Anatomía Digital

ISSN: 2697-3391
Vol. 7 No. 3, pp. 120 – 136, July – September 2024

www.anatomiadigital.org

Innovación odontológica: impresión 3D de dientes caninos para mejorar la formación endodóntica

Dental innovation: a 3D printing of canine teeth to improve endodontic training

[1] Matthew Leonidas Flores Sacoto https://orcid.org/0009-0008-5477-2977
Student, Catholic University of Cuenca, Cuenca, Ecuador.
matefll@hotmail.com
[2] Paola Alexandra Duran Neira https://orcid.org/0000-0001-7030-2221
Professor of Dentistry, Catholic University of Cuenca, Cuenca, Ecuador.
pdurann@ucacue.edu.ec
[3] Magda Zulay Bastidas Calva https://orcid.org/0000-0003-1874-3649
Professor of Dentistry, Catholic University of Cuenca, Cuenca, Ecuador.
zulybastidas@hotmail.com
[4] Diana Patricia Alvarez Alvarez https://orcid.org/0000-0001-7046-2137
Professor of Dentistry, Catholic University of Cuenca, Cuenca, Ecuador.
dalvareza@ucacue.edu.ec

Scientific and Technological Research Article
Sent: 05/18/2024
Revised: 06/15/2024
Accepted: 29/07/2024
Published:26/08/2024
DOI:**https://doi.org/10.33262/anatomiadigital.v7i3.3150**

Please quote: Flores Sacoto, ML, Duran Neira, PA, Bastidas Calva, MZ, & Álvarez Álvarez, DP (2024). Dental innovation: 3D printing of canine teeth to improve endodontic training. Digital Anatomy, 7(3), 120-136.https://doi.org/10.33262/anatomiadigital.v7i3.3150

DIGITAL ANATOMY is an electronic, quarterly journal that will be published in electronic format and has the mission of contributing to the training of competent professionals with a humanistic and critical vision who are capable of presenting their investigative and scientific results to the same extent that positive changes in society are promoted through their intervention.https://anatomiadigital.org
The journal is published by Editorial Ciencia Digital (a prestigious publisher registered with the Ecuadorian Book Chamber with membership number 663).www.celibro.org.ec

Palabras claves: Impresión tridimensional, diente canino, endodoncia, modelos dentales, diente artificial.

Resumen

Introducción. La odontología ha evolucionado con la impresión 3D, permitiendo una planificación quirúrgica precisa y la creación de modelos dentales tridimensionales para prácticas educativas y profesionales. Este estudio explora la fabricación de dientes caninos sintéticos impresos en 3D para prácticas de endodoncia. **Objetivo.** explorar el uso de la impresión 3D para la fabricación de dientes caninos sintéticos destinados a prácticas de endodoncia. **Metodología.** Se realizó un estudio experimental para evaluar dientes artificiales impresos en 3D en comparación con dientes reales, utilizando CBCT y tecnología de impresión 3D. Se seleccionó un paciente adulto con dentición completa y saludable. Se reconstruyeron los dientes con software especializado y se imprimieron prototipos en resina fotosensible. Estos prototipos fueron evaluados clínicamente y se realizaron pruebas endodónticas, incluyendo la preparación y obturación del conducto, para comprobar su idoneidad en condiciones simuladas. **Resultados.** Los prototipos mostraron alta precisión morfológica y resistencia mecánica adecuada, aunque con algunas variaciones en la anatomía del conducto radicular. La conformación de cavidad, conductometría y preparación químico-mecánica fueron efectivas, aunque se observó fragilidad en el tercio apical. La obturación con gutapercha fue exitosa, concluyendo el tratamiento endodóntico de manera eficaz. **Conclusión.** Los dientes caninos impresos en 3D para endodoncia son precisos y personalizables, pero tienen limitaciones en la morfología interna y fragilidad apical. Su uso mejora la experiencia educativa y clínica, requiriendo más investigación para optimizar durabilidad y replicar mejor la anatomía dental natural. **Área de estudio general:** Odontología. **Área de estudio específica:** Endodoncia. **Tipo de estudio:** Artículos originales

Keywords: 3D printing, canine teeth, endodontics, dental models, artificial teeth.

Abstract

Introduction. Dentistry has evolved with 3D printing, enabling accurate surgical planning and the creation of three-dimensional dental models for educational and professional practices. This study explores the fabrication of 3D-printed synthetic canine teeth for endodontic practices.**Objective.**exploring the use of 3D printing for the fabrication of synthetic canine teeth for endodontic practices. Methodology.An experimental study was conducted to evaluate 3D

ISSN: 2697-3391
Vol. 7 No. 3, pp. 120 – 136, July – September 2024
www.anatomiadigital.org

printed artificial teeth compared to real teeth, using Cone beam computed tomography (CBCT) and 3D printing technology. An adult with patient complete and healthy dentition was selected. The teeth were reconstructed with specialized software, and prototypes were printed using photosensitive resin. These prototypes were clinically evaluated; endodontic tests, including canal preparation and obturation, were performed to check their suitability under simulated conditions.**Results.**The prototypes showed high morphological precision and adequate mechanical resistance, although with some variations in the root canal anatomy. Cavity shaping, conductometry, and chemical-mechanical preparation were effective, although fragility was observed in the apical third. Gutta-percha obturation was successful, concluding the endodontic treatment effectively.**Conclusion.**3D-printed canine teeth for endodontics are accurate and customizable, but they have limitations in internal morphology and apical fragility. Their use enhances the educational and clinical experience, requiring further research to optimize results.

Introduction

Dentistry, as a medical discipline, has undergone a remarkable evolution in recent decades, largely driven by technological advances.(1)One of the most promising developments in this field is 3D printing technology, which has revolutionized numerous aspects of dental practice, from surgical planning to the manufacturing of customized dental prostheses.(2).

In particular, endodontics, a branch of dentistry dedicated to the treatment of the internal tissues of the tooth, has found in 3D printing an invaluable tool to improve the quality and precision of its procedures.(3, 4)The ability to accurately replicate dental anatomy using three-dimensional models significantly facilitates the practice of endodontics, allowing professionals to develop and hone their skills in a controlled and realistic environment.(5, 6).

Clinically, endodontic therapy effectively treats various pathologies such as pulpitis, necrosis and periapical periodontitis. This therapy includes processes such as chemical-mechanical preparation, shaping, sterilization and obturation of the root canal.(7). During the treatment processes it is crucial to determine the length of the root canal, its morphology and direction to avoid the creation of false pathways, perforation, underfilling or overfilling of the canal which are the cause of failure in a treatment, showing that the percentage of failure of endodontics occurs in 24%(8).

Canine teeth have longer, more steeply curved roots compared to other teeth, which can make it difficult to properly access the root canals during endodontics. This irregular anatomy increases the likelihood that endodontic instruments will not be able to reach all the nooks and crannies of the root canals, which can result in incomplete cleaning or inadequate filling. Anatomical variability is also a factor to consider when treating canine teeth in root canals; the presence of additional root canals, such as lateral or accessory canals, is common in these teeth, which can go unnoticed during treatment and lead to persistent infection or recurrence of symptoms.(9).

Furthermore, the strategic position of canine teeth in the mouth, especially in the upper jaw, can make cameral and root access difficult during endodontic treatment. This may require the use of advanced imaging techniques, such as digital radiography or CT scanning, for better visualization and treatment planning.(10).

Endodontic training using 3D tooth models has revolutionized the way dental students and professionals acquire practical skills. These three-dimensional models offer an accurate representation of dental anatomy, allowing students to practice endodontic procedures in a realistic manner that is safe for patients. By interacting with these models, future endodontists can develop skills in root canal identification, use of endodontic instruments, and application of obturation techniques, contributing to more complete and effective training. In addition, the availability of 3D models facilitates practical preclinical teaching and access to continuing education for established professionals, thus promoting advancement in clinical practice and improving endodontic treatment outcomes.(2).

In this context, the present work focused on exploring the use of 3D printing for the fabrication of synthetic canine teeth intended for endodontic practices, as well as these dental models, based on radiographic images and high-precision tomographic scans, provide a faithful representation of dental morphology, including complex internal structures such as root canals and dental pulp.

Methodology

Patient selection and protocol

A cross-sectional descriptive experimental study was conducted to evaluate the compatibility between 3D printed artificial teeth and the teeth of a real patient, by using CT scans and 3D printing technology.

A single patient was selected who met the following criteria: being an adult with complete permanent dentition, enjoying optimal periodontal and systemic health. Patients with caries, periodontal disease, incomplete or altered dentition, root canal treatment, as well as those with soft and hard tissue pathologies were excluded.

Once the patient who met the aforementioned criteria was selected, he or she was asked to sign an informed consent for the management of his or her data and clinical examinations, as well as their use in the experimental part.

Permission for the study was granted by the human research ethics committee of the Catholic University of Cuenca CEISH-UCACUE-2023-177.

Creation of 3D prototypes

The 3D image data obtained from the CBCT scans were exported to the 3DSlicer software (5.22) to separate the dental tissue from the corresponding alveolar bone and guide the reconstruction of the tooth. The file was then exported to Meshmixer (3p5) to align and adjust the internal morphology of the tooth, taking as reference the literature on dental anatomy, with the aim of achieving millimetric precision.

The 3D data of the modified teeth were then exported for 3D printing. Using ultra-precision photosensitive resin (Water-wash resin+ Anycubic clear and Water-wash resin+ Anycubic white) and a 3D printer (Anycubic Photon M3), the in vitro 3D printed artificial teeth were produced with an accuracy and XY resolution of up to 51 microns (0.051 mm) and a Z resolution of up to 10 microns (0.01 mm).

The process was replicated with slight modifications in several versions in order to perfect the prototype and ensure it meets the parameters of clinical morphological precision and chemical-mechanical resistance in the endodontic process.

Iteration and evolution of the prototype

To evaluate the clinical outcome and mechanical performance that allowed us to arrive at the final prototype that is the object of the study, a methodology has been implemented that uses an evaluation table with a categorical scale of bad, average and good. This table classifies two key aspects: the clinical result, which compares the morphology and appearance of the 3D tooth with the characteristics described in the literature, and the mechanical performance, which analyses the resistance, durability and effectiveness of the printed tooth in endodontic practice.

He The procedure involves collecting data at different stages, which are then recorded in the table with their respective characteristics. Subsequently, an analysis of the results is carried out to identify areas for improvement and success, and to determine whether the prototype meets the expected functional requirements (Table 1).

Prototype analysis

In line with the main objective of the study, a practical analysis of a clinical nature in the endodontic field was carried out to evaluate the quality and usefulness of the prototypes. The tests consisted of visual, clinical and mechanical endodontic analysis.

Clinical-visual examination

The 3D printed tooth was then examined to assess its overall shape, size, and anatomical details. During this assessment, possible surface imperfections such as air bubbles or poorly defined areas were noted.

An assessment of the shape and length of the root of the 3D printed tooth was carried out to ensure that it matched the expected anatomical characteristics. This examination focused on verifying the absence of deformities that could affect the natural anatomy of the tooth, using a caliper and taking as reference data demarcated in the literature.

To assess the permanent upper and lower canines, several essential parameters were considered to ensure their accuracy. These include crown length (10 mm in the upper canines and 11 mm in the lower ones) and root length (approximately 17 mm in both). Root morphology was analysed, which should be robust, with a single root in most cases and a straight or slightly curved root canal. The mesiodistal width of the crown was also measured, with an average of 7.5 mm in the upper canines and 7 mm in the lower ones. In terms of internal parameters, the internal structure of the tooth was checked, including the density and integrity of the dentin, as well as the patency of the root canal.(11).

Endodontic mechanical examination

The stepback technique was used(12), to carry out the treatments on the printed prototype. During the procedure, chamber access was achieved using a blue-coded, long-necked, coarse-grained round bur. The sensation of "falling into the void" when breaking the chamber roof was verified, and the correct conformation of the cavity was assessed. Canal patency was checked using pre-series K-type manual files, and resistance at the apical

Anatomía Digital
ISSN: 2697-3391
Vol. 7 No. 3, pp. 120 – 136, July – September 2024
www.anatomiadigital.org

limit was assessed using first- and second-series K-type manual files (Dentsply) including sizes 15 to 80. Through chemical-mechanical preparation, possible irregularities, cracks or thinning of the walls that could compromise structural resistance or hermeticity against EDTA irrigants, 2.5% sodium hypochlorite and physiological saline solution were analyzed. Finally, the compatibility and resistance with filling materials such as calcium hydroxide-based cement (sealapex), first and second series gutta-percha (Dentsply) were analyzed. These were manipulated by using lateral and vertical condensers (Dentsply). This entire process was accompanied at each step of the protocol by periapical radiographic analysis.

This clinical analysis provided crucial information on the suitability of the prototypes in the endodontic context, allowing a thorough evaluation of their quality and functionality in simulated clinical situations.

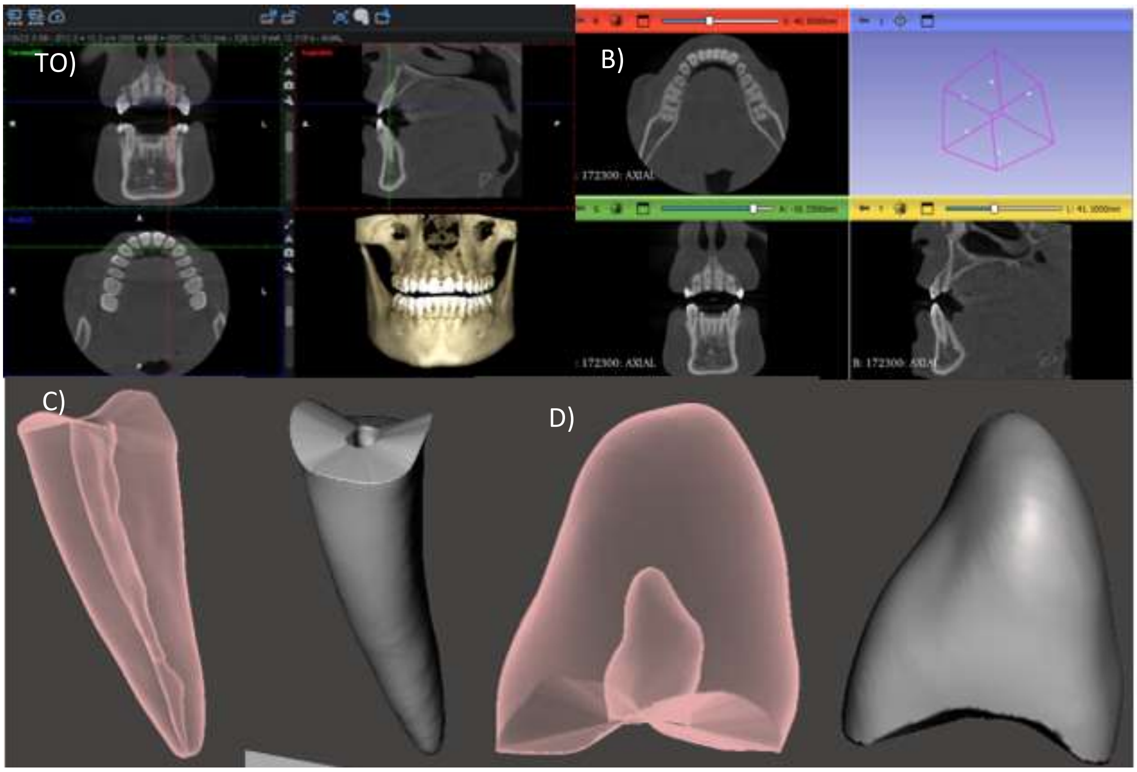

Figure1: A) CBCT file of selected patient, B) DICOM export in 3dslicer software, C) root and canal modeling of dental piece in meshmixer, D) coronal modeling of dental piece in meshmixer

Results

The development process was carried out in several phases to perfect its design and functionality. Based on the principle of trial and error, adjustments and modifications were made until the desired model was obtained.

*Prototype iteration:*versions developed before the final model

Anatomía Digital
ISSN: 2697-3391
Vol. 7 No. 3, pp. 120 – 136, July – September 2024
www.anatomiadigital.org

During the development of the dental prototype, multiple versions were made, each of which underwent phases of improvement before reaching the final version. These versions were evaluated and adjusted to improve specific aspects such as strength, compatibility with endodontic treatments and precision in the shaping of the accesses. The changes and improvements implemented in each iteration allowed the design to be optimized, ensuring that the final prototype met the clinical and mechanical requirements necessary for effective treatment (Table 1).

Board1. *Dental prototyping iteration in development phases*

Phases	Characteristics			Clinical Outcome	Performance Mechanic
	Crown	Conduit	Root		
Initial (figure 2)	Translucent with paint coating	Visible with red acrylic filling	Translucent wide morphology	Bad	Bad
Intermedia (figure 2)	Translucent	Visible gap	Translucent	Well	Regular
End (figure 2)	White with defined access	Visible gap	Translucent correct morphology	Well	Well

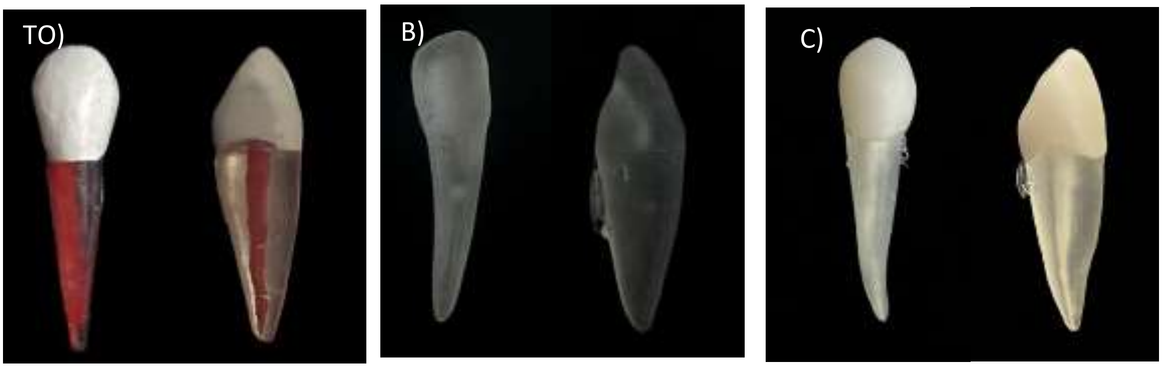

Figure2:*A) Initial phase dental prototype, B) Intermediate phase dental prototyping, C) Final phase dental prototype*

In the development and evaluation of 3D printed dental prototypes, their morphological accuracy and mechanical strength during endodontic procedures were analyzed. The results demonstrated that the artificial teeth presented a high degree of similarity to real teeth, as well as adequate strength during clinical treatments, ensuring their viability and effectiveness in dental applications.

Clinical morphological accuracy in clinical view

The shape of the 3D printed artificial teeth reconstructed by combining CBCT and UV LCD printing technology was consistent with that of the patient's teeth in the oral cavity.

ISSN: 2697-3391
Vol. 7 No. 3, pp. 120 – 136, July – September 2024
www.anatomiadigital.org

The results indicated that the 3D printed artificial teeth had a high degree of fit with the patient's analyzed teeth and showed high similarity. In addition, clinical and radiographic examinations revealed that the cross-sections in cervical, middle and apical sections of the root canals of the 3D printed artificial teeth were similar to those of the patient's teeth at the corresponding positions, with a slight discrepancy in the root canal anatomy.

Mechanical resistance in endodontic protocol

Chamber access and cavity shaping of the dental prototype were carried out using coarse-grained diamond burs with blue coding and Endo-Z burs. The tooth reacted optimally, showing adequate strength without deformation or fracture, similar to a human tooth, allowing for high-quality cavity shaping.

Subsequently, the canalometry was performed, revealing a permeability comparable to that of a real tooth. The prototype showed variability in radiolucency and radiopacity at different density points, allowing visibility of the instruments inside and thus facilitating the progress of the clinical treatment (Figure 3).

The next step was the chemical-mechanical preparation. The prototype demonstrated remarkable resistance to endodontic irrigants such as sodium hypochlorite, EDTA and saline solution, with no evidence of detachment or corrosion. This procedure, performed with endodontic files, indicated great compatibility and provided clinical sensations identical to those obtained in real treatments. However, fragility was identified in the apical third, which slightly reduced the quality and sensations of the treatment (Figure 3).

Finally, the obturation was carried out with gutta-percha cones, which achieved excellent compatibility and adaptation inside the prototype. These were clearly visualized using periapical radiographs, which facilitated the successful completion of the endodontic treatment (Figure 3)..

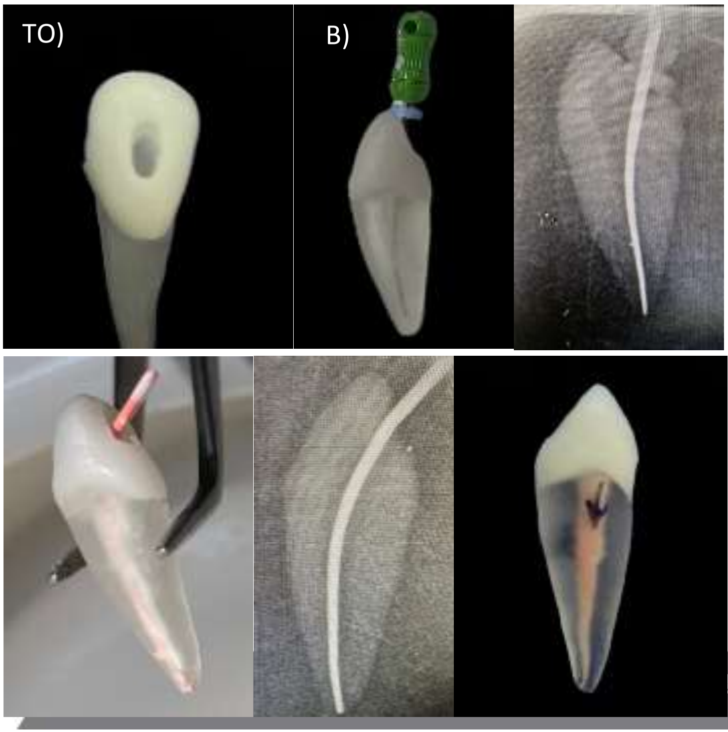

Figure3:*A) chamber opening, B) conductometry, C) conometry, D) final obturation*

Discussion

3D printing has emerged as an indispensable tool in modern dentistry, especially in the field of endodontics, due to its ability to create custom dental models with exceptional accuracy and detail.(13)This technology has revolutionized the way treatments are planned and performed, facilitating the production of anatomically identical replicas and endodontic guides adapted to the specific needs of each patient.(14).

The fabrication of ultra-realistic anatomical replicas or biomodels from medical images such as computed tomography (CT) scans or magnetic resonance imaging (MRI) using advanced 3D printing allows medical staff to rigorously assess patient anatomy in high detail. This is especially useful for analyzing root morphology, the presence of accessory canals, curvatures, and other features that can complicate endodontic treatment.(15). By having an accurate physical model, the practitioner can select the appropriate endodontic instruments, and anticipate possible difficulties, allowing them to practice on realistic clinical cases without risk to patients. They can also be used to explain to patients their condition and the treatment plan in a more understandable way.(16).

In this study, it was found that replicating accurate anatomical models of a patient's dental structures allows one to predict how an endodontic treatment will develop and to visualize what should be done or avoided to minimize complications during the clinical procedure. Authors such as Shah & Chong(17), highlight that 3D printed models can be used in endodontics as a teaching aid for students to better understand tooth, root and canal morphologies, and to simulate access cavity and root canal preparation. These models allow students to practice and hone their skills in a controlled and repeatable environment, which is crucial for their professional development. Furthermore, 3D printed models can be used to assess students’ skill progression in a standardized and unbiased manner.

This research was able to create a preview of how to improve the aesthetics and functionality of practice models for students by improving their confidence and future vision in real clinical episodes. It was noted that the use of 3D printed teeth is preferred in endodontics because these models not only look better and are more accurate compared to traditional alternatives, but also allow compliance with all the steps necessary for a complete endodontic treatment. The high precision of 3D printed models facilitates an exact representation of dental anatomy, which is crucial to effectively simulate the access cavity and root canal preparation. This ensures that students and professionals can practice and perfect their techniques in a controlled environment, which translates into greater efficiency and effectiveness in real treatments.(18).

However, Kolling et al.(19), mention that there are limitations to the use of this technology. New innovative models in endodontic teaching should be carefully reviewed and compared with the usual training models. To date, extracted teeth are considered the gold standard in preclinical teaching. The key question lies to what extent 3D printed models can live up to this standard. Equity in obtaining the appropriate material, opportunities for acquiring skills, standardization of practical examinations and fundamental hygienic aspects ultimately determine the choice of teaching method.(20).

This research has identified that 3D printed teeth have optimal characteristics for dental training of students in the area of endodontics. These models allow a complete treatment to be carried out, from start to finish, without interruptions or discomfort, providing a continuous and effective learning experience. Contrary to this study, the results of the work of Al-Sudani & Basudan(21)suggest that although artificial resin teeth have multiple advantages, they cannot replace natural teeth due to the lack of certain variations and the hardness of real teeth. However, 3D printing technology has great potential to expand its horizons in the field of teaching, creating new pre-treatment planning methodologies that reduce errors and avoid omitting pathologies.

Additionally, according to Reis et al.(22), this technology can improve the management of endodontic procedures by allowing for duplication and accurate record keeping, patient education, and aiding in treatment planning through improved visualization and determination of important anatomical landmarks or pathologies such as internal/external root resorption. It also allows for the fabrication of surgical or directional guides, significantly improving procedural accuracy.

The main question remains as to how the didactic approach and the opportunity to practice in preclinical courses actually influence the outcome of root canal treatment in the clinical setting. In this respect it should be noted that Tchorz et al.(23), could not detect quality differences based on prior training with models when performing root canal treatments on first-time patients.

In the study by Peters et al.(24), it is emphasized that dental replicas made from CBCT or microCT scans can complement natural teeth. Improvements in resin materials and 3D printing hardware will lead to even more realistic models for better skill acquisition, avoiding the use of biological tissues.

Despite some doubts and limitations, the positive results of recent studies and the recognized advantages suggest that 3D printed teeth should be integrated into dental training on a routine basis. 3D printing technology allows educators to reproduce any tooth shape and/or root-canal system variation found in endodontic classifications. Further technical development of 3D printed teeth will lay the foundation for training in integrated medical-dental teams and improve patient-centered care in the future.(25).

Conclusion

- In conclusion, the 3D printed canine teeth prototype for endodontic training has proven successful in several key aspects, facilitating the creation of a useful model in dentistry, specifically in the endodontic area. Although it stands out for its fidelity and the customization capacity offered by 3D printing, it is essential to recognize the current limitations, especially in the internal morphology and fragility of the model, specifically in the apical third, which limit its effectiveness and durability in clinical situations.
- The integration of these technologies into dental education and practice provides a more realistic and detailed learning experience. However, to achieve their full potential, further research and development is required to improve the durability of printed materials and achieve a more accurate reproduction of the anatomical and biological complexity of natural teeth.
- Consequently, continuing to explore and refine these technologies is critical to increasing their effectiveness and applicability in endodontic training, thereby ensuring significant advances in the field of modern dentistry.

Acknowledgements

Acknowledgement: To the formative research department of the Catholic University of Cuenca for their support since the work belongs to a formative research project called: Dental prototypes: 3D printing of artificial teeth for endodontic practices, in the dentistry degree of the Catholic University of Cuenca, February 2024 - December 2024. (PIFCV22-78)

Financial support: Catholic University of Cuenca

Data availability statement: Data available upon request to the authors.

Conflict of interest

There is no conflict of interest on the part of the authors regarding the article produced for the research

Authors' contribution statement

All authors participated equally in the article at all stages of its preparation.

Bibliographic References

1. Dobroś K, Hajto-Bryk J, Zarzecka J. The 3D printed teeth models intended for hands-on practice in conservative dentistry.Folia Medica Cracoviensia [Internet]. 2022 [cited 2024 Jun 12]; 62(1): 29–41. Available from: https://pubmed.ncbi.nlm.nih.gov/36088591/

2. Höhne C, Schmitter M. 3Dprinted teeth for the preclinical education of dental students. Journal of Dental Education [Internet]. 2019[cited 2024 Jun 12]; 83(9): 1100–1106. Available from: https://pubmed.ncbi.nlm.nih.gov/31133619/

3. Anderson J, Wealleans J, Ray J. Endodontic applications of 3D printing.International Endodontic Journal [Internet]. 2018[cited 2024 Jun 12]; 51(9): 1005–18. Available from: https://pubmed.ncbi.nlm.nih.gov/29486052/

4. Reis T, Barbosa C, Franco M, Baptista C, Alves N, Castelo-Baz P,Martin-Cruces J, Martin-Biedma B. 3D-printed teeth in endodontics: why, how, problems and future—a narrative review. International Journal of Environmental Research and Public Health [Internet]. 2022 [cited 2024 Jun 12]; 19(13). Available from: https://pubmed.ncbi.nlm.nih.gov/35805624/

5. Reymus M, Fotiadou C, Kessler A, Heck K, Hickel R, Diegritz C. 3D printed replicas for endodontic education.International Endodontic Journal [Internet]. 2019 [cited 2024 Jun 12]; 52(1): 123–130. Available from: https://pubmed.ncbi.nlm.nih.gov/29900562/

6. Liang X, Liao W, Cai H, Jiang S, Chen S. 3D-printed artificial teeth: Accuracy and application in root canal therapy.Journal of Biomedical Nanotechnology [Internet]. 2018 [cited 2024 Jun 12]; 14(8): 1477–1485. Available from: https://pubmed.ncbi.nlm.nih.gov/29903062/

7. Walmsley A, Walsh T, Lumley P, Burke F, Shortall A, Hayes R, Pretty I. Restorative Dentistry [Internet]. 2nd ed. Edinburgh, Scotland. Churchill Livingstone. 2007 [cited 2024 Jun 12]. p. 89–113. Available from: https://shop.elsevier.com/books/restorative-dentistry/walmsley/978-0-443-10246-2

8. Sanchez J, Garcia C. Categorization of failure for primary endodontic treatment. Acta Odontológica Colombiana [Internet]. 2019 [cited 2024 Jun 12]; 9(2): 10–23. Available from: https://www.redalyc.org/journal/5823/582361537010/html/

9. Oporto V. GH, Fuentes F. RE, Soto P. CC. Anatomical variations of the roots and canal systems.International Journal of Morphology [Internet]. 2010 [cited 2024 Jun 12]; 28(3): 945–50. Available from:

https://www.scielo.cl/scielo.php?script=sci_arttext&pid=S0717-95022010000300046

10. Morales F. Classification of retained canines and their clinical application. Journal of the Mexican Dental Association [Internet]. 2001[cited 2024 Jun 12]; 1(1): 21–30. Available from: https://www.medigraphic.com/cgi-bin/new/resumen.cgi?IDARTICULO=5520

11. HeronM. Dental Anatomy Second Edition [Internet]. 2nd ed. Bogota, Colombia. El Manual Moderno; 2015 [cited 2024 Jun 12]. 41 p. Available from: https://es.studenta.com/content/114116794/anatomia-dental-riojas-garza-2-da-edicion-pdf

12. El-Kishawi M, Khalaf K. Anupdate on root canal preparation techniques and how to avoid procedural errors in endodontics. The Open Dentistry Journal [Internet]. 2021 [cited 2024 Jun 22]; 15(1): 318–324. Available from: https://www.researchgate.net/publication/353286621_An_Update_on_Root_Canal_Preparation_Techniques_and_How_to_Avoid_Procedural_Errors_in_Endodontics

13. Meglioli M, Mergoni G, Artioli F, Ghezzi B, Manfredi M, Macaluso GM,Lumetti S. A novel self-assessment method for training access cavity on 3d printed endodontic models. Dentistry Journal [Internet]. 2023 [cited 2024 Jun 22]; 11(6). Available from: https://doi.org/10.3390/dj11060152

14. Kucher M, Dannemann M, Modler N, Böhm R, Hannig C, Kühne MT. Determinationof a representative and 3d-printable root canal geometry for endodontic investigations and pre-clinical endodontic training-an ex vivo study. Dentistry Journal [Internet]. 2023 [cited 2024 Jun 23]; 11(5). Available from: https://pubmed.ncbi.nlm.nih.gov/37232784/

15. Fakhr M, Nagy MM. Three-Dimensional tooth models for better teaching and treatment outcomes.European Journal of Dental Education [Internet]. 2023 [cited 2024 Jun 23]; 27(3): 695–699. Available from: https://pubmed.ncbi.nlm.nih.gov/36153811/

16. Petre AE, Pantea M, Drafta S, Imre M, Țâncu AMC, Liciu EM,Didilescu A, Pituru S. Modular digital and 3D-printed dental models with applicability in dental education. Medicine [Internet]. 2023 [cited 2024 Jun 23]; 59(1). Available from: https://www.mdpi.com/1648-9144/59/1/116

17. Shah P, Chong BS. 3D imaging, 3D printing and 3D virtual planning in endodontics.Clinical Oral Investigations [Internet]. 2018 [cited 2024 Jun 23]; 22(2): 641–54. Available from: https://pubmed.ncbi.nlm.nih.gov/29330656/

18. Pouhaër M, Picart G, Baya D, Michelutti P, Dautel A, Pérard M,Clerc J. Design of 3D-printed macro-models for undergraduates' preclinical practice of endodontic access cavities. European Journal of Dental Education [Internet]. 2022 [cited 2024 Jun 23]; 26(2): 347–353. Available from: https://pubmed.ncbi.nlm.nih.gov/34358393/

19. Kolling M, Backhaus J, Hofmann N, Keß S, Krastl G, Soliman S, & König S. Students' perception of three-dimensionally printed teeth in endodontic training. European journal of dental education: official journal of the Association for Dental Education in Europe [Internet]. 2022 [cited 2024 Jun 23]; 26(4): 653–661. Available from: https://pubmed.ncbi.nlm.nih.gov/34921718/. https://doi.org/10.1111/eje.12743

20. Jeong M, Radomski K, Lopez D, Liu JT, Lee JD, Lee SJ. Materialsand applications of 3d printing technology in dentistry: an overview. Dentistry Journal [Internet]. 2024 [cited 2024 Jun 23];12(1). Available from: https://doi.org/10.3390/dj12010001

21. Al-Sudani DI, Basudan SO. Students' perceptions of pre-clinical endodontic training with artificial teeth compared to extracted human teeth.European Journal of Dental Education [Internet]. 2017 [cited 2024 Jun 23]; 21(4): e72–5. Available from: https://pubmed.ncbi.nlm.nih.gov/27495270/

22. Reis T, Barbosa C, Franco M, Silva R, Alves N, Castelo-Baz P,Martin-Cruces J, Martin-Biedma B. Three-Dimensional printed teeth in endodontics: a new protocol for microcomputed tomography studies. Materials (Basel) [Internet]. 2024 [cited 2024 Jun 23]; 17(8). Available from: https://doi.org/10.3390/ma17081899

23. Tchorz JP, Brandl M, Ganter PA, Karygianni L, Polydorou O, Vach K,Hellwing E, Altenburger M. Preclinical endodontic training with artificial instead of extracted human teeth: does the type of exercise have an influence on clinical endodontic outcomes? International Endodontic Journal [Internet]. 2015 [cited 2024 Jun 23]; 48(9): 888–893. Available from: https://pubmed.ncbi.nlm.nih.gov/25266846/

24. Peters O, Scott R, Arias A, Lim E, Paqué F, Almassi S,Hejlawy S. Evaluation of dental students' skills acquisition in endodontics using a 3d printed tooth model. European Endodontic Journal [Internet]. 2021 [cited 2024 Jun 23]; 6(3): 290–294. Available from: https://pubmed.ncbi.nlm.nih.gov/34967333/

25. Tawasinchanadech N, Thammasitboon S, Buranadham S, Thammasitboon K. Masterylearning in preclinical endodontics using customized 3d-printed tooth

ISSN: 2697-3391
Vol. 7 No. 3, pp. 120 – 136, July – September 2024

models for deliberate practice: an application of educational design research. Journal of Endodontics [Internet]. 2024 [cited 2024 Jun 23]; 19(24). Available from: https://pubmed.ncbi.nlm.nih.gov/38906527/

ISSN: 2697-3391
Vol. 7 No. 3, pp. 120 – 136, July – September 2024
www.anatomiadigital.org