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ORIGINAL

Open Educational Resources in 3D format for teaching stomatognathic system anatomy in dentistry: development, implementation and evaluation

Recursos Educativos Abiertos en formato 3D para la enseñanza de la anatomía del sistema estomatognático en odontología: elaboración, implementación y evaluación

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ABSTRACT

Introduction: the COVID-19 pandemic exposed the scarcity of digital and 3D-printed Open Educational Resources (OER) in the Dentistry program at Facultad de Estudios Superiores Zaragoza (FES Zaragoza), UNAM, limiting the teaching-learning process of stomatognathic anatomy.
Objective: to develop 3D-printed models of the maxilla and mandible from real patient computed tomography scans as innovative OERs, assess their educational utility, and document the benefits for dental anatomy teaching.
Method: design thinking approach. DICOM files from two real patients were processed using Materialise Mimics and Blender to generate 3D print files, produced with an Anycubic Kobra Max printer. Four dental interns participated in a theoretical-practical session using the models and evaluated the material through a Google Forms questionnaire.
Results: 100 % of participants found the models easy to handle, interest-generating, conducive to clarifying doubts, and adequate for their didactic purpose. Between 75 % and 100 % correctly identified anatomical structures from all views. Main improvement suggestions focused on color differentiation of structures.
Conclusions: 3D-printed models derived from real patient CT scans are innovative, accessible, and highly effective OERs for teaching maxillary and mandibular anatomy, with potential use across multiple modules of the Dentistry program.

Keywords: Open Educational Resources; Three-Dimensional Models; 3D Printing; Dental Education; Stomatognathic Anatomy; Emerging Pedagogies; Educational Technology.

RESUMEN

Introducción: la pandemia por COVID-19 evidenció la escasez de Recursos Educativos Abiertos (REA) digitales e impresos en 3D en la carrera de Cirujano Dentista de la Facultad de Estudios Superiores Zaragoza (FES Zaragoza), UNAM, limitando el proceso de enseñanza-aprendizaje de la anatomía del sistema estomatognático.
Objetivo: elaborar modelos tridimensionales (3D) impresos de los huesos maxila y mandíbula a partir de tomografías computarizadas de pacientes reales como REA innovadores, evaluar su utilidad didáctica y documentar sus beneficios para la enseñanza de la anatomía del sistema estomatognático.
Método: estudio con enfoque en pensamiento en diseño. Se obtuvieron tomografías computarizadas de dos pacientes reales; los archivos DICOM fueron procesados con Materialise Mimics y Blender para generar archivos de impresión 3D, producidos en una impresora Anycubic Kobra Max. Cuatro pasantes la Licenciatura de Cirujano Dentista participaron en una sesión teórico-práctica con los modelos y evaluaron el material mediante un cuestionario en Google Forms.
Resultados: el 100 % de las participantes consideraron que los modelos facilitan la manipulación, generan mayor interés en el aprendizaje de la anatomía, permiten externar dudas más fácilmente y cumplen adecuadamente su función didáctica. Entre el 75 % y el 100 % identificaron correctamente las estructuras anatómicas desde todas las vistas. Las principales sugerencias de mejora se orientaron al color y diferenciación de estructuras.
Conclusiones: los modelos 3D impresos derivados de tomografías de pacientes reales constituyen REA innovadores, accesibles y altamente eficaces para la enseñanza de la anatomía de la maxila y la mandíbula, con potencial para ser empleados en múltiples módulos de la carrera de Cirujano Dentista.

Palabras clave: Recursos Educativos Abiertos; Modelos Tridimensionales; Impresión 3D; Enseñanza Odontológica; Anatomía Estomatognática; Pedagogías Emergentes; Tecnología Educativa.

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INTRODUCTION

The teaching of human anatomy in health-related degree programs has historically relied on physical resources such as natural skulls, plastic models, and illustrated atlases. In the context of the Dental Surgery Program at the Zaragoza School of Higher Studies (FES Zaragoza), UNAM, the study of the anatomy of the stomatognathic system—particularly the maxilla and mandible—takes place in the Multimedia Morphophysiology Unit, a space equipped since 2016 with interactive resources for multiple programs. However, the dental surgery program lacks its own anatomical models developed in that space.

The COVID-19 pandemic (2019–2020) accelerated the crisis in the availability of teaching resources by suspending in-person activities and highlighting the scarcity of up-to-date digital open educational resources (OERs) in the institutional repositories of UNAM and other universities. This situation significantly limited students' acquisition of clinical skills, given that anatomy is essentially a descriptive and tactile discipline in which direct interaction with the object of study is essential.

The natural skulls available at the institution show wear and tear and loss of structures and cannot be disarticulated, which hinders the complete observation of bone views, surfaces, and edges. In response to this problem, the incorporation of digital fabrication technologies—such as 3D printing based on computed tomography (CT) scans of real patients—emerges as an innovative, accessible, and institutionally viable educational alternative, given that the Zaragoza School of Health Sciences has had a 3D printer in its Morphophysiology laboratory since 2023. Several studies support the pedagogical value of 3D models in health sciences. Brumpt et al.[1], Ferneez et al.[2], Inca[3], León[4], Moreno et al.[5], Orozco et al.[6], and Pardo et al.[7] reported that the use of 3D models obtained from CT scans enhances the acquisition of anatomical knowledge, facilitates the expression of questions, improves student–teacher interaction, and promotes more active and participatory learning.

This study is part of the PAPIME P8202124 project titled "Learning Mediated by 3D Open Educational Resources and the Integration of Knowledge from Basic Sciences with Clinical Practice" and has as its central purpose the development of 3D-printed OERs of the maxilla and mandible based on CT scans of real patients, incorporating them into a teaching session, and evaluating their utility for the teaching–learning process of the anatomy of the stomatognathic system, documenting their benefits, limitations, and potential for expansion to other modules of the degree program.

Open Educational Resources Movement (MREA)

The Open Educational Resources Movement (MREA) has increasingly gained greater presence and relevance at the international and national levels, primarily because of two factors. The first refers to its integration into the broader Open Science movement, which is projected as the expansion of scientific and technological knowledge that multiplies the productive forces and the possibilities for communication and healing available to human beings. In 2002, UNESCO coined the term "open educational resource" to refer to freely accessible educational resources—such as teaching, learning, or research materials—that are in the public domain or have been published under an intellectual property license that allows for their free use, adaptation, and distribution. To date, these resources have not been adopted by various institutions of higher education, such as universities, teacher training colleges, and teacher education institutions. The Recommendation on Open Educational Resources (OER), adopted by the UNESCO General Conference at its 40th session on November 25, 2019, is the first international normative instrument covering the field of open-licensed educational materials and technologies in education.

METHOD

Study Design

This study adopted the design thinking approach, an iterative, user-centered methodology that allows for the identification of real educational needs, the prototyping of solutions, and their evaluation in context. The subject of the study was the teaching–learning process of the anatomy of the maxilla and mandible in the Stomatognathic System module of the Dental Surgery Program at FES Zaragoza, UNAM.

Participants

Figure 1. Project participants

The sample consisted of five dental surgery students enrolled in the Social Service Program "Use and Adoption of Technologies for the Analysis of Oral Abnormalities." Selection was intentional and was based on their active participation in the program and their availability for the session. The study was anonymous and confidential; the participants provided informed consent at the beginning of the evaluation questionnaire (figure 1).

Acquisition and processing of tomographic images

Two computed tomography (CT) scans of actual patients with abnormalities in the maxilla and mandible were used, provided by the project advisor from his teaching archive and by a student in the orthodontics and maxillofacial orthopedics specialty. The DICOM files were processed using the Materialise Mimics application for the segmentation and extraction of bone structures and subsequently edited with Blender (free 3D modeling software) to optimize the geometry and generate the print files in STL (STereoLithography) format.

3D Model Production

The models were printed on the Anycubic Kobra Max printer, available in the Morphophysiology Laboratory at FES Zaragoza Campus I, using a PLA (polylactic acid) filament. The printing process required continuous supervision to prevent the equipment from overheating and to ensure the correct operation of the X and Y axes. Models of the maxilla, mandible, and a sagittal section of the viscerocranium of the second patient were obtained to illustrate the extent of bone pathology.

Educational Implementation

An individual theoretical-practical session was conducted with the four interns. The session included (1) an explanation of the general principles and descriptive anatomy of the maxilla and mandible using 3D models to point out, delineate, and manipulate the structures; (2) a presentation and discussion of two clinical cases using printed models of CT scans from actual patients—a chronic periapical abscess in the upper second molar involving the maxillary sinus and an osteolytic lesion of the mandible consistent with a keratocyst or ameloblastoma; and (3) a question-and-answer session with active manipulation of the models.

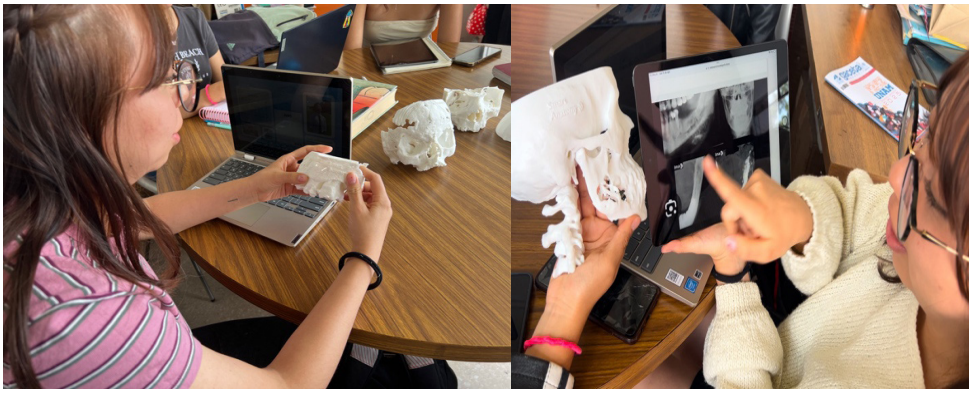

Figure 2. Learning with maxillary and mandibular biomarkers

Evaluation

At the end of the session, participants completed a structured questionnaire designed in Google Forms, consisting of closed-ended (yes/no dichotomous scale) and open-ended questions. The instrument assessed the similarity in color and size of the models to real bone; the visibility of anatomical structures from six views for each bone (anterior, posterior, lateral, inferior, and superior); the ease of handling; the ability to generate interest; the ease of expressing doubts; the ability to complete the educational function; and suggestions for improvement.

RESULTS

Evaluation of the maxillary model

With respect to the three-dimensional maxillary model, 75 % of the participants considered that the color and size resembled those of the actual bone; 25 % noted differences in the accuracy of the impression. With respect to the visibility of structures, 75 % correctly identified the structures from the anterior, posterior, and inferior views, whereas 100 % correctly identified them from the lateral and superior views. These difficulties were attributed to the presence of material burrs and the uniform color of the PLA filament, which made it difficult to differentiate adjacent structures.

Evaluation of the jaw model

In the mandibular model, 75 % of the participants considered the size and color to be similar to those of the actual mandible. The visibility of structures was correct for 75 % of the images from the anterior, lateral, and inferior views and for 100 % of the images from the posterior and superior views. Notably, interaction with the model facilitated an understanding of the course of the inferior alveolar canal and its anatomical variations, a structure of particular clinical relevance for procedures such as branch block anesthesia, third molar surgery, endodontics, and osseointegrated implants.

Overall evaluation of the models

Compared with standard resources (books and digital presentations), 100 % of the participants agreed that the models are easy to handle, generate greater interest in the study of anatomy, facilitate the expression and understanding of questions, and adequately fulfill their function as teaching materials. In explaining their responses, the participants highlighted that the ability to pick up, rotate, and closely observe the models enhanced their understanding of anatomical relationships and stimulated critical-deductive reasoning. One hundred percent suggested modifications related to color, with the goal of assigning different shades to each anatomical structure to facilitate identification (figure 3).

Figure 3. Students evaluating the 3D-printed resources

Use in clinical cases

The incorporation of models derived from CT scans of real patients—including a pathological case—allowed for the contextualization of anatomical knowledge within specific clinical scenarios. Participants more easily identified the affected structures in each case and actively participated in diagnostic and therapeutic discussions, demonstrating the models' potential for developing clinical reasoning from the early stages of training.

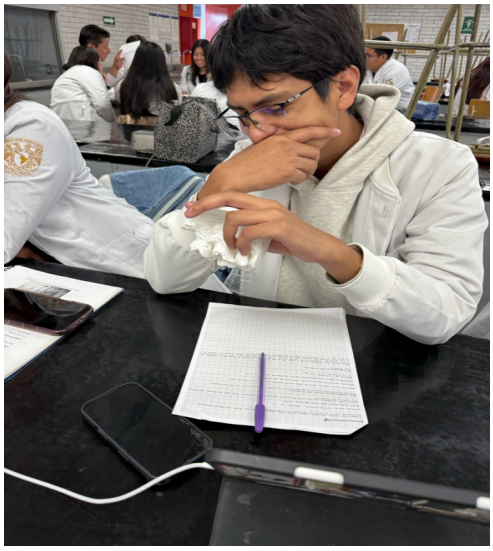

Figure 4. Trainee analyzing a clinical case with the aid of a 3D biomodel

DISCUSSION

The results of this study are consistent with findings reported in the international literature on the use of 3D models in health sciences education Brumpt et al.[1], Ferneez et al.[2], Inca[3], León[4], Moreno et al.[5], Orozco et al.[6], and Pardo et al.[7]. The integration of 3D printing based on CT scans of real patients represents a significant pedagogical innovation in the dental context, as it overcomes the limitations of worn natural skulls—which cannot be disarticulated and do not guarantee the integrity of all structures—and of commercial models that lack anatomical details and are prohibitively expensive for many public educational institutions.

The fact that these models are Open Educational Resources—produced in FES Zaragoza's own facilities using free software (Blender) and institutional hardware (Anycubic Kobra Max printer)—makes them reproducible, scalable, and accessible to teachers and students at any point during the school year. This feature is particularly relevant within the framework of the innovation and

teaching improvement project aimed at strengthening the open education movement in contexts of uncertainty.

The high level of acceptance of the models by the participants—which was unanimous in terms of handling, generating interest, addressing questions, and fulfilling the didactic function—supports their implementation in the regular teaching practice of the Stomatognathic System module. Similarly, the ability to present real clinical cases using 3D-printed models of the patient themselves constitutes a pedagogical approach that develops deductive reasoning and clinical decision-making, which are core competencies in the training of dental surgeons.[8]

Among the identified limitations, the following stand out: the limited color fidelity of the PLA filament—noted by 25–100 % of the participants depending on the aspect evaluated—, the presence of printing burrs, the considerable time required for the production of each model, and the costs of equipment maintenance and staff training. The widespread suggestion to differentiate structures by color points toward the use of multicolored filaments or the subsequent painting of models as improvement strategies.[9]

The potential for expanding this teaching material to other modules of the degree program—such as Oral Medicine and Pathology and Comprehensive Stomatology Clinic—opens the possibility of building a repository of models derived from CT scans of real clinical cases from UNAM clinics and other institutions, enriching the learning environment and preparing students for the diversity of anatomical structures and clinical situations they will encounter in their professional practice (figure 5).

Figure 5. Instructor and student analysis a clinical case with the aid of printed 3D OERs

CONCLUSIONS

The 3D-printed models of the maxilla and mandible, obtained from CT scans of real patients, constitute innovative, accessible, and institutionally viable open educational resources for teaching the anatomy of the stomatognathic system in the Dental Surgery Program at the Zaragoza School of Dentistry (FES), UNAM. Their evaluation by students revealed that they facilitated the visualization and manipulation of anatomical structures, generated greater academic interest, improved communication between students and instructors, and promoted the acquisition of meaningful knowledge with direct clinical applicability.

The production of models from CT scans of real patients—both healthy and with pathologies—enables contextualized teaching that stimulates clinical-deductive reasoning from the early stages of training, preparing students to address anatomical variability and the complex clinical situations that characterize their professional practice.

The identified limitations—color fidelity, the presence of printing burrs, production time, and training costs—can be improved through the use of multicolored filaments, refinement of printing parameters, and strengthening of the technology training program for faculty and students.

It is recommended to expand the evaluation sample, replicate the experience in regular first-year cohorts, develop an institutional repository of 3D models with documented clinical cases, and incorporate these resources into the curriculum of the stomatognathic system module as permanent support materials, thereby responding to the pedagogical demands of the open educational movement in the context of postpandemic higher education.

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FINANCING

None.

CONFLICT OF INTEREST

None.

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