Three-dimensional printing of orbital computed tomography scan images for use in ophthalmology teaching

Impressão tridimensional de imagens médicas de tomografia computadorizada para uso no ensino de oftalmologia

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ABSTRACT

Introduction: The use of tridimensional (3D) printing in healthcare has contributed to the development of instruments and implants. The 3D printing has also been used for teaching future professionals. In order to have a good 3D printed piece, it is necessary to have high quality images, such as the ones from Computerized Tomography (CT scan) exam, which shows the anatomy from different cuts and allows for a good image reconstruction.

Purpose: To propose a protocol for creating digital files from computerized tomography images to be printed in 3D and used as didactic material in the ophthalmology field, using open-source software, InVesalius®, Blender® and Repetier-Host©.

Methods: Two orbit CT scan exam images in the DICOM format were used to create the virtual file to be printed in 3D. To edit the images, the software *InVesalius®* (Version 3.1.1) was used to delimit and clean the structure of interest, and also to convert to STL format. The software *Blender®* (Version 2.80) was used to refine the image. The STL image was then sent to the *Repetier-Host©* (Version 2.1.3) software, which splits the image in layers and generates the instructions to print the piece in the 3D printer using the polymer polylactic acid (PLA).

Results: The printed anatomical pieces printed reproduced most structures, both bone and soft structures, satisfactorily. However, there were some problems during printing, such as the loss of small bone structures, that are naturally surrounded by muscles due to the lack of support.

Conclusion: Despite the difficulties faced during the production of the pieces, it was also possible to reproduce the anatomical structures adequately, which indicates that this protocol of 3D printing from medical images is viable.

RESUMO

Introdução: O uso de impressão em 3-D na área da saúde tem contribuído para o desenvolvimento de instrumentos e próteses. A impressão 3-D tem sido usada para o ensino de futuros profissionais. Para se alcançar uma boa peça em 3-D, é necessário ter imagens de alta qualidade, como aquelas geradas pelo exame de Tomografia Computadorizada (TC), que mostra a anatomia sob diferentes cortes e permite uma boa reconstrução de imagem.

Objetivo: Propor um protocolo para a criação de arquivos digitais a partir de imagens de tomografia computadorizada a serem impressas em 3-D e usadas como modelo de material didático oftalmológico usando software de código aberto, InVesalius®, Bender® e Repetier-Host©.

Métodos: Foram utilizadas imagens em formato DICOM provenientes de dois exames de tomografia computadorizada de órbitas para a impressão tridimensional. Para manuseio das imagens, foram utilizados o InVesalius®, versão 3.1.1, para delimitar e limpar a estrutura de interesse e também para converter em formato STL. O Blender®, versão 2.80 foi usado para refinamento. A imagem em STL foi então enviada para o programa Repetier-Host, versão 2.1.3, que divide a imagem em camadas e gera as instruções para impressão da peça em ácido polilático na impressora tridimensional.

Resultados: As peças anatômicas impressas reproduziram de forma satisfatória a maioria das estruturas ósseas e musculares. No entanto, houve dificuldade durante a impressão das estruturas ósseas menores, como perda de estrutura óssea pequena, que não possuíam sustentação, por serem envoltas pelo músculo.

Conclusão: Apesar das dificuldades encontradas na produção dessas peças de estudo, foi possível reproduzir estruturas com fidelidade, indicando que o protocolo proposto viabiliza a impressão de imagens oriundas da tomografia computadorizada para impressão tridimensional.

INTRODUCTION

The field of radiology has undergone a major evolution in the last century. The development of digital technology equipment for diagnostic procedures has improved the image quality, providing greater precision in diagnostics and, consequently, in treatment and life expectancy.[1] It is important for the health care professional to analyze images that contain the anatomical or pathological structures and metabolic activity of the region under study. The purpose of medical images is to assist in the diagnosis and to provide material to monitor treatments.[1-5]

The acquisition of medical images has to follow protocols depending on how the image is acquired and the processing it will undergo after its reconstruction. After acquiring the digital image (raw image), the acquisition software automatically processes it. Thus, each region of the image can be edited and have a different grey tone value.

The computed tomography (CT) image formation process is divided into two phases, data acquisition and image reconstruction. The first phase comprises the basic operation of the CT scan, while the second is the conversion of the captured data into an image.[6] The standard Digital Imaging and Communications in Medicine (DICOM) was created to homogenize the processing and formatting of images and printing.[7] The DICOM standardizes the images of all types of exams (CT, magnetic resonance, radiography, ultrasound), storing them in a single format. This enables the exchange of information.

The images from the CT scan have more details when compared to conventional radiography because the CT scan ones can be reconstructed in several planes. The CT scan images allow contrasting any lesions with the other structures of the orbit, for example.[8] The CT scan has been considered the basic method of orbital imaging semiology due to its ability to display the bone structure in detail and provide accurate information about all orbital structures.

With the increasing development of technology, it would not be unexpected to witness the development of a printer that prints objects in three dimensions (3D).[9] Three D printing enabled the creation of custom objects from a virtual project. This technique consists of the automated construction of solid objects, layer by layer, with a certain type of material, from a digital file with the 3D image of the object.[3,10,11]

Medical applications for 3D printing have expanded in recent years and it is expected to revolutionize health by providing many benefits, such as customization of medical products, medicines, and equipment, increasing the effectiveness of known procedures, and increasing reproduction of innovative techniques.[10,12] Examples of medical uses of 3D printing are the manufacture of living tissues and organs, the creation and customization of prostheses, implants, and anatomical models for pharmaceutical use[12].

The materials used to print in 3D are called filaments, and, among these, the most known and used is the polylactic acid (PLA), a bioplastic polymer that has good malleability, lightness, ease of processing, and a variety of colors.[13] The 3D printer prints from a 3D digital file that must be in the stereolithography (STL) format, which is a format that is compatible with various digital design software and widely used for rapid prototyping or any other form of computerized manufacturing.

When the image is in STL format, it can be processed by Cura slicing software (Ultimaker), which is responsible for dividing the solid into layers, leading it to be printed layer by layer until it shapes the final object. For that, it is necessary to set up the software in advance with the information about the maximum printing area, the thickness of the filament, the desired thickness for each layer, the printing speed and the codes to start and stop the machine. By combining and using the correct parameters, it is possible to obtain a piece printed in 3D that is faithful to the original image.[13]

As additive manufacturing is being used in the medical field, several ideas and projects have emerged in different areas, including the visual sciences field, where prototypes of instruments, implants, and educational models have been created at an accessible cost.

Based on this, we propose a protocol for using 3D printing to enhance teaching and promote the 3D printing technology in health care.

METHODS

This study was approved by the ethics committee of the Universidade Federal de São Paulo number 1225/2019.

Computed tomography scan images of the orbits in the DICOM format were acquired from two exams performed at the Department of Diagnostic Imaging at Hospital São Paulo of the Escola Paulista de Medicina of the Universidade Federal de São Paulo.

The software InVesalius, version 3.1.1, developed at the Renato Archer Technology and Information Center (CTI Renato Archer), and the software Blender, version 2.80, both free and licensed by the General Public License, were used to edit the images and convert planar images into three-dimensional images.

The 3D models created from the CT scan images were saved in the STL format to be transferred between the software. The 3D printer Hadron Lite and PLA plastic filaments were used to print the anatomical parts.

The protocol followed to elaborate the virtual orbit model for 3D printing was divided in four phases.

Quality and acquisition of computed tomography scan orbit images

The quality of the image acquisition will influence the quality of the 3D reconstruction of the piece. It is ideal that during the exam there should be a minimum of noise and movement artifacts, as this directly influences the manipulation and printing of the image in three-dimensional models.

Evaluation of anatomical structures

The exam should be performed using the highest image resolution and the thinnest cut available, usually 1mm. The thickest the cut, the worse will be the image quality, making it difficult to produce a good 3D image to be printed and possibly missing some important anatomical structures of the orbit.

Delimiting and cleaning the virtual model using the software InVesalius and Blender

The CT images were imported to the InVesalius software. Before selecting the regions of interest, it was important to understand the grey scale representation of the exam. The lighter shades of grey represent the denser tissues, while the darker shades represent the less dense tissues.

Masks are created to select different regions, which represent structures by their density, making it possible to select bone, muscular or other tissues. In this scenario, we selected the bone structure that can be seen layer by layer in the axial, coronal and sagittal planes, as seen in the figure 1.

After choosing which anatomical structure will be worked on, we start delimiting the regions that are relevant to the project and excluding the other regions. After the virtual model is completed, the export feature is used to save the file in STL format so that further editing can be performed in the Blender software, such as eliminating image-damaging artifacts and refining the virtual model for better reproduction by the 3D printer.

Preparation for 3D printing

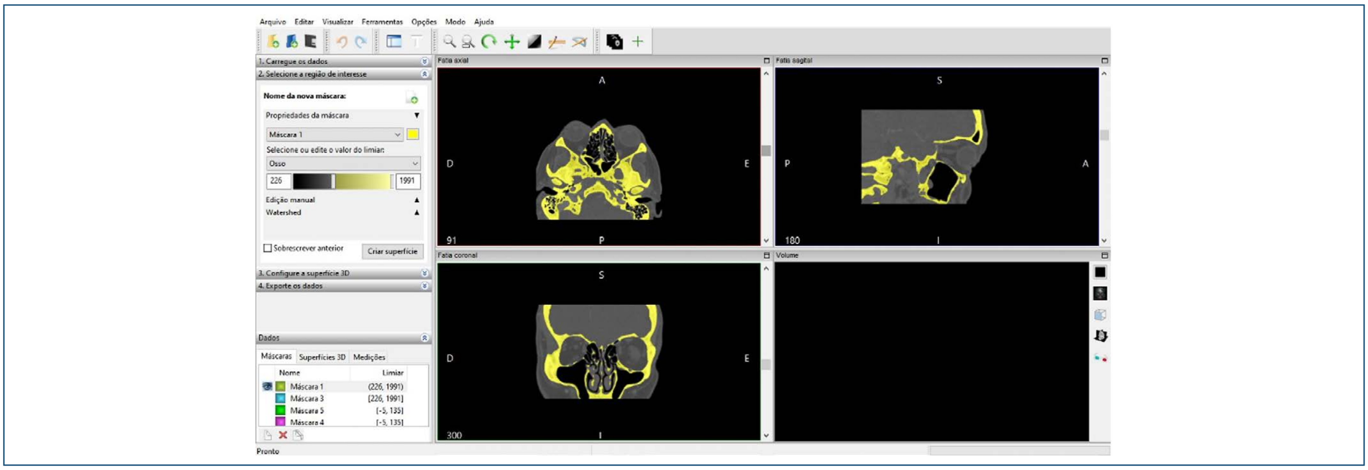
The software Repetier-Host is responsible for converting the STL file into an archive with instructions for the 3D printer to perform as programmed. Features such as speed, type of support and thickness are defined using this software.

In this project, we used the thickness of 0,2mm, a layer slightly thicker than a strand of hair. These features vary according to the type of material and the 3D printer in use.

The 3D printer we used was the 3D Hadron Lite. The extruding part of this printer is 0,2-mm thick, which results in a good printing quality. We used a temperature of 200ºC, adequate for the PLA material.

The support structure was created as lines, since it facilitates the removal afterwards and reduces the risk of damaging the final piece. However, line support structures also have a smaller contact area with the piece, reducing support and consequently causing a small quality loss in structures with more angles.

During the printing process, it was necessary to use active forced ventilation to enable faster solidification of the material after extrusion, avoiding deformations and speeding up the printing process.



Source: Modified from the software InVesalius (https://invesalius.github.io).

Figure 1. Selection of the bone structure.

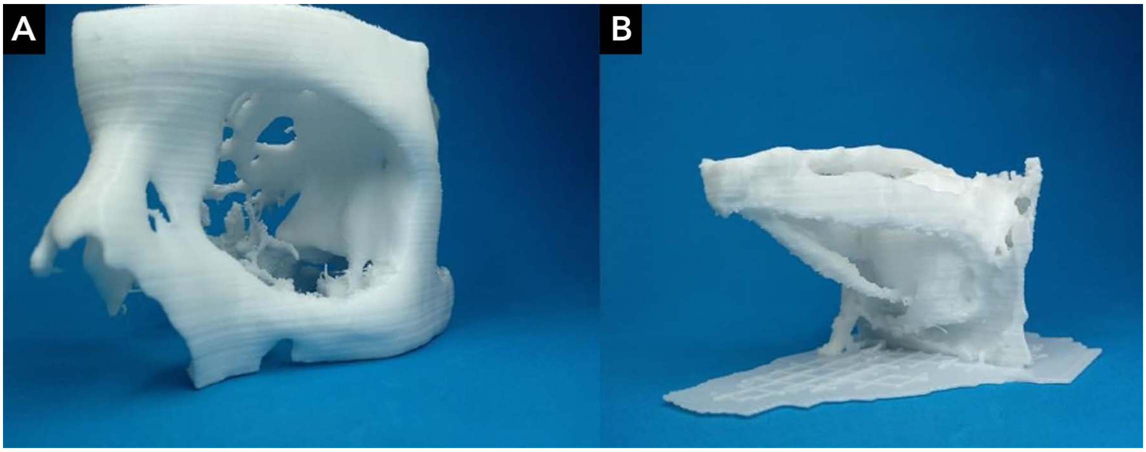


Figure 2. Three-dimension structure (A) of the bone tissue, (B) of the soft tissue.

RESULTS

The printed anatomical pieces reproduced most structures, both bone and soft structures, satisfactorily, as shown in figure 2. However, there were some problems during printing, such as the loss of small bone structures that are surrounded by muscles and lack other support. These parts ended up being lost when the line supports were removed.

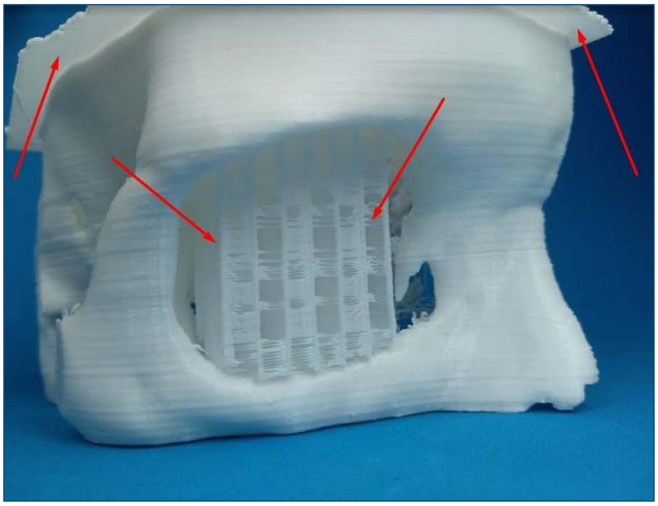


Figure 3. Printed piece with the line support indicated by the arrows.

The support used for printing is slightly less resistant compared to the printed parts, facilitating its removal. Even so, there is some loss of structures that are very close together, and there are some remains of the line support left because they are in very narrow places that prevent their removal, as seen in figure 3.

Figure 4 shows that the quality of the anatomical models printed can vary according to the software used for its refinement, even when using the same type of material.

The use of the Blender software to refine the virtual model significantly improves the quality of printing, because it polishes the piece, bringing the piece a little closer to the real anatomical structure.

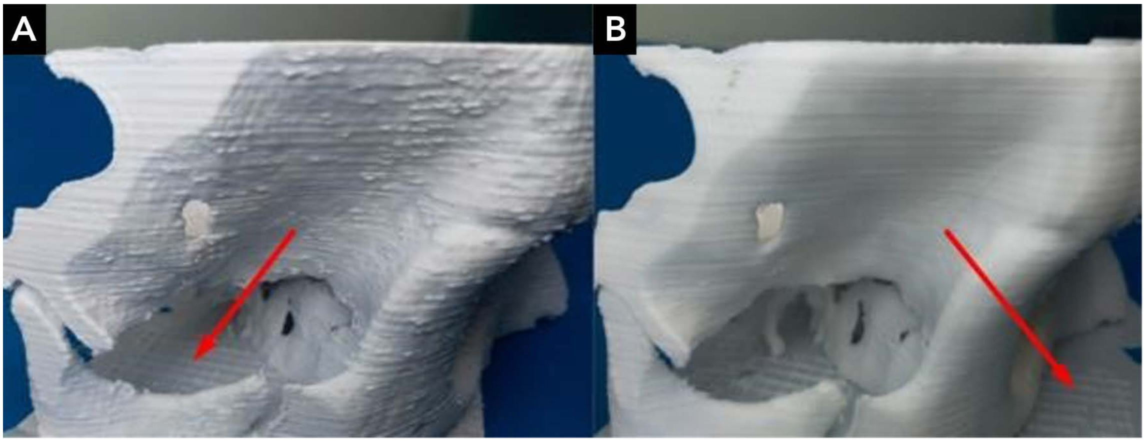
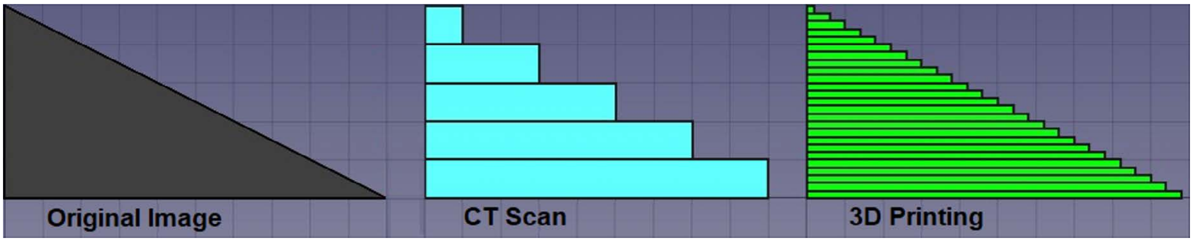


Figure 4. Printing of the piece using (A) InVesalius software without any refining, (B) after refining with the Blender software. It is possible to observe the support parts left in the piece.



CT: computed tomography; 3D: three dimensions.

Figure 5. Comparison among the thickness of the computed tomography scan image (1mm), the three dimension printing (0,2mm) and the original image that is 5x10mm.

Since the CT scan makes 1mm slices, it produces a kind of "step" in the model during the transition from one cut to the next, making it look rougher and coarse.

The thinnest slice provided by the CT scan is 1mm, and the printer has a 0.2mm extruder nozzle, which enabled the creation of 5 layers for each cut of the CT scan. The Blender software helps to smooth the structures of the CT scan images so that it is possible to recover part of the real structure, and then generate an image with higher definition, as shown in figure 5.

DISCUSSION

The image acquiring method of the CT scan will influence the quality of the 3D image created to be printed. It is important to have thin cuts, of 1mm, to allow for a better-quality 3D reconstruction of the image. [6] During the CT scan examination, it is important that the patient does not move, because the movement can generate artifacts in the images acquired, making the images blurry and not adequate to be used for the 3D image reconstruction process.

The InVesalius is a software especially used to work with medical images. Its use enables the refining of a predetermined region into a three-dimensional image to be printed. This is made through the selection of darker and lighter pixels, following a grey-scale and reconstructing the image. It is worth noting that the selection of regions that are not of interest also occurs, and that is why it is important to use the Blender software afterward. This software will virtually clean the image, allowing for a printing process without a significant quality loss.

The process of delimiting and cleaning the image requires time, experience, and knowledge about the anatomy of the region being studied. The orbital region is very complex and composed of many structures, so it is important for the person who is working with the images to have enough knowledge to identify the small structures that could otherwise be excluded inadvertently.

The printing speed was reduced to increase the quality of printing in order to maintain resemblance with the medical image, preserving the details and getting the most out of the 3D printer capacity. The 3D printer and the material we used in this project have an accessible cost, which explains a more modest quality of printing.

The challenges encountered during the printing process were the misalignment of some layers, the fall of supports, the fall of regions lacking enough support and "stringing", which is a known process in 3D printing. Stringing is the creation of filament fillets during the movement of the 3D printer through transverse parts of the piece. This leaves imperfections on the surfaces and also makes it difficult to clean.

Some problems are commonly faced while working with 3D printed pieces. One of the problems is the difficulty in removing the support structures from the piece. The support structure is necessary when printing pieces that have a slope closer to the horizontal line or that are suspended, unconnected to the main piece. The removal of the support structure may cause damage and loss of parts if the support firmly adheres to the piece.

Another difficulty may be the opposite reason, the lack of supports due to avoiding the placement of more supports to prevent damage during their removal. In this case, structures may collapse, especially in areas with more horizontal inclinations, which can cause the loss of relevant parts of the printed piece.

The use of water-soluble material for the support parts would be ideal because it makes it easier to remove the support parts, with less risk of loss of small structures and damage to the piece. The water-soluble material has a higher cost and requires a 3D printer that supports the use of two filaments simultaneously, which makes this option less accessible. The support removal in this project was manual with the aid of tools due to the material resistance during the removal.

The quality and resistance of the printed piece were considered adequate. The good resistance was due to the configuration implemented for printing, increasing the density of the piece. These configurations also impacted the printing time, varying from 3 to 8 hours of printing time depending on the structure bring printed, being soft tissues faster and bone structures longer.

Despite the problems encountered during the printing process and the removal of the supports, the anatomical piece printed in 3D managed to reproduce well most of the essential structures of the orbit needed for the student's learning.

CONCLUSION

The medical images printed in three dimensions resembled well the actual orbital structure. This indicates the viability of this protocol to produce more three-dimensional printed pieces from computed tomography scan images with a didactic goal.

Using this same protocol, it will likely be possible to print different pieces from other anatomical areas. It is important to recognize that it is still not possible to print in three dimensions print a piece that is 100% equal to the actual anatomical structure, but the resemblance is probably enough to use it as an additional resource for teaching purposes.

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