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***Research paper***

# Information Technological System for Maxillofacial Area Bones Prototyping

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**Abstract**

The research is devoted to the sequential movement of digital information between different software products, eliminating at each stage the problems of conversion, recognition, fine-tune the parameters of operations, that is, the development of a kind of technological map of the process of obtaining a material model of a part of a human skeleton for use in maxillofacial surgery. An information technology system for obtaining 3D models of the lower jaw bones with the use of tomography and free CAD/CAM InVesalius 3 and Autodesk software is developed. InVesalius 3 software was used to provide semi-automatic image segmentation using the Hounsfield scale and build a specific three-dimensional voxel model, based on the virtual layered individual images combination. Voxel models convert to STL file and editing surface «artifacts» (inaccuracies) with Autodesk, MeshMixer. Completed prototyping bone and implant models obtained on a FDM 3D printer are used in maxillofacial surgery.

***Keywords***: *Autodesk MeshMixer, CAD/CAM , software information technology system, InVesalius 3, prototyping.*

## 1. Introduction

The purpose of the study is to find out the possibility for creating human body bone structure elements material models according to:

- Preliminary medical diagnostic examination by means of tomography;
- Further transformation of medical data into digital format, understandable for recognition of CAD\CAM systems;
- Editing a computer model for 3D printing and CNC milling;
- Prototyping bone and implant models (dentures) optimal process technological map designing using 3D printer with materials and settings different types.

## 2. Information technological system

Our research would have been impossible without fruitful cooperation with the specialists of Orthopedic Dentistry Department with Implantology «VSNZU» Ukrainian Medical Stomatological Academy», especially, Ph.D. L. B. Eris provided the basis for previous scientific developments [1-3], which main purpose is to materialize in the implants function the removed parts of the jaw or designing individual in the form of broken bones embedded lockers.

Structural research can be reduced to the consistent transfer of digital information between different software products eliminating at each stage the problems of conversion, recognition, fine-tuning the parameters of operations (see Figure 1), that is, kind of technological map designing for human skeleton material model part obtaining process to use in maxillofacial surgery.

Due to information and technological innovations, modern medicine, including through computerized diagnostic equipment, has entered a qualitatively new stage in the provision of medical services, extending the duration and quality of human life, and the development of scientific and technological progress helps patients with physical disabilities a wide range of prosthetics, adaptive devices.

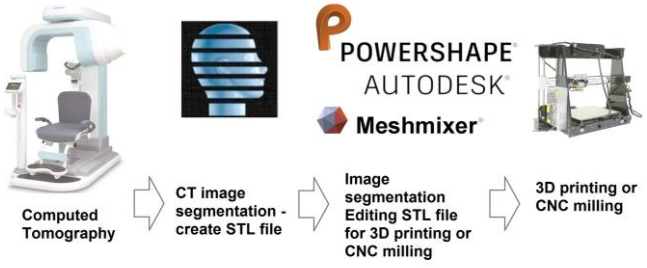



**Fig. 1**: Research structural scheme

### 2.1. Definition of unsolved aspects of the problem

The task of designing and further manufacturing individual dentures, auxiliary anchorages of a complex form, etc., taking into account the ergonomic needs of human anatomy, became possible due to three-dimensional scanning digital technologies development, and rapid prototyping additive technologies development (3D printing) can significantly reduce installing risks The prior acquaintance of surgeons with the form of anatomical objects, to our mind, will allow using the information obtained to optimize the planning of operations, can reduce its duration, reduce risks. In

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addition, it is advisable to organize a digital repository objects models for proper actions which have already been performed, and implants (prosthetics and others), and medical simulator for students and undergraduates to organize a training simulator for medical students or advanced training participants.

The causes of bone tissue destruction in craniofacial surgery are not the subject of our study. Our previous studies concerned both the effects of injuries and diseases such as osteomyelitis and tumors [1-3]. At fractures for restoration fragments of bones which were formed during an injury were used and the task of fixing these debris on the given positions of the primary form with the help of various fixators (osteosynthesis of bones) was solved. Also, for the restoration of mechanical potencies of bone tissues, metal prostheses were developed that replaced the of the removed bone part functionality.

### 2.2. Problem statement

For the development of a three-dimensional digital model, data is required on the exact geometry of the object (bone) and the location and nature of the damage. At the present stage of development medical equipment for obtaining such information, specialists actively use patient diagnostic three-dimensional scan using a computer (CT) or magnetic resonance imaging (MRI). In our case, three-dimensional digital image data came from a computer tomography, which forms a series of two-dimensional X-ray images of the interior object with a given step. For a surgeon, such images increase diagnosis informative nature and make it possible to construct a treatment plan more efficiently, and we can model a three-dimensional image based on these data.

### 2.3. Material and results

Computer tomography operation general principle is a patient gradual layer scan by X-ray technique with a thin beam. The object of diagnosis may be the head, neck, throat, thorax, pelvic organs, limbs, etc. For example, CT of the jaw occurs once and device operating time is not more than a minute. The results of the study are stored in a special format of the industry standard for the creation, storage, transmission and visualization medical imaging CT patients scans DICOM (Digital Imaging and Communications in Medicine). The format is based on the standard ISO 12052: 2006 «Health informatics - Digital imaging and communication in medicine (DICOM), including workflow and data management» and the standard of the developer NEMA PS3 [4]. Formally, as a result of the CT scan process, we have a computer directory with several hundred files with *.dcm* extensions, which represent a raster single layer X-ray image. Each file also contains document attributes (patient information, equipment, institution, diagnostic medical staff, etc.). The distance between the layers depends on CT machine type, generation, technical characteristics, particular instance. Our research was based on CT data DICOM with steps 0.2 and 0.3 mm.

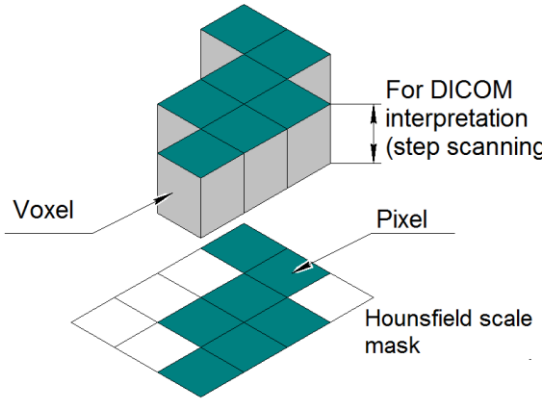



**Fig. 2**: Interpreting raster DICOM files in voxel model

Further CT data interpretation requires specialized software that can build a specific three-dimensional model based on the virtual layered individual images combination. Voxel is the term originated from English words volumetric and pixel, a virtual volume elementary particle is an analogue of 2D pixels in a three-dimensional space [5]. Voxels, when interpreting DICOM files, can be graphically represented in fig. 2

Such specialized software can be both commercial and free, based on open source code. For our research, InVesalius 3 software was used to provide semi-automatic image segmentation using the Hounsfield scale.

The scale of the Hounsfield units (densitometric index, HU) is a quantitative scale of X-ray density, that is, the linear radiation attenuation relative to distilled water, which X-ray density is assumed to be 0 HU at standard pressure and temperature [6]. The proposed Hounsfield method, from computer graphics point of view, is a quantitative scale that describes the density of the resolution raster image in the X-ray image and sets the average value of grayscale in accordance with the density of the area to be segmented (separating from the general form), which makes it possible to distinguish between air, fat, water, muscles, and bones (see Figure 3).

| Substance | | HU |
|---|---|---|
| Air | | −1000 |
| Fat | | −120 to −90 |
| Soft Tissue, Contrast | | +100 to +300 |
| Bone | Cancellous | +300 to +400 |
| Bone | Cortical | +1800 to +1900 |

**Fig. 3**: Hounsfield scale average densitometric indexes [6]

InVesalius 3.0 (a free product for research, Figure 4), developed by the IT Center Renato Archer (Brazil) [7], proved to be a fairly practical choice for our work. The program can be downloaded directly from the home page, and available versions for Linux, Mac, 32 or 64-bit Windows operating systems. The language of the interface can be English, but User Guide only in Portuguese (a bit uncomfortable, but again we emphasize we do not use unlicensed programs in our development works).

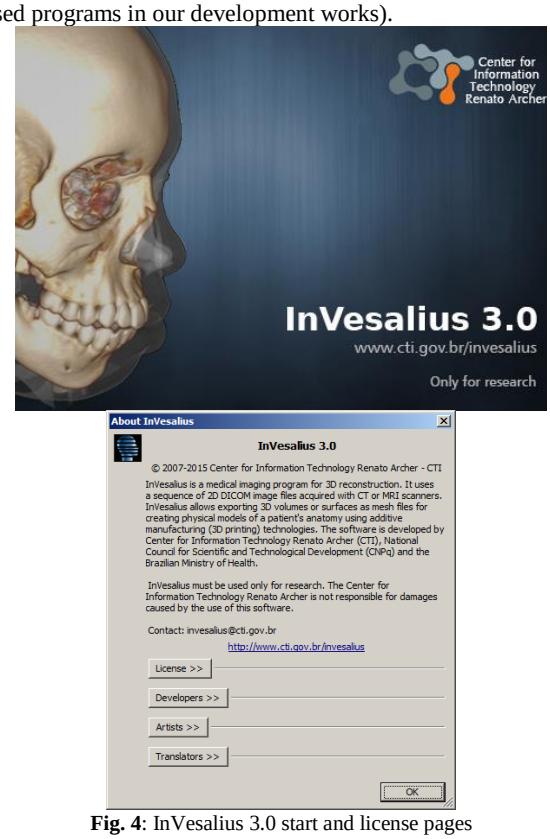



**Fig. 4**: InVesalius 3.0 start and license pages

After loading DICOM files (Figure 5), importing and creating a new .inv3 project, for the correct interpretation of the CT data, it is needed to make individual settings (Figure 6).

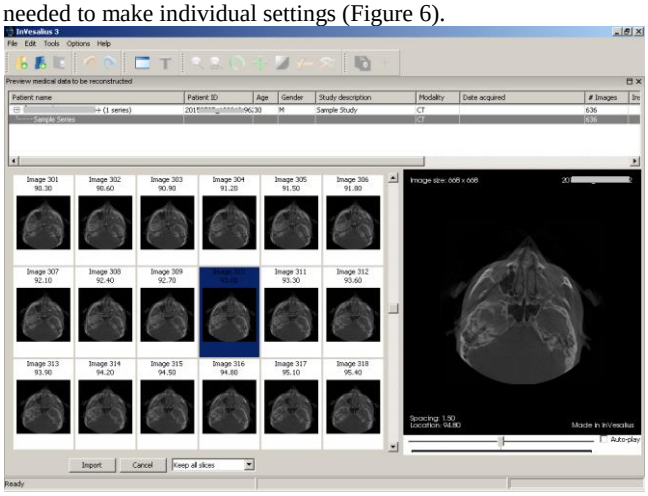


**Fig. 5**: Imported DICOM data in InVesalius 3.0

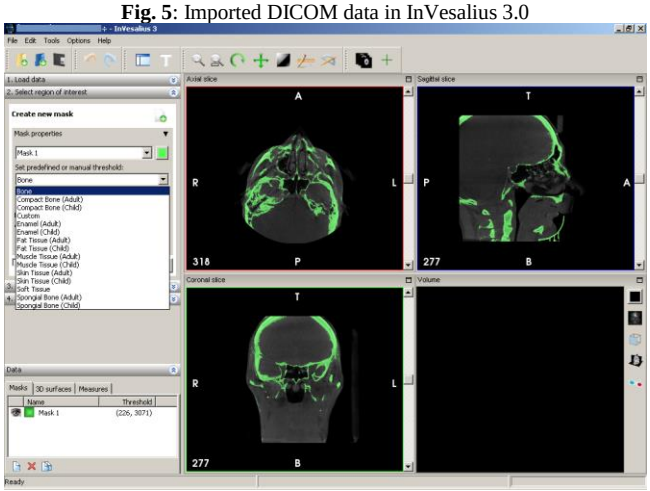


**Fig. 6**: InVesalius 3.0 program interface and mask parameters selection process

First, choose organ type for recognition (in this case, it's bones), then create a mask, a special color layer, which in fact is a reference to raster pixels having a densonometric density, according to standard or custom settings (Figure 6). Set the required parameters with two color scale scrollers. If necessary, several different masks parameters (color and outside HU) masks can be created. In particular patient tomograms, HU values were set by default, were corrected, as influenced by individual patient characteristics, diagnostic apparatus type and calibration. Determining the optimal parameters for each project has always taken several tests and needed a modern powerful hardware computer, such as a graphic station. Our conclusion is that it is advisable to take the standard parameters as a basis and to bring the subtle settings to the optimum quality, gradually improving the quality by applying the manual mode of defining threshold values for the segmentation (Threshold). Also, when manually identifying a segment user in Manual Mode, knowledge of anatomy and a good understanding of grayscale raster handling become the essential basis for creating a high-quality voxel three-dimensional model. For example, the initial threshold values for a patient's X tomography were (226-3071 HU), but the several implants presence and particular tomograph design features revealed the need to change both the minimum and the maximum threshold HU, and after considering 5-6 options, the final values (585- 3890 HU). Minimum threshold values varied from 320 to 700 HU, and in two cases, even more up to 740 HU.

Changes in the settings are displayed in three windows that correspond to the orthogonal view on one of the cutting surfaces (the angle of inclination can be changed to the user using the mouse), and the fourth window shows the voxel model created by these parameters (Figure 7).

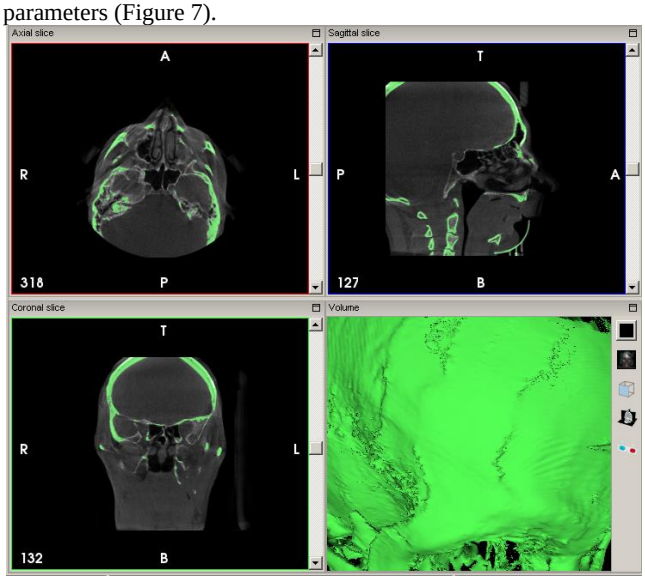



**Fig. 7**: Three-dimensional model based on interpreted CT data

The user can use raster editing tools, erase commands, drawing, you can change the threshold of the segmentation (Threshold, that is, select in the image only pixels whose intensity is within the threshold set by the user), select the region of interest and split all not connected parts of the model. If the scans were captured and screened, then to remove them from the voxel model, either in one of the projection windows, to erase these areas in each layer, where there are superfluous elements (in Figure 5 in the upper part window «Sagittal slice» is shown 277th layer from 554, so this procedure will be very painful) or in several layers of manual editing, gradually changing the segmentation threshold to divide the skull and lower jaw, and then select the target region, in this case, the jaw.

At the last stage, InVesalius 3.0 offers the either saving a raster image or exporting a voxel model option to one of the 9 most widely used file formats Inventor, Polygon File Format, and others.

For the needs of our work, the binary format STL (Stereolithography) was chosen because it is a universal triangulation data that is imported without difficulty by various professional CAD\CAM computer packages or so-called «icons» viewing programs.

At the stage of creating and exporting three-dimensional surface model, we encountered many «artifacts» (inaccuracies) in the received STL files. The fact is that the technology of the use of the Hounsfield method from the very beginning has the limitations that are known by the developers of the program InVesalius [8]. As noted above, the «elementary» X-ray of a cut does not itself separate soft tissues and other components of the human body, as well as foreign objects that have crossed the ray of scanning (protective screens, prostheses, bullets, fragments of firearms, etc. .) In addition, the design features of CT machines, their calibration, the process of calculating voxel forms (Fig. 6) are also influenced. All this means that you need to have an additional tool for editing the resulting STL model, which we first applied to Autodesk PowerShape.

Since 2010, Poltava National Technical Yuri Kondratyuk University (PoltNTU) has joined the Delcam plc (UK) project «Delcam Advanced Computer Technologies for Ukrainian Universities», where the university has access to a full-featured PowerSolution computer software package (three-dimensional model development and development platform based on them). For today's CNC machines, Delcam is a division of the world-famous Autodesk Corporation (USA). Since receiving intellectual and patent support, PowerShape and PowerMill software development has become one of a number from the Autodesk program, such as Autocad, Inventor, and others (the current title refers to legal affilia-

tion, for example Autodesk PowerShape). PoltNTU and other Universities of Ukraine have received from Autodesk's official representatives an agreement to continue cooperation in the field of education for the next 3 years with the use of the most up-to-date licensed software. Information fact «Center of advanced computer technologies PoltNTU» from 2011, constantly joins the scientific developments with the use of this software, including medical needs [9-10].

PowerShape is a bright representative of powerful CAD\CAM systems, which stands out among the competition's competitors with trilogy modeling capabilities. It is a special technology (Tribrid Modelling), which allows to apply commands (and in fact, essentially different mathematical bases) as Surface, Solid state and Triangulation (depending on the needs of the designer). The consistent use of all available simulation types in one program avoids export and import data transfer operations to third-party software, and eventually escape the inevitable conversion errors. Trilogy modeling is also directly related to the «reverse engineering» method. This term [11] means the possibility of defining three-dimensional details of the part in the absence of design documentation. For our investigation, functional commands with triangulation (also used terms polygonal, facsimile) models, such as the STL format that we received with InVesalius, are particularly useful. As it has been mentioned, during previous years, by means of reverse engineering, based on CT data and triangulation models, surface or solid-state models of implants and prostheses [1-3] were developed and using PowerMill processing codes for CNC machines.

If the problem of designing the implant with the further manufacturing process development arose, Autodesk PowerShape and PowerMill use is functionally feasible, but it should not be forgotten that these are commercial software products, which cost is justified in terms of three-dimensional modeling uniqueness. Also, the lack of such a choice may be in a small quantity of specialists using such programs. If the task of fabricating a material anime object with the help of additive technologies (3D printing) arose, the use of commercial software products becomes unjustified, so we propose editing triangulation models with the help of MeshMixer from Autodesk (Figure 8). After processing several models, we learned that such a connection of digital tomography processing was introduced earlier in Sintesi Sad Academy, Italy [12], but it only confirmed that we are on the right way.

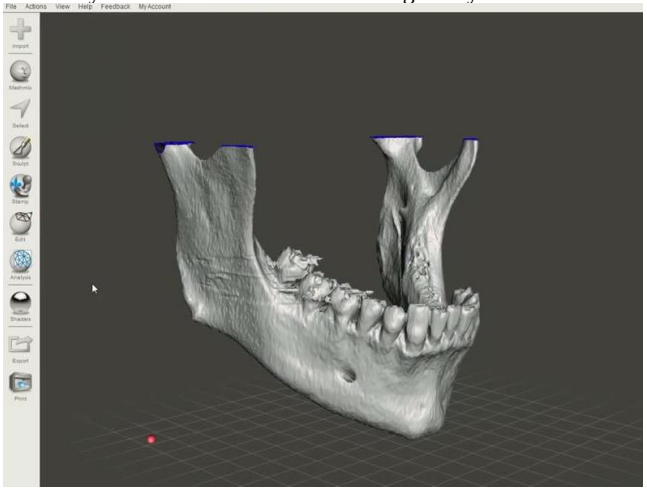


**Fig. 8**: Autodesk MeshMixer interface

Autodesk MeshMixer editing tools are significantly different from Autodesk PowerShape, they have a fundamentally different foundation, same program some useful facilities have no analogues in the other (for example, smoothing the Grid in PowerShape applies to the entire object, while MeshMixer uses the usual «computer graphics» experts Brushes with variable properties that affect only a certain part of the grid (Figure 9). It is necessary to monitor obtained data reforming process closely and not distort the important sites of damage or fracture sites. Autodesk MeshMixer command description and features can be found by the link [13, 14].

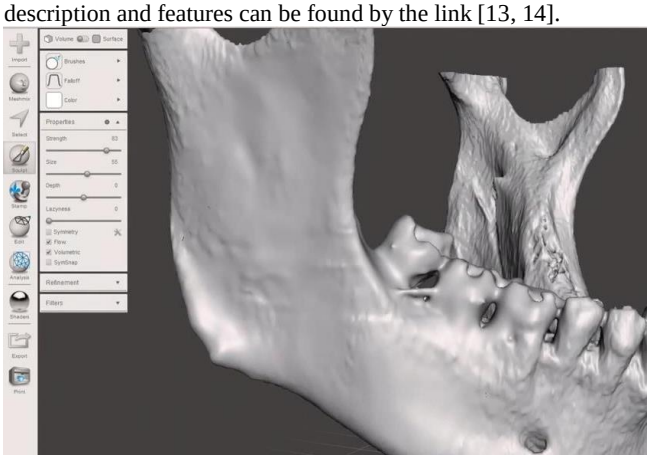


**Fig. 9**: Editing jaw model in Autodesk MeshMixer

Ultimately, after completing all the procedures for computer model pre-production, we proceed to the last stage of our study.

If there is no need in a material copy (moulage), the model can simply be observed in the program window, returning it and bringing the fragments closer, but if there is such a need, you can get a fairly accurate copy of it using modern 3D printing additive technologies (prototyping).

Additive technology is the most dynamic direction in world scientific and technological progress [15], is the layered build-up of a solid three-dimensional object, relying on a digital model. If the tomographic scans the human body gradually, then three-dimensional printing consistently recreates the profile of an interesting plot for us. Our research was based on a quite low-budget Fused Deposition Modeling (FDM) 3D printer and additive technologies the most common materials usage PLA, Plastics (Ecologically pure polylactic acid) or ABS thermoplastic resin (acrylonitrile butadiene styrene) [16]. Unfortunately, FDM materials can not be used for implants, but the published models were a new component of the surgeon's preparation for surgery, since the tool selection, cutting angles, etc., did not take place during the operation, but in advance (Figure 10).



**Fig. 10**: Prototyping model

## 3. Conclusions

The information and technology system for prototyping bones of the maxillofacial area model based on the software connection «InVesalius 3 - MeshMixer - 3D printer» or proved to be the most optimal for the production of material copies (jaws) that can be used for surgical operations preparation and possible implant variants selection. Student scientific development works conducted under the supervision of the article authors took prize places (Fig-

ure 11) at the international student's works contests 2015 (Delcam competition) and 2016 (Autodesk competition).




**Fig. 11**: Certificates of prize places at international student's works contests 2015 (O. Kostenko) and 2016 (V. Mesevrenko)

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