchart for processing the source DICOM images.

Figure 7 contains three projections of resulting DICOM images using a modified algorithm. The distance of all projection planes from the MSCT starting point in Figure 7 is identical to those in Figures 2 and 5.
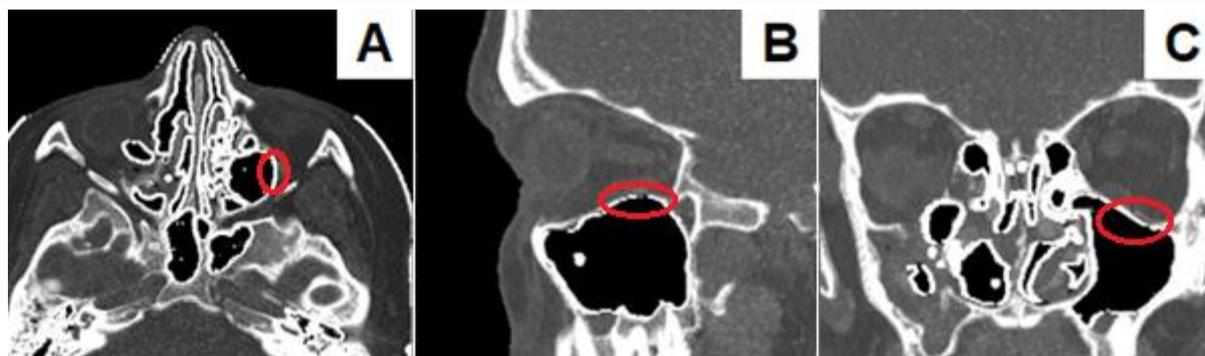
Figure 7. Three projections of the patient's head, constructed on the basis of the original DICOM images converted by modified special software: a – axial orientation; b – sagittal orientation; c – coronal orientation.

As a result of processing the original DICOM images with modified special software and performing operations 2 through 4 of the proposed technological chain, we built a three-dimensional model of the bones of the facial skull (Figure 8). When analyzing the image in Figure 8, we can see that the left eye socket of the three-dimensional model (the right part of the figure) has clear, without holes, the bones of the orbit. This allows you to uniquely identify the eye socket with damaged bones. Later, using 3D modeling editors, it is possible to build a three-dimensional model of the orbital bones.

Calculation of the loss of information on the bones of the eye sockets during the construction of a three-dimensional model of the bones of the facial skull showed that when using DICOM images without preliminary processing, the average loss value is 22 – 31 % at the scan step 0,63 mm, using DICOM images after processing the developed software – 3 – 5 %.
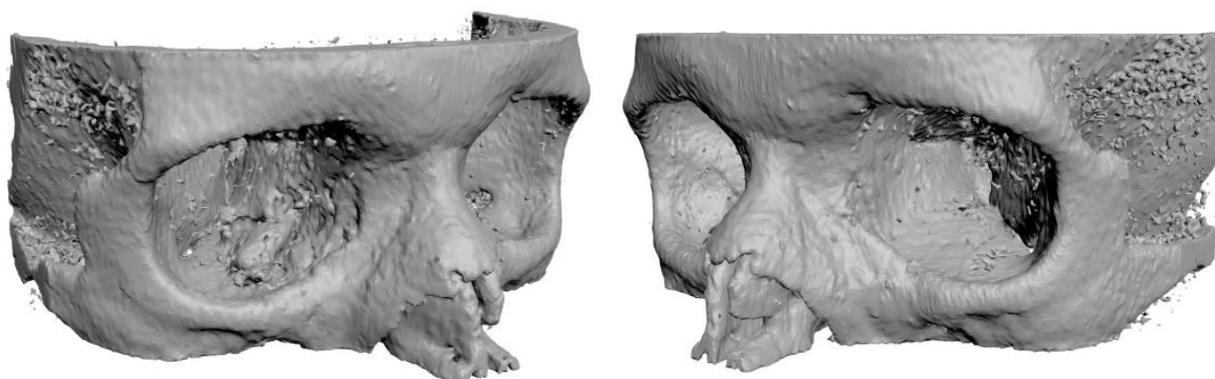

Figure 8. The appearance of the three-dimensional model of the bones of the facial skull after processing by special software: the result of construction by a 3D editor.

We built four versions of 3D-models based of DICOM images with expanding of white color by one, two, three and four pixels. Analysis of four versions of 3D-models showed that it is enough to expand white color by one pixel to achieve a level of data loss of 3-5%.

4. Conclusions

Expanding of bone tissue color over one pixel during preliminary processing by special software is the optimal amount for constructing a three-dimensional model with preservation of complete information about the structure of the orbital bones.

Processing of the original DICOM images with developed software decreases the loss data level about the orbital bones from 22-31% to 3-5% during constructing a three-

dimensional model of the bones of the facial skull. The DICOM image correction was performed automatically using developed software.

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