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EDUCATION & TRAINING

Different Digitalization Techniques for 3D Printing of Anatomical Pieces

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Abstract
The use of different technological devices that allow the creation of three-dimensional models is in constant evolution, allowing a greater application of these technologies in different fields of health sciences and medical training. The equipment for digitalization is becoming increasingly sophisticated allowing obtaining three-dimensional which are more defined and similar to real image and original object. In this work, different modalities of designing 3D anatomical models of bone pieces are presented, for use by students of different disciplines in Health Sciences. To do this we digitalized bone pieces, with different models of scanners, producing images that can be transformed for 3D printing, with a Colido X 3045 printer by digital treatment with different software.

Keywords Teaching anatomy · 3D printing · Skull model · Additive manufacturing

Introduction

Teaching anatomy in the faculties of Health Sciences has undergone changes due to the incorporation of new technologies in their learning [1]. The creation of 3D models using 3D printers and their incorporation into teaching in recent years has allowed students have greater access to anatomical pieces for learning [2, 3]. 3D printers have allowed, in an accessible way economically and temporally, obtain physical objects starting from a digital object [4]. The appearance of different free access software, applied to the hardware, has allowed a greater diffusion of these 3D models. It has become possible not only to replicate an anatomical model but also to be able to study, copy, modify and distribute more identical copies of this model, thus allowing greater diffusion and access to this technology [5, 6]. The applications of 3D printing are very varied from the printing of industrial parts [7] to their use in medical fields [8, 9].

The obtaining of these 3D models is preceded by processing of images created by scanners. Images were transformed into models using a software CAD (Computer Aid Desingn) and exported to .stl format for 3D printing. With a program for machine code generation, the trajectory of movement by layers and extrusion commands are created in GCode format, which is read by a software that allows the printer communicate with the image in the computer and following the instructions of the GCode initiate the movements to create 3D model [10].

The scanners used in creating the images of the real pieces are becoming increasingly advanced allowing more precise images. Before object scanning, factors such as the distance to be scanned, preparation of the anatomical piece and the position from which the images will be taken should be optimized. The captured images are processed including image alignment, noise elimination, removal of unwanted and null data and optimization of cloud points density for the selection of best points in order to create precise models [11–14]. In this work our objective was to present different modalities and techniques of digitalization of an anatomical image, using diverse scanning devices; with the purpose to achieve anatomical models by additive manufacturing using 3D printers to enable their subsequent use in medical training.

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Methodology

The 3D models obtained in this work, which will be used for the study of anatomy by Health Sciences students were previously scanned, using different scanners for digitalization and post-processing to obtain high quality models and database to generate layering codes for posterior 3D printing with an FDM printer (Colido X 3045). We will now describe different modalities of obtaining anatomical images using different scanning devices.

CT Aquileon 64 CFX scanner

A computed tomograph model Aquileon 64 CFX (Fig. 1) was employed as a first anatomical imaging system, allowing obtaining versatile and high quality sectional images. The relationship between the signal and noise determines image quality. With each rotation, 64 simultaneous layers of 0.5 mm are acquired, providing real-size images. A low resolution of contrast was employed in order to obtain a resolution superior than 35 mm for small details.

The creation of 3D models are preceded by processing of images from the scanner, in DICOM format (Digital Imaging and Communication in Medicine), with 3DSlicer software, which aligns and resizes the images for their homogenization. We obtained isotropic images with 1 mm voxels of same size in all dimensions. Posteriorly, the polygonal meshes were read by the layering software that generated the code required for 3D printer.

Artec Eva hand-scanner

Another modality of digitalization of bone pieces was through the use of handheld scanner, Artec Eva (Fig. 2), which allowed obtaining high resolution 3D images of scanned anatomical structures. The scanner provides 0.5 mm resolution with 0.1 mm dot accuracy, processing capacity of 4,000,000 triangles/GB Ram, data acquisition speed of 2 million points/s and 1.3 mp of texture resolution.

Fig. 2 Hand scanner model Artec Eva used for the digitalization of bone pieces

This scanner allows observing the anatomical model in real time while working in the incorporated fusion mode (Fig. 3) and also aligns the scanned data with great precision. The software that incorporates this Artec Studio 3D scanner is user-friendly and allows it to be easily integrated with the Systems Geomagic Desing X 3D computer-aided program. This software supports importing more than 60 formats and combination of data obtained with the scanner, which allows creating solid editable models. By digitalizing the object, a point cloud is obtained, posteriorly treating by Geomagic Desing X transforming the point cloud by triangulation into a polygonal planes mesh, which is treated by adjusting dimensions, eliminating damaged areas to obtain high quality image. After finishing the meshing process, we proceeded to create the model in STL format (stereoLithography) that passed to the layering program, CURA, in order to create the layering codes read by the 3D printer. For digital processing of scanned anatomical piece, Dell Latude E5440 model notebook with the corresponding software was used as a workstation (Fig. 3).

Fig. 1 Aquileon 64 CFX computerized tomograph for scanning of anatomical parts

Fig. 3 Digitization of bone pieces with Artec Eva model hand scanner and graphic workstation

Fig. 4 Arm Scan Platinum model scanner digitalizing the jaw

Faro Arm Scan Platinum

Another technological procedure used for the digitalization of bone pieces was Faro Arm Scan Platinum (Fig. 4). It is characterized by its flexibility and precision, allowing an amplitude of movements to be able to digitalize all the faces of anatomical piece without making any contact with it at a performance of 14,000 points/s. The resolution and high precision of +35 μm allows a high performance in the acquisition of point cloud referenced in a coordinate system, representing the anatomical piece with great accuracy.

The point cloud is then transferred to Geomatic Design X software (Fig. 5) which through a triangulation process, leads to the creation of mesh optimized by eliminating surface noise, closing holes, softening faces to create the model in STL format read by the 3D printer for generating the model by additive manufacturing.

Faro edge scan arm HD

The highest scanning accuracy was achieved with the Faro Edge Scan Arm HD scanner (Fig. 6), which presented high accuracy with a scan ranging up to 45,120 points/s. The quality of point cloud was much superior to that obtained by previous scanners. This device has the smallest hand-piece on the market, which offers great flexibility due to its arm and possess a great aptitude for contactless scanning of the piece and probing digitalization. Probing digitalization allows scanning the geometric areas or reference coordinates more accurately and precisely, scanning the areas that require the greatest number of points. This point cloud is treated with the Geomatic Design X software to create the mesh, which after processing is transformed into the STL format, so that it can be printed in 3D following the procedure mentioned previously.

CURA software (Ultimaker house) was employed (Fig. 7) to generate and optimize the code for division into layers to be read by 3D printer using the models obtained in *.stl format. The codes obtained in the data files *.gcode incorporates the trajectory for the deposition of fused material and its extrusion parameters for additive fabrication. The FFF (fused filament

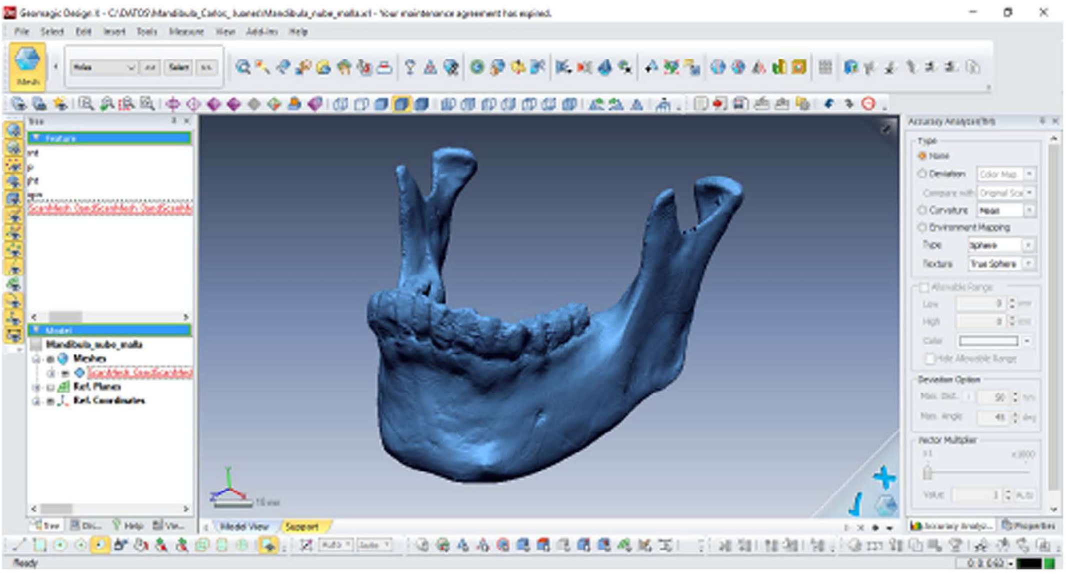

Fig. 5 Interface of the Geomagic Design X software that allows the treatment of the scanned image

Fig. 6 Faro Edge Scan Arm HD model arm scanner

fabrication) printer used was the ColidoX 3045 model (Fig. 8).

PLA (Polylactic Acid), a biocompatible, recyclable and cost-effective material was used as printing material which gave the 3D model required hardness and strength suitable for use by anatomy students.

The characterisitics of the imprinting profile for this material and the machine used are given in the Table 1.

Results

After 3D printing, different anatomical bone pieces have been able to assess and analyze different morphological details of the printed bones as a whole. The skull is usually a much deteriorated structure in medical schools laboratorics. Therefore, in this work a 3D model has been created by employing additive manufacturing, presenting each detail of the bone piece (Fig. 9). The high quality model will allow anatomy students use it for better learning (Fig. 10).

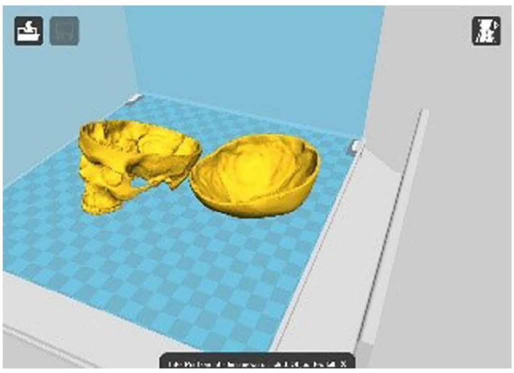

Fig. 7 CURA software interface to create STL formats

Fig. 8 Printer model ColidoX 3045, used for our study

The reliability of the anatomical data provided by the scanners depends on two main values: resolution and accuracy. The resolution is determined by the amount of details that can be seen from the image and is characteristic of each scanner. The accuracy is measured for a specific sample and tells us to what extent the value taken is true. The arm scanners allowed greater mobility and approach to the piece during scanning, enabling greater optimization of the image and provide better point cloud. The Faro Edge Scan Arm HD scanner allowed both scanning modes, with and without contact with the piece, obtaining a high resolution and quality image.

Discussion

The 3D images allow the visualization of the organs and bone pieces, valuing spatial relationships with other neighboring body structures [15]. Likewise, the 3D anatomical models, obtained by means of 3D printers will facilitate the access of

Table 1 Characteristics of printing profile

PLA material (diameter in mm)	1.75
Layer thickness (mm)	0.1
Extruder (mm)	0.4
Printing density (%)	25
Thickness perimeter of closure of each layer (mm)	1.6
Closure and base thickness (mm)	2.4
Temperature (°C)	213
Printing velocity (mm/s)	60

Fig. 9 3D model of the skull printed with polylactic acid (PLA)

the students to the complete osseous anatomical parts, thus supplying the details on the morphological deficiencies and deteriorations found in original structures, which in many cases are found in the anatomical departments [16]. The quality of these anatomical models printed in 3D, is increasing due to the materials used, which are more similar to the real piece and partly to the acquisition of images by means of very precise scanners with increasingly advanced techniques [17–22].

For teaching in faculties, its use has been disseminated in recent times, both in learning and allowing students access to these technologies [23]. In the field of medicine the use of 3D technologies is widespread, there are several fields in which they are useful in the preparation of surgical interventions as well as in the assessment of clinical pathologies [24–26]. In the teaching of anatomy along with using for the learning and training of undergraduate students [16] in the faculties of Health Sciences, these are also being employed in different medical specialties, to mention an important one is surgery [27–29].

Fig. 10 3D model of the jaw printed with polylactic acid (PLA), compared with a real piece

Conclusions

The evolution of the technological means used for the creation of 3D anatomical models, is allowing these devices to generate objects that are more and more similar to the real piece and its use in different disciplines of the health sciences is increasing. The different types of scanners used, for the digitization of anatomical parts and their subsequent 3D printing, have proved to be very effective for the achievement of objectives designed in this work, thus improving the quality of the anatomical parts that are used in the practices of teaching human anatomy in the educational centers; which undoubtedly results in a more productive teaching. Therefore, this joint collaboration between anatomists who know well the morphology of the body part and the industrial engineers, who dispose and handle the technological procedures and software necessary for their development, has led to constitute an excellent working model, for three-dimensional anatomical corporal creations, which are currently being extended to different medical specialties.

Compliance with ethical standards

Informed consent Informed consent was obtained from all individual participants included in the study.

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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