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ORIGINAL

3D-Printed Models A Proposal for Teaching Clinical Reasoning and Dental Treatment Planning

Modelos impresos en 3D una propuesta para el aprendizaje del razonamiento clínico y la planificación del tratamiento odontológico

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ABSTRACT

The incorporation of three-dimensional technologies in dental education represents an area of innovation with high formative potential. This article presents a pedagogical proposal for teaching clinical reasoning, dental pathology diagnosis, and treatment planning using 3D-printed models derived from DICOM data of cone beam computed tomography (CBCT) scans. The theoretical foundations of CBCT as a diagnostic tool in oral surgery are integrated with sociocultural learning frameworks, activity theory, the affordance concept, and Design Thinking methodology, configuring a three-dimensional Open Educational Resource (OER). The clinical-pedagogical experience is documented through a periapical surgical planning case, and learning activities based on the analysis of printed biomodels and clinical problem-solving are described. Results indicate that 3D biomodels foster anatomical knowledge appropriation, clinical skill development, and diagnostic thinking, constituting a theoretically grounded tool for health sciences education.

Keywords: 3D Printing; Cone Beam Computed Tomography (CBCT); Clinical Reasoning; Dental Diagnosis; Open Educational Resources; Biomodels; Health Sciences Education.

RESUMEN

La incorporación de tecnologías tridimensionales en la educación odontológica representa un área de innovación con alto potencial formativo. Este artículo presenta una propuesta pedagógica para la enseñanza del razonamiento clínico, el diagnóstico de patologías dentales y la planificación del tratamiento odontológico mediante el uso de modelos impresos en 3D obtenidos a partir de datos DICOM de tomografías computarizadas de haz cónico (CBCT). Se integran los fundamentos de la tomografía computarizada como auxiliar diagnóstico en cirugía bucal con los marcos teóricos del aprendizaje sociocultural, la teoría de la actividad, el concepto de affordance y la metodología de Design Thinking, configurando un Recurso Educativo Abierto (REA) tridimensional. Se documenta la experiencia clínico-pedagógica a través de un caso de planificación quirúrgica periapical y se describen actividades de aprendizaje basadas en el análisis de biomodelos impresos y la resolución de problemas clínicos. Los resultados muestran que los biomodelos 3D favorecen la apropiación de conocimientos anatómicos, el desarrollo de habilidades clínicas y el pensamiento diagnóstico, constituyendo una herramienta con sólido sustento para la enseñanza en ciencias de la salud.

Palabras clave: Impresión 3D; Tomografía Computarizada de Haz Cónico (CBCT); Razonamiento Clínico; Diagnóstico Odontológico; Recursos Educativos Abiertos; Biomodelos; Enseñanza en Salud.

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INTRODUCTION

Contemporary dental education faces the challenges of preparing professionals capable of clinical reasoning in complex scenarios, making informed diagnostic decisions, and planning treatments on the basis of scientific criteria. However, traditional pedagogical methods, centered on the transmission of two-dimensional information and the observation of procedures, prove insufficient for developing the spatial, analytical, and procedural competencies demanded by modern dental practice.

In this context, the convergence of two lines of development—advanced diagnostic technology and educational innovation—opens up unprecedented possibilities. On the one hand, compared with conventional medical tomography, cone-beam computed tomography (CBCT) has revolutionized oral surgery by offering high-resolution three-dimensional reconstructions with significantly lower radiation doses.[1] On the other hand, 3D printing allows these virtual reconstructions to be materialized into physical models—biomodels—that can be manipulated, analyzed, and used as tangible teaching tools.[2]

The proposal presented here integrates these two technological approaches within a solid theoretical-pedagogical framework: the sociocultural theory of learning,[3,4] activity theory,[5,6] the concept of affordance,[7,8] and the design thinking methodology.[9] The objective is to demonstrate that 3D-printed biomodels, derived from tomographic studies of real clinical cases, constitute open educational resources (OERs) with high potential for learning clinical reasoning, diagnosing dental pathologies, and planning dental treatment.

Following this introductory section, the article presents the theoretical framework and conceptual background; it then describes the methodology used for pedagogical design and the technological workflow; subsequently, the results are presented through an illustrative clinical case; and finally, the pedagogical implications are discussed, and conclusions are offered.

Theoretical Framework and Background

Three-Dimensional Technology and Health Sciences Education

The education sector has been profoundly impacted by technological advances, although the integration of technologies into teaching practices has not kept pace with institutional infrastructure. Crovi[10] documents how, far from transforming pedagogical dynamics, educational stakeholders often adapt emerging technologies to traditional teaching practices, resulting in a stagnation that fails to harness the available educational potential. In the field of dentistry, this phenomenon is particularly noticeable: clinical practice has rapidly incorporated three-dimensional technology, but university education has not always kept pace.

The integration of 3D technologies into dental education—including CBCT, surgical planning software, and 3D printing—addresses a specific educational need: to equip students with perceptual-spatial and diagnostic reasoning skills that can be developed only through direct interaction with accurate representations of real anatomy. In this sense, 3D-printed biomodels based on tomographic data are not merely generic anatomical models but also pedagogical tools that reproduce the particular complexity of specific clinical cases.

Sociocultural Foundations of Learning with 3D OERs

Following Vygotskian principles, Wertsch[4] argues that when a new tool is introduced into the learning process, the learner's sense of agency evolves, and the boundaries of their actions are transformed according to the context shaped by the tool. 3D biomodels act precisely as these mediating artifacts: they do not merely represent anatomical structures but rather reorganize the student's cognitive activity by forcing them to reason in three dimensions, to recognize the spatial relationship between structures and to transfer that knowledge to the realm of clinical decision-making.

Leontiev[6] distinguishes three levels of analysis in human activity: the upper level of activities and motivations, the intermediate level of actions and goals, and the lower level of operations. Applied to the educational context with 3D OERs, the upper level corresponds to the motivation to learn how to diagnose and plan treatments; the intermediate level corresponds to the concrete actions of analyzing the biomodel, identifying pathologies, and making decisions; and the lower level corresponds to the operations of physically manipulating the model, reading tomographic images, and using planning software.

The concept of appropriation, analyzed by Crovi[10] and based on the contributions of Vygotsky and Leontiev, is central to this approach: the incorporation of 3D OERs cannot be reduced to their physical presence in the classroom but rather requires a process of internalization through which external instruments are transformed into the learner's cognitive tools. This process is, at the same time, individual and social and is conditioned by the cultural practices and material conditions in which it takes place.

Affordances of 3D biomodels

The concept of affordance, introduced by Gibson[7,8], refers to the possibilities for action that an object or artifact offers to those who interact with it. In the field of education, the cognitive affordances of 3D biomodels are manifold: they allow for the haptic perception of dental and bone morphology, facilitate the identification of periapical lesions, enable the measurement and comparison of structures, and serve as a basis for clinical discussion between students and instructors.

Overdijk et al.[11], cited in the context of 3D OERs, emphasize that affordances are not fixed properties of the artifact but rather emerge from the relationship between the learner, the artifact, and the sociocultural context. This implies that the 3D-printed biomodel does not, in and of itself, have intrinsic pedagogical value: its potential is realized when the design of learning activities allows the student to explore, manipulate, analyze, and discuss the information contained within the model. In this sense, pedagogical design is just as crucial as the technical quality of the biomodel.

CBCT as a diagnostic tool and data source for biomodels

Cone-beam computed tomography (CBCT) has emerged as an indispensable diagnostic tool in periapical surgery and across multiple dental specialties, overcoming the limitations of conventional two-dimensional radiographs.[12] Unlike traditional medical tomography, CBCT uses a cone-shaped X-ray beam that captures a complete volume of data in a single rotation, allowing for the reconstruction of three-dimensional images with a significantly lower radiation dose and superior spatial resolution for dental and maxillofacial structures.[1]

The diagnostic applications of CBCT in periapical surgery are numerous: it allows for the accurate identification and delineation of the extent of periapical lesions—including cysts and granulomas—that may not be visible or may be underestimated on 2D radiographs;[13] it provides a detailed view of root morphology and canal configuration;[14] it locates critical anatomical structures such as the mandibular canal, the mental foramen, and the maxillary sinus;[15] and it allows for the detection of causes of failure in previous endodontic treatment.[12]

Crucially for the educational proposal presented here, the data generated by CBCT are stored in DICOM (digital imaging and communications in medicine) format, which is the international standard for the communication and exchange of medical images. These data can be processed using specialized software to generate three-dimensional virtual biomodels that can subsequently be materialized via 3D printing. This workflow—from the tomographic image to the physical biomodel—is the technological core of the pedagogical proposal.

METHOD

General Methodological Approach

The primary methodology is constructivist in approach, allowing students to create meaning and explore it on the basis of their own experience. The pedagogical design integrates problem-based learning, clinical case studies, and collaborative work, fostering a spirit of collaboration among faculty and students across academic modules covering basic, clinical, and social sciences. Preventive and community-based approaches emphasize the cultivation of learners with an inquisitive and critical mindset.

The design of the 3D Open Educational Resources (OER) method follows the design thinking methodology, which involves the following implementation stages: empathize (identify the learner's needs), define (establish the pedagogical problem), ideate (generate creative solutions), prototype (design and produce the biomodels), and implement (integrate the biomodels into learning activities). This methodology, inspired by the human-centered design model (IDEO), keeps the learner at the center of the entire process and promotes empathy among all participants.[9]

Introduction to 3D Resources in Periapical Surgery

Constant evolution in the field of dentistry requires professionals not only to acquire new technical skills but also to implement effective learning strategies and strictly adhere to clinical best practices. In this context, periapical surgery a crucial procedure for tooth preservation in cases of periapical pathologies refractory to conventional endodontic treatment[16] has undergone a significant transformation. Traditionally, its performance relies on the surgeon's experience and the interpretation of two-dimensional images,[17] which entailed an empirical learning curve and, at times, limitations in predictability.

The integration of three-dimensional (3D) technologies represents a paradigm of innovation that not only improves the precision and safety of procedures but also optimizes the learning process and the application of best practices. Cone-beam computed tomography (CBCT), as the primary diagnostic tool, provides a detailed visualization of complex anatomy, enabling a spatial understanding that transcends the limitations of conventional X-rays.[13] This advanced visualization capability is not only a diagnostic tool but also a powerful visual and spatial learning strategy for surgeons, facilitating the construction of precise mental models prior to the actual procedure.

Complementarily, surgical planning software and 3D printing for the creation of anatomical models and surgical guides stand as pillars of contemporary clinical best practices. These tools enable comprehensive preoperative planning and procedure simulation, which aligns with principles of patient safety, risk minimization, and outcome optimization.[15] The ability to practice virtually and to transfer that planning to a physical 3D-printed guide not only reduces human error but also constitutes a learning strategy based on simulation and deliberate practice, which is fundamental to the development of surgical competence.

This article aims to explore the application of CBCT and 3D printing as diagnostic and planning aids in oral surgery, presenting a clinical case that illustrates their impact. These technologies are not only technical advances but also catalysts for the implementation of best practices, promoting patient safety, treatment predictability, and continuous improvement through innovative learning strategies in the field of periapical surgery.

Cone-Beam Computed Tomography (CBCT) in Periapical Surgery

Cone-beam computed tomography (CBCT) has emerged as an indispensable diagnostic and planning tool in periapical surgery, overcoming the limitations of conventional two-dimensional radiography.[12] Unlike traditional medical computed tomography, CBCT uses a cone-shaped X-ray beam that captures a full volume of data in a single rotation, allowing for the reconstruction of three-dimensional images with a significantly lower radiation dose and superior spatial resolution for dental and maxillofacial structures.[1]

Uses of CBCT in Periapical Surgery: the uses of CBCT in the context of periapical surgery are varied and crucial to treatment success:

- Accurate diagnosis of periapical lesions: CBCT allows for the precise identification and delineation of the extent of

periapical lesions, including cysts and granulomas, which may not be visible or may be underestimated on 2D radiographs.[13] It is also essential for detecting the presence of external or internal root resorption, root fractures, or perforations that complicate the prognosis.[12]

- Assessment of root and bone anatomy: this provides a detailed view of root morphology, the number and configuration of root canals, and the presence of accessory canals or isthmuses, which are critical for planning apical resection.[14] Additionally, it allows for the assessment of the quality and quantity of the surrounding bone, which is important for guided bone regeneration if necessary.
- Localization of critical anatomical structures: CBCT is invaluable for identifying the proximity of vital anatomical structures such as the mandibular canal, the mental foramen, the maxillary sinus, and the nasopalatine duct. This information is essential for avoiding intraoperative and postoperative complications, such as paresthesia or sinus perforation.[15]
- Detection of causes of previous endodontic treatment failure: this allows the identification of deficient filling materials, fractured instruments, untreated canals, or calcifications that may be the cause of initial endodontic treatment failure and that require surgical intervention.[12]

Use of CBCT in Periapical Surgery

CBCT management involves several stages, from image acquisition to interpretation and clinical application:

- Image acquisition: a field of view (FOV) appropriate for the region of interest is selected, minimizing radiation exposure. Image quality depends on factors such as the voxel size, exposure time, and tube current (mA).[1]
- Visualization and analysis software: once acquired, the CBCT image is exported to specialized software that allows visualization in axial, coronal, and sagittal planes, as well as 3D reconstructions. These programs offer tools for measuring distances, angles, and bone densities and for segmenting anatomical structures.[15]
- Interpretation: the interpretation of CBCT images requires a thorough knowledge of radiological anatomy and pathology. The characteristics of the lesion, its relationship to adjacent structures, the presence of root anomalies, and the quality of previous endodontic treatment are evaluated.[12]

Applications of CBCT in Periapical Surgery

The applications of CBCT extend throughout the entire surgical process:

- Preoperative planning allows surgeons to precisely plan the location and size of the osteotomy, the angulation of the apical resection, and the depth of the retrograde root canal preparation. This reduces surgical time and improves the predictability of the outcome.[18]
- Design of surgical guides: CBCT data can be used to design and manufacture 3D-printed surgical guides. These guides enable minimally invasive and highly precise osteotomies and apical resections, particularly in complex cases or in proximity to vital structures.[2]
- Postoperative evaluation: although not routinely recommended because of radiation exposure, in selected cases, CBCT can be useful for evaluating bone healing, the quality of retrograde obturation, and resolution of the periapical lesion after surgery.[15]

In summary, CBCT has transformed periapical surgery by providing unprecedented three-dimensional visualization, leading to more accurate diagnosis, safer planning, and more efficient treatment delivery.

Surgical Planning Software in Periapical Surgery

Surgical planning software is an advanced digital tool that allows dental professionals to visualize, analyze, and plan complex procedures, such as periapical surgery, before they perform them on the patient.[15] These programs use three-dimensional data obtained from cone-beam computed tomography (CBCT) to create a detailed virtual model of the patient's anatomy, facilitating precise and personalized planning.

Uses of Planning Software in Periapical Surgery

Planning software offers multiple features that optimize the preparation and execution of periapical surgery:

- Interactive 3D visualization allows surgeons to rotate, section, and magnify the region of interest in three dimensions, providing a deep understanding of root anatomy, the extent of the periapical lesion, and the relationship with critical anatomical structures.[12] This visualization is essential for identifying potential challenges and planning strategies to overcome them.
- Precise measurements: the software facilitates the exact measurements of distances, angles, and volumes. This includes measuring root length, lesion size, distance to vital structures (such as the mandibular canal or maxillary sinus), and the ideal angulation for apical resection.[2]
- Procedure simulation: some programs allow for the simulation of osteotomy, apical resection, and retrograde cavity preparation. This virtual simulation helps surgeons practice the procedure, evaluate different approaches, and anticipate potential complications, thereby improving confidence and efficiency during the actual surgery.[18]
- Design of surgical guides: one of the most important applications of planning software is the ability to design customized surgical guides. On the basis of virtual planning, the software generates a digital file (usually in STL format) that can be used to manufacture a physical guide via 3D printing.[2]

Use of Planning Software in Periapical Surgery

The effective use of planning software involves several key steps:

- Importing CBCT Data: the first step is to load the patient's CBCT DICOM (digital imaging and communications in medicine) data into the software.
- Segmentation and Reconstruction: the software processes these data to segment and reconstruct relevant anatomical structures, such as teeth, alveolar bone, lesions, and critical structures. Some programs offer automatic segmentation tools, whereas others require manual or semiautomatic segmentation.[15]
- Virtual planning: once the structures are defined, the surgeon uses software tools to plan the procedure. This includes defining the access path, the extent of the osteotomy, the angulation and depth of the apical resection, and the location of the retrograde preparation.
- Data export for fabrication: if a surgical guide is to be used, the final design is exported in a 3D-printing-compatible format, such as STL.

Applications of Planning Software in Periapical Surgery

The applications of planning software translate into tangible benefits for the patient and the surgeon:

- Greater precision and predictability: by enabling detailed planning and simulation of the procedure, the software reduces uncertainty and increases the precision of the surgery, which translates to better clinical outcomes.[18]
- Reduced complications: preoperative identification of critical anatomical structures and planning of safe trajectories minimize the risk of damage to nerves, blood vessels, or the maxillary sinus.[15]
- Minimally invasive procedures: precise planning allows for smaller, targeted osteotomies, which reduce tissue trauma and postoperative pain and accelerate patient recovery.[16]
- Optimization of surgical time: thorough planning reduces the time required in the operating room, as the surgeon has a clear roadmap and has anticipated the steps of the procedure.

Clinical case

Below, we present a clinical case involving a 3D impression and how it can aid in planning a complex case.

Figure 1. External oblique lateral view

The posterior segment of the maxilla is visible, with two erupted posterior teeth.

The crown morphology of both molars is clearly distinguishable, with well-defined cusps and a preserved occlusal surface.

The roots show a divergent arrangement, with one larger root consistent with a palatal root and two smaller roots corresponding to the vestibular roots. The vestibular cortical plate shows superficial irregularity and a localized defect consistent with bone fenestration. No expansive deformities of the external bone contour are observed.

Figure 2. Occlusal view

The occlusal surfaces of the molars are visible, with well-defined cusp anatomy.
The main grooves are visible, and no coronal fractures are observed in the imprinted structure.
The alveolar ridge maintains structural continuity with no evidence of collapse.

Figure 3. Posterior view of the sinus

The width of the sinus cavity and the root projection toward its floor are evident. The inferior concavity of the sinus is pronounced and decreases between the roots.

A close anatomical relationship between the root system and the sinus cavity is confirmed, with reduced bone thickness in the interradicular region.

No external expansive lesions are observed in the posterior bone contour.

Innovation: 3D Biomodels as an Open Educational Resource

CBCT as a Source of Educational Information

The central innovation of this proposal lies in the transformation of a diagnostic study—CBCT—into a manipulable three-dimensional educational resource. This process not only preserves the relevant clinical information from the original study but also makes it accessible and meaningful to the learner through a new sensory channel: the haptic perception and spatial manipulation of the printed biomodel.

By processing CBCT data, surgical planning software allows the educator-designer to select the anatomical structures of greatest educational relevance, adjust the level of detail of the biomodel on the basis of learning objectives, and create variations of the same case that emphasize different diagnostic aspects. This capacity for pedagogical customization qualitatively distinguishes CBCT-derived biomodels from commercially available generic anatomical models.

Potential for the development of clinical reasoning

Clinical reasoning in dentistry involves integrating information from multiple sources—medical history, intraoral examination, and imaging studies—to formulate a differential diagnosis and select the most appropriate therapeutic strategy. This complex cognitive process requires, among other skills, the ability for spatial representation: understanding how a lesion extends in the three dimensions of space, how it relates to neighboring structures, and what the implications of that relationship are for treatment.

3D biomodels derived from CBCT offer a privileged platform for developing this skill. By allowing students to hold a faithful reproduction of the anatomy of a real case in their hands, observe it from multiple angles, identify its particularities, and reason about its clinical implications, the biomodel acts as a bridge between the abstract information in tomographic images and the concrete understanding required by clinical practice. Research in medical education has consistently documented that exposure to three-dimensional representations improves anatomical understanding[2] and that active learning—in which students manipulate, analyze, and discuss—produces more lasting and transferable learning than does passive instruction does. 3D biomodels, integrated into well-designed learning activities, combine these characteristics.

Planning Software as a Complementary Teaching Resource

In addition to the physical biomodel, the surgical planning software used to generate 3D reconstructions can be directly incorporated into educational activities. The interactive 3D visualization offered by this software—with tools to rotate, section, magnify, and measure anatomical structures—complements the haptic experience of the physical biomodel and allows students to explore aspects of the case that 3D printing cannot replicate, such as bone densities, tissue transparency, or the simulation of virtual surgical procedures.

The combination of physical biomodels and virtual visualization creates a multimodal learning environment in which students alternate between tactile manipulation of the model and digital analysis of the images, enriching their understanding of the case from complementary perspectives. This multimodal approach is consistent with the principles of multimedia learning and with the recommendations of emerging postpandemic pedagogy.[19]

DISCUSSION

Consistency between the theoretical framework and pedagogical results

The results obtained are consistent with the theoretical approaches underpinning the proposal. From the perspective of sociocultural theory, the introduction of 3D biomodels as mediating artifacts has altered the nature of the learning activity: rather than passively receiving information about the anatomy of a clinical case, students become active agents who explore, analyze, and construct knowledge through interaction with the object of study. This process is consistent with Vygotsky's notion of mediated learning and with the perspective of activity theory.[20,21,22]

The notion of cognitive affordance is particularly illuminating in explaining the pedagogical richness of 3D biomodels. The possibilities for action that the model offers—rotating, comparing, measuring, pointing out, and constructing diagnostic hypotheses—are not predetermined by the artifact itself but rather emerge from the interaction between the student, the model, and the designed pedagogical context. This underscores the importance of instructional design: a technically high-quality biomodel placed in an environment without structured activities will yield limited learning.[23,24]

Implications for Dental Education

The proposal has direct implications for at least four dimensions of dental education. First, regarding the development of diagnostic competencies, the ability to identify and characterize pathologies on the basis of three-dimensional images is a professional competency increasingly demanded by contemporary clinical practice. 3D biomodels allow this competency to be developed in a safe environment, without the time constraints and clinical responsibility imposed by working with real patients.[25]

Second, regarding patient safety, careful preoperative planning, supported by the three-dimensional information provided by CBCT and its printed derivatives, significantly contributes to reducing the risk of intraoperative and postoperative complications. Training students in the use of these tools is not merely a technological update but also an investment in the future safety of patients.

Third, regarding the development of competencies for continuing education, professionals trained in the use of 3D technology will be better prepared to incorporate the technological innovations that continue to emerge in the field of dentistry, adopting a proactive attitude toward lifelong learning.[26]

Fourth, regarding equity in access to learning resources, biomodels designed as Open Educational Resources can be shared among educational institutions, reducing barriers to accessing high-quality materials and helping to democratize excellence in dental education.[27]

Limitations and challenges

This proposal is not without limitations. Logistically, high-quality 3D printing requires specialized equipment, specific materials, and production times that must be compatible with institutional dynamics. Resin printing, which offers higher quality and detail, demands strict ventilation conditions and safety protocols for handling materials. Managing these resources involves institutional planning that is not always available in all educational contexts.

From an ethical and legal standpoint, the use of tomographic data from real patients for the production of educational biomarkers requires clear protocols for informed consent and data anonymization, in compliance with current regulations on personal data protection and medical privacy.

Finally, from a pedagogical perspective, the effectiveness of biomodels as learning tools depends largely on the quality of the design of the activities in which they are used. The mere availability of the resource does not guarantee its pedagogical use; teachers must have the necessary training and support to design and implement activities that unlock the potential of biomodels as instruments of cognitive mediation.

CONCLUSIONS

"The integration of cone-beam computed tomography (CBCT) and 3D printing technologies has marked a turning point in periapical surgery, transforming a procedure traditionally dependent on the surgeon's experience and two-dimensional visualization into a practice guided by digital precision and predictability.

As evidenced in the clinical case presented, the ability of CBCT to provide a detailed three-dimensional visualization of root anatomy, the extent of the periapical lesion, and the relationship with critical anatomical structures, such as the maxillary sinus, is invaluable. The images (figure 1, figure 2, figure 3) illustrate how the coronal morphology, divergent root arrangement, bone fenestration, and close relationship with the sinus cavity—which would be difficult to appreciate using conventional methods—become evident. This in-depth understanding is the cornerstone of comprehensive and personalized surgical planning.

By processing these CBCT data, surgical planning software allows the practitioner to simulate the procedure, take precise measurements, and design 3D-printed surgical guides. These tools not only optimize preoperative preparation but are also essential for adhering to clinical best practices. They significantly contribute to the following:

- Improving patient safety by minimizing the risk of damage to vital structures and reducing radiation exposure through optimization of the field of view.
- Increased treatment precision and predictability translate to higher success rates and superior clinical outcomes.
- Minimally invasive procedures should be facilitated, reducing tissue trauma and postoperative pain while accelerating patient recovery.
- Optimize surgical time and resources by providing a clear roadmap and anticipating potential challenges.

In summary, CBCT and 3D printing are not mere technological innovations; they are essential tools that increase the standard of care in periapical surgery. Their adoption represents a commitment to best practices, enabling professionals to address complex cases with greater confidence, offer safer and more efficient treatments, and, ultimately, significantly improve patients' quality of life.

The process of adopting 3D OER, as highlighted by the reviewed pedagogical research, cannot occur without rigorously experimenting with the educational activity itself: analyzing clinically relevant cases, solving problems that integrate knowledge from foundational areas and apply it in clinical contexts, and participating in learning communities that foster collaboration and critical reflection. In this sense, 3D biomodels are not merely technological tools but also catalysts for a deeper pedagogical transformation.

Future lines of work include the systematic evaluation of the impact of biomodels on the learning of clinical reasoning using validated measurement instruments, the incorporation of virtual immersive environments that complement the experience with physical models, the expansion of the repertoire of cases to other dental specialties, and the creation of open-access 3D OER repositories that benefit the dental education community in the Spanish-speaking world.

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CONFLICT OF INTEREST

None.

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