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Development and Printing of a Customized 3D Model of a Solitary Humeral Cyst as a Stage in Surgical Treatment of Bone Defects Using Orgignal Bone Replased Material

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Abstract

Objective: To study the possibilities of using 3D technology in preoperative planning and surgical treatment for solitary bone cyst.

Methods. As part of this work, a 3D model of a solitary cyst of the proximal humerus of a 14-year-old teenager was formed based on CT scans for printing a bone defect sample on a 3D printer.

Results. During processing, 3D slicer, 3D paint and Rhinoceros programs were used to create a virtual bone model and edit it further. Printing was done using ABS plastic and thermoplastic polyurethane using the FDM method. A comparison of the samples was made, taking into account the necessary characteristics for future filling of the model with bone plastic material and formation of an individualized graft.

Conclusion. The results of the study showed the feasibility and simplicity of the technique for creating and printing 3D bone models. This method can be fully utilized to create customized grafts that are identical in shape to the bone cyst.

Keywords: bone cyst, additive technologies, 3D technologies.

Introduction

Bone cysts (CC) are benign neoplasms that occur in bone tissue. They are most common in children (85% of cases) aged 5 to 15 years. CC ranks third in frequency of occurrence among all primary bone formations. The lesion can develop in any bone of the skeleton, but most often CC is localized in the proximal humerus (more than 50%) and femoral (25%) bones [2].

Despite the fact that several theories have been proposed to explain the development of bone cysts, the exact causes of their occurrence have not been fully studied.

Although bone cysts are usually benign, they can cause pain, bone deformity, and even fractures. In some cases, cysts can degenerate into malignant tumors.

Also, complications of this pathology are pain, bone deformity, and pathological fractures [15].

The only effective method of treating a bone cyst is surgical treatment. The most proven method is curettage of the cavity or radical excision of the cyst with replacement of the resulting defect. To date, the choice of material for bone grafting is extensive. Thanks to the ongoing research, the scientific community is offering more and more innovative, affordable, easy-to-use and effective materials for filling bone defects. Thus, one of the fairly developed areas in this field is the use of additive technologies in preoperative planning and modeling of bone defects.Modern 3D modeling capabilities in the arsenal of orthopedists make it possible to get a detailed idea of the structure and location of the cyst. This helps to plan a more accurate and less invasive operation [17].

The use of 3D-printed navigation templates and implants makes it possible to improve the accuracy and safety of the operation, as well as reduce the time of its implementation, which has a positive effect on the outcome of treatment due to a reduction in the surgical load and complete anatomical bone restoration [14]. Such technologies have been actively used over the past 10 years in many countries, including Russia [3]. The novelty of the research is due to the variety of software tools and the variety of materials used in additive technologies, as well as various applications of 3D modeling in operational techniques.

As part of this work, preoperative planning and modeling of a bone cyst of the upper third of the humerus of a 13-year-old patient was carried out using 3D-Slicer and Rhinoceros programs.

According to the information available to us, there has never been a study using this software in 3D modeling of bone cysts.

The purpose of this study is to explore the possibilities of using 3D technologies in preoperative planning and surgical treatment of solitary bone cysts.

This work is part of a study on the development and application of bone-plastic material with the addition of bone allograft, prepared using the Marburg bone bank technology. This type of allograft was chosen due to its proven clinical effectiveness both in emergency traumatological operations with a bone defect and in orthopedic restoration of bone integrity [1].

As part of this work, it is extremely important to obtain a detailed impression of the inner wall of the cyst in order to further fill the model with bone-plastic material and form a so-called primary bone filling. In the future, it is planned to develop a method for the surgical treatment of bone defects using pre-prepared bone fillings.

Materials and methods

We conducted a simulation of a solitary cyst of the proximal humerus of a 13-year-old patient.From the patient's medical history, the symptoms of the cyst were not noted, and therefore the initial diagnosis of the cyst occurred with a pathological fracture, which was noted a year before the treatment. After consolidation of the fracture, surgical treatment of the bone cyst in the volume of scraping the walls and filling the cyst with bone allograft was carried out as planned. During a follow-up examination, a recurrence of the cyst was noted a year later. Based on the CT scan of the shoulder joint at the time of diagnosis of recurrence, it was decided to simulate a cyst. The 3DSlicer program, version 5.6.2, was used for this purpose.

The 3D Slicer used in this study is a free, open source medical image processing software that works seamlessly on a personal computer and is compatible with various systems[8]. It allows you to significantly reduce the cost of medical services and is convenient for use in clinical research.

The first version of Slicer software was presented by David Goering in 1999 as part of his master's thesis at the Massachusetts Institute of Technology [9] It was based on the developments of MIT research groups and the Laboratory of Surgical Planning (SPL) [11]. Later, Steve Piper became the chief architect of the project and led its transformation into a full-fledged software package.

Since 1999, Slicer has been continuously developing under the leadership of Ron Kikinis in the SPL. Today, professional engineers, algorithm developers and scientists from various fields are working on its creation. IsomicsInc., Kitware Inc. and GE Global Research are also involved in the development process, as well as the Slicer user community.

Slicer was originally conceived as a system of neurosurgical guidance, visualization and analysis [9, 16]. Over the past decade, it has evolved into an integrated platform that is used in various clinical and preclinical studies, as well as for image analysis unrelated to medicine [11].

The initial processing was carried out in the Paint 3D application, as in the most accessible and widespread software for working with 3D models.

Paint 3D is a raster graphics editor and a program for 3D modeling and printing, introduced in the Windows 10 Creators Update. Designed by LIFT London Studio. Paint 3D includes the functions of the Microsoft Paint and 3D Builder applications, combining an easy hybrid 2D-3D editing method that allows users to select various shapes from the application, their personal computer [13].

With the help of this program, the cyst model was divided into two halves for ease of printing and further filling it as a mold for possible plastic materials based on bone allograft, and the dimensions were changed identically to the CT study data.

Subsequent processing was carried out in the Rhino® program (V 6.0 SR 23, Robert McNeel&Associates) - engineering software for 3D reconstruction of surfaces.

It is mainly used in industrial design, architecture, ship design, jewelry and automotive design, CAD/CAM design, rapid prototyping, reverse engineering, as well as multimedia and graphic design.

The model created in Rhino demonstrates NURBS surfaces (Flamingo rendering).

Rhino specializes in NURBS modeling. Plugins developed by McNeel include Flamingo (retrace rendering), Penguin (non-photorealistic rendering), Bongo (animation) and Brazil (complex rendering). There are over a thousand third-party plugins for Rhino. As with many other modeling programs, Rhino has its own scripting language based on Visual Basic, and the SDK allows you to read and write files directly [10].

Results

CT images in DICOM format were used in the simulation. The dimensions of the inner walls of the cyst are shown in Figure 1.

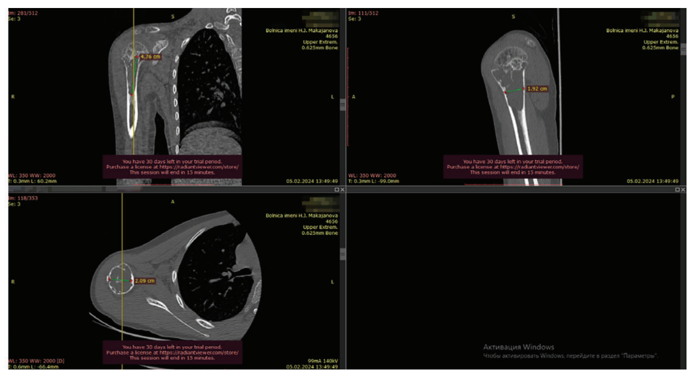

Figure 1 – Dimensions of the inner walls of the cyst on CT scans

Using the Thresholding tool from the Segment Editor set, the bone part of the images was selected directly. The presence of this tool helped to quickly separate the soft tissues that are not applicable for research on all layers, creating a three-dimensional model of all the bones available on the slices. The result is shown in Figure 2.

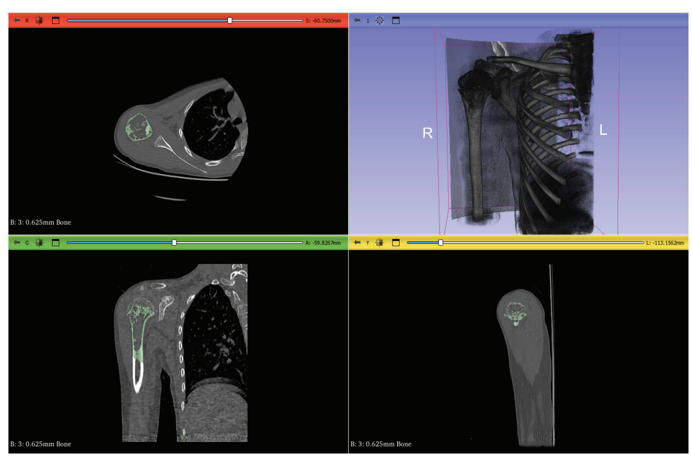

Figure 2– Screenshot of working in 3D Slicer

Next, using the Scissors tool from the same set, the scapula, clavicle and ribs, as well as the distal humerus, were isolated and removed. Thus, a 3D model of the proximal humerus with an existing cyst was obtained, which was exported in stl format. For greater printing convenience, the resulting sample was divided longitudinally into two parts in the Paint 3D program. The result is shown in Figure 3.

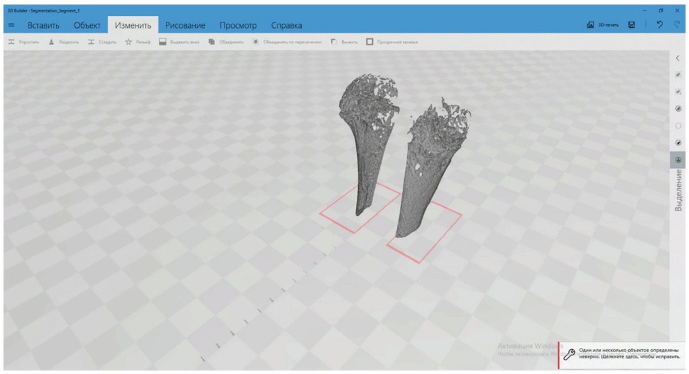

Figure 3 – 3D model of the proximal humerus

This model was printed by FDM printing on a commercial basis in the company "3DStudio" with white ABS plastic. The result is shown in Figure 4.

Figure 4 – Printed 3D model. ABS, FDM printing

As you can see, the printed model is well suited as a training material and as a sample for preoperative planning. However, for filling the mold with bone plastic material, it cannot be called successful due to the difficulties with filling voids and holes formed during the printing of growth zones. Thus, there was definitely a need for further processing with a detailed isolation of the cyst cavity itself and its separation from the cavities of the growth zones where possible.

In this connection, further, also on a commercial basis, the post-processing of the model in the Rhinoceros program was carried out by 3DStudio with further printing by FDM printing with PLA plastic. Due to the characteristics of the selected material, the sample turned out to be more flexible, easily removed from the frozen biocomposite without violating the integrity of the structure, preserving all the details of the inner surface of the bone cavity. The visually printed model is shown in Figure 5.

Figure 5 – Printed 3D model. Thermopolyuretan, FDM printing

Discussion

In this case, the demonstrative effectiveness of the proposed method is clearly visible.The resulting sample reflected all the irregularities and protrusions of the inner wall of the cyst, which, in fact, was a cast of the inner cavity of the cyst. The possibilities of visualization, analysis and processing of CT images available to orthopedists with the transformation of the latter into a 3D model are also clearly demonstrated.

However, given the young age of the patient and the presence of growth zones, the resulting sample is not suitable for the manufacture of adequate replacement material during preoperative planning.

It should be noted here that more detailed processing is possible only in 3D engineering design programs that require additional skills. This may be a difficulty for orthopedists planning surgical treatment with further filling with bone-plastic material or any similar technique involving the formation of a kind of "bone filling".

Despite this, the primary printed sample of a bone cyst is quite suitable for practicing the technique of scraping the walls of the cyst or completely removing the necessary area with the formation of individual tools and templates. Prepared guide templates are used to resect the required area both in the recipient's bone and in the donor allograft. This technique is quite actively used in Europe [5, 12, 4] and in mainland China [18, 7, 6]. The authors also note the disadvantages of the chosen technique, such as a large traumatization of the patient during surgery, a long period of rehabilitation, the need for a large amount of donor material and premature lysis of the allograft, leading to instability and rejection of the transplanted area.

The technology we have in development eliminates the above disadvantages due to the fact that the filling of the scraped cyst cavity occurs evenly, without damage to the cortical bone. The presence of an additional adhesive in the bone-plastic material makes it possible to solve the issue of early lysis of allograft. To date, in parallel with the work described above, a search is being carried out for a suitable adhesive composite and its optimal concentration in combination with bone allograft for sufficient stimulation of bone resorption.

Conclusions

The results of the work have shown the accessibility and simplicity of the technique of forming and printing 3D models of bone defects in the preoperative planning of their surgical treatment. This technique can be fully used to form customized grafts identical in shape to a bone cyst. This technique aims to obtain a negative bone cavity with a detailed repetition of the irregularities of the inner wall and volume of the cavity for the preoperative formation of a positive bone cyst from the original biocomposite. This study requires further work in terms of finding the optimal composition of the biocomposite and preclinical studies.

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