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Article

Use of cone beam computed tomography, a desktop 3D printer and freeware for manufacturing craniofacial bone prostheses: a pilot study.

Utilización de la tomografía cone-beam para la confección de protesis óseas craniofaciales por impresora 3D de escritorio usando programas libres: un estudio piloto.

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Abstract: The aim of this study was to reconstruct missing bone parts using cone beam computed tomography (CBCT), freeware and a desktop 3D printer. **Materials and Methods:** A human skull was used and osteotomies were performed in the frontal process of the zygomatic bone, zygomatic process of the temporal bone and part of the parietal bone. The 3D image was then obtained CBCT and the DICOM file was transformed into STL and exported using *InVesalius* software. Missing bone parts were modeled by overlapping with *OrtogOnBlender* software for later printing using a desktop 3D printer. **Result:** The obtained prostheses had very good adaptation to the missing bone parts. **Conclusion:** It is feasible to make bone prostheses by 3D printing using low-cost desktop printers, as well as the use of free open-source software programs through CBCT.

Keywords: *Cone-Beam Computed Tomography; printing, three-dimensional; prostheses and implants; software; osteotomy; skull.*

Resumen: El objetivo de este estudio fue el de reconstruir partes óseas faltantes usando tomografía computarizada de haz cónico, programas de licencia libre e impresora 3D de escritorio. **Materiales and Métodos:** Se utilizó un cráneo humano y se le realizó osteotomías en la apófisis frontal del hueso cigomático, apófisis cigomática del temporal y parte del parietal. Seguidamente se obtuvo la imagen en 3D por medio de la tomografía cone-beam y se exportó el formato DICOM para STL usando el programa libre InVesalius. Se modelaron las partes óseas faltantes por superposición con el programa libre OrtogOnBlender para su posterior impresión utilizando una impresora 3D de escritorio. **Resultados:** Las prótesis obtenidas tuvieron muy buena adaptación en las partes óseas faltantes. **Conclusión:** Es factible confeccionar prótesis óseas por impresión 3D utilizando impresoras de escritorio de bajo costo, así como la utilización de programas libres de código abierto a través de la tomografía cone-beam.

Palabra Clave: *Tomografía Computarizada de Haz Cónico; impresión tridimensional; prótesis e implantes; programas informáticos; osteotomía; cráneo.*

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INTRODUCTION.

The reconstruction of cranial defects requires great skills on the part of surgeons, who use commercially available materials, sometimes extremely expensive, to be able to correct the function and aesthetics of the missing bone parts.[1] About 20 to 50 million people are injured in road traffic accidents each year, resulting in between 3 to 9 million bone fractures that leave patients with defects.[2]

Maxillofacial reconstruction and cranioplasty are improving thanks to advancing technology that involves a multidisciplinary approach and various medical specialties.[3] There are several rehabilitation techniques and procedures in this field, such as transplantation of autologous or heterologous tissues, as well as the implantation of alloplastic materials, which can be modeled or printed during or before surgery.[4]

Resins, such as polymethylmethacrylate, have been used since 1940 for the reconstruction of cranial bones with good biocompatibility, availability, low cost, strength, resistance, and good moldability.[5]

Rapid prototyping is a technology that has been widely used in the last 10 years to reconstruct missing structures with great precision in oral and craniomaxillofacial surgeries.

Specialized medical reconstruction software has been developed, and training in its use has been carried out so that surgeons themselves can plan and solve their clinical cases.[6,7]

However, specialized software is very expensive and design specialists are required for its use, which in turn increases the costs even more.

Thus, open-source and free-license 3D design software is an alternative to specialized software, producing digital designs with great precision, and with programming that can be adapted to the needs of the specialist.

The aim of this research was to reconstruct missing bone parts using cone beam computed tomography (CBCT), free-license software (freeware), and a desktop 3D printer.

MATERIALS AND METHODS.

Manipulation and visualization of lesions by CBCT

Osteotomies were performed on the left side of the frontal process of the zygomatic bone, zygomatic process of the temporal bone and part of the parietal bone in a human skull (Figure 1A).

Imaging was then obtained using a CareStream 9300 tomograph (CareStream Dental, GB) from the School of Dentistry at Universidad Católica de Santa María, Arequipa, Peru (Figure 1B).

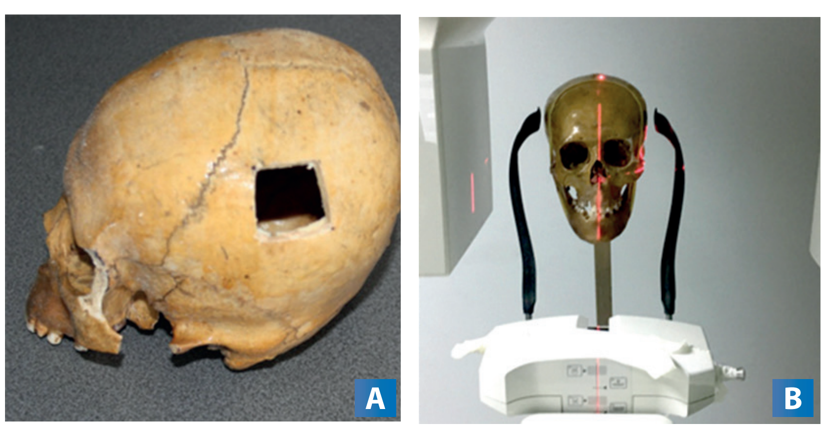
The resulting image was analyzed by the CS 3D Imaging Software (CareStream Dental, GB) to detect the presence of artifacts. Next, the InVesalius software was used to convert the DICOM format to STL.[8]

Prosthetic modeling

To perform the modeling of the prostheses, Ortog-OnBlender, freeware based on Blender, was used, a 3D design freeware created by Cicero Moraes.

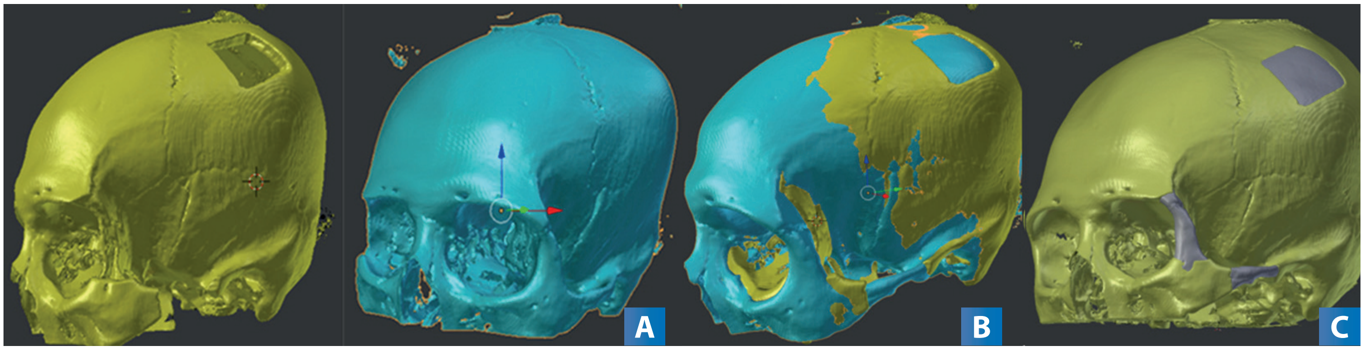
Defects were manipulated and repaired according to Tan,[9] duplicating and mirroring the model (Figure 2A), and superimposing it (Figure 2B). Thus, they were customized, giving them volume, according to the defect, according to the individual characteristics (Figure 2C).

Figure 1. Definition of bone defects and their digital capture using cone-beam tomography.



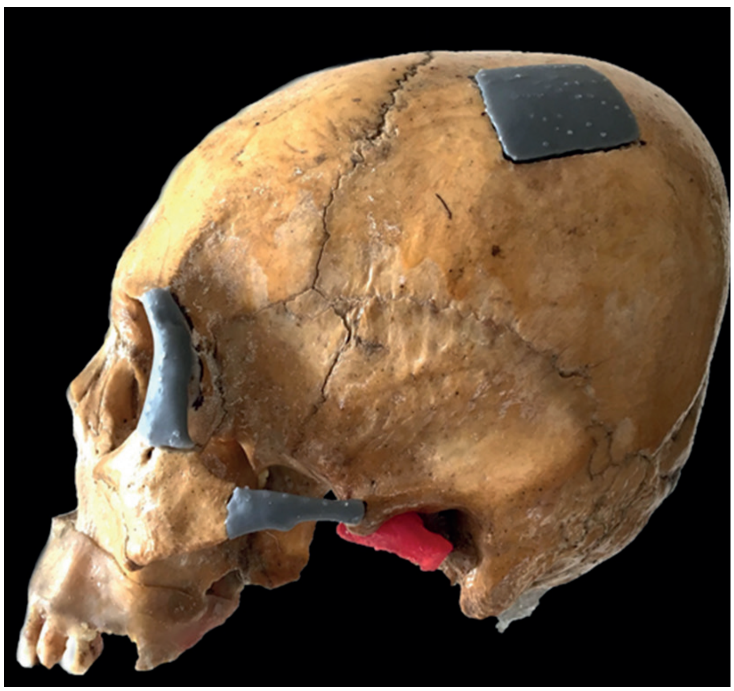
A: Bone defects produced in the frontal process of the zygomatic bone, zygomatic process of the temporal bone and part of the parietal bone. **B:** Obtaining the tomographic image using cone-beam tomography.

Figure 2. Digital image processing and preparation of the prostheses.



A: Duplicating and mirroring of the image in the OrtogOnBlender software. **B:** Image overlapping to digitally cover the defects with the mirror image. **C:** Selection, customization according to the defect and its volume.

Figure 3. Obtaining and fitting the prostheses by 3D printing.



Obtaining the bone prostheses of the frontal process of the zygomatic bone, the zygomatic process of the temporal bone and part of the parietal bone with a high degree of precision.

Printing of prosthesis

The data were exported in STL format for treatment with the PreForm software (FormLabs, Massachusetts, USA), where resin density and printing mode were configured, and then exported to the FormLabs Form 2 3D printer (FormLabs, Massachusetts , USA).

Prosthesis verification

The prostheses were verified by placing them on the defects and assessing their adaptation to the missing bone parts taking into account the perimeter of the defect.[8] Five maxillofacial surgeons participated in this procedure, and provided their opinions on the printings.

RESULTS.

Printing of the prostheses was made with great precision, because the edges of the prostheses fitted perfectly with the bone perimeter of the defects located in the frontal process of the zygomatic bone, the zygomatic process of the temporal bone, and part of the parietal bone (Figure 3).

Likewise, the opinion of the specialists regarding the methodology adopted was positive.

DISCUSSION.

Cranial reconstruction involves the employment of various techniques that use biocompatible resins to rehabilitate missing bone defects. Most of these resins require modeling during their polymerization,[8] making it difficult to customize the prosthesis, from design to completion,[10] which may expose the patient to an infection[11] and increase the length of the surgery.[12]

In the last decade, the design of these prostheses has been produced by computer software,[13] requiring specialized 3D programs and printers whose prices range between US$37,000 and $310,000,[8,14] or commercially available prostheses, such as titanium metal grids, with prices reaching US$10,000,[9,14,15] which make them unaffordable in developing countries.[10]

In this study, the versatility of producing customized prostheses by using low-cost resins, desktop 3D printers, free-license open-source software, and dental CBCT is evidenced. Resin prostheses have a very good adaptation to bone defects. Similar results have been described in the literature using low-cost 3D printers and free open-source software.[1,6-11,16]

The use of software such as InVesalius and Ortog-OnBlender in this study had very good results and provided benefits compared to programs such as 3D Slicer 4.3.2 (Surgical Planning Laboratory) for image segmentation, as well as MeshMixer 2.4 (Autodesk, Inc.) and MakerWare 2.4.1.35 (MakerBot Industries) for 3D modeling; the main free-license software used by Tan.[9] The prosthesis manufacturing technique was performed directly from the tomography data.

This makes it possible to produce bone prostheses before surgery avoiding additional risks of infection and reducing the length of the surgery, compared to the modeling of resin prostheses during the procedure.

The price of the 3D printer used in this study is approximately US$6,000, which is quite reasonable in relation to the current prices of commercial and industrial 3D printers. Likewise, a liter of resin costs around US$150 to $200.

The total amount of resin used for the preparation of the bone prostheses in this study was 75mL, about US$40 worth. In terms of price, the low cost of using desktop 3D printers,[6,7,9,11] has also been documented in the scientific literature, and compared to commercially available titanium,[15] zirconium,[17] and hydroxyapatite[18] implants. Although the resin used for this study was type Gray V4 (FormLabs, Massachusetts, USA) for rapid prototyping, the same company offers the Dental SG resin (FormLabs, Massachusetts, USA), which is biocompatible, allowing bone prostheses made with this resin to be placed directly on the patient after disinfection.[19]

In addition, this printer allows the use of external resins, thus allowing the use of more biocompatible resins. Similarly, the development of implantable medical devices is regulated in Peru by the Peruvian legislation of the Sanitary Directive within the framework of law No. 29459, which establishes that all implantable medical devices belong to Class IV Medical Devices-Critical in Risk Matters.

This is an important issue to review in the legislation of other countries so this type of prosthesis can be made and used.

CONCLUSION.

Taking into account the limitations of this small pilot study, it can be concluded that it is feasible to make bone prostheses by 3D printing using low-cost desktop printers, as well as free, open-source software, by means of cone-beam computed tomography.

Conflict of interests: Authors have no conflict of interest with this report.
Ethics approval: Not necessary for this study
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