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ORIGINAL ARTICLE

Evaluation of the Use of 3D-Printed Tooth Models in Endodontic Practical Training

3D Baskılı Diş Modellerinin Endodontik Uygulamalı Eğitimde Kullanımının Değerlendirilmesi

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Abstract

Introduction: In this study, the use of three-dimensional (3D)–printed dental models for practical endodontic training is evaluated.

Methods: To evaluate the efficacy of incorporating 3D-printed dental models into their educational curriculum, an extensive examination was conducted among 84 third-year dental students at Pamukkale University Faculty of Dentistry. Statistical analysis was conducted using SPSS 25 software.

Results: No significant gender biases were observed. More than 80% of the students suggested the incorporation of 3D models into preclinical endodontic education improves their manual proficiency in carrying out cavity preparation and filling. Students acknowledged the effectiveness of 3D models in optimizing skills that are related to various procedures, such as access cavity preparation, root canal preparation, rubber dam application, upper filling restoration, and matrix band application. Despite these positive aspects, 60.7% of students perceived 3D model teeth as inappropriate in terms of hardness when compared with real teeth.

Discussion and Conclusion: The findings emphasize the potential transformative impact of 3D-printed dental models on dental education, which contributes to increased student satisfaction and enhanced skill acquisition. To delve into broader implementation and enhancements in integrating this technology into educational practices, further research is recommended.

Keywords: Cone beam computed tomography; 3D print; Root canal treatment; Cavity

In dental education, conventional approaches are heavily dependent on resources such as extracted teeth,[1] human cadavers, or resin blocks for preclinical exercises, each posing distinct challenges.[2] Various studies have been conducted to enhance the quality of student education and assess the outcomes.[3,4] Extracted teeth, although providing semi-realistic simulation, face issues in terms of availability and storage. Simultaneously, three-

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dimensional (3D) printing has become a cornerstone in preclinical research, which has generated numerous identical prototypes for investigating various dental aspects. Studies have delved into factors including the centering proficiency in performing endodontic access preparations,[5] diverse filling methods for C-shaped root canals,[6] shaping ability of different rotary file systems,[7] and stress values associated with these systems.[8] Benefiting from controlled canal configurations, these investigations obtain precise and comparable evaluations. A notable contribution by Mohmmed et al.[9] introduced a novel *in vitro* model using 3D printing to demonstrate E. faecalis biofilm growth on stereolithography apparatus (SLA) materials, comparable with dentine. This model was further employed to evaluate irrigation techniques, underscoring the potential of 3D printing in advancing *in vitro* methodologies.[10] The continuous evolution of 3D printing materials further enhances the creation of more realistic alternatives to extracted teeth, expanding the horizons of dental research.

During endodontic practical training in the third grade, the utilization of extracted teeth not only raises concerns regarding hygiene[1] but also introduces challenges that are related to calcified canals, which can be curved, narrow, or exhibit irregular anatomy, which complicates the treatment process.[11] This study aims to establish a questionnaire using the "Likert" scale, which questions how teeth produced from a 3D printer that can solve the above-mentioned concerns are utilized by students during education and how they evaluate 3D tooth models compared with extracted teeth. The experiences and skill acquisition of students in preclinical exercises using these 3D-printed dental models will be investigated. Moreover, the study will explore the advantages and challenges of incorporating this new method into the educational process.

This study aims to evaluate the use of 3D-printed dental models for practical endodontic training. The null hypothesis suggests that 3D-printed models do not offer significant advantages or disadvantages compared to traditional extracted teeth in the context of dental education.

The survey employed a 5-point Likert scale, a common tool in contemporary research. Originally comprising 5 options, Likert-type questions have since been adapted to include varying numbers of options, typically ranging from 3 to 7, with different labeling systems.[12] In our survey, we used a 5-point Likert scale, with response options ranging from "strongly approve" to "strongly disapprove," allowing respondents to select one of five available answers.

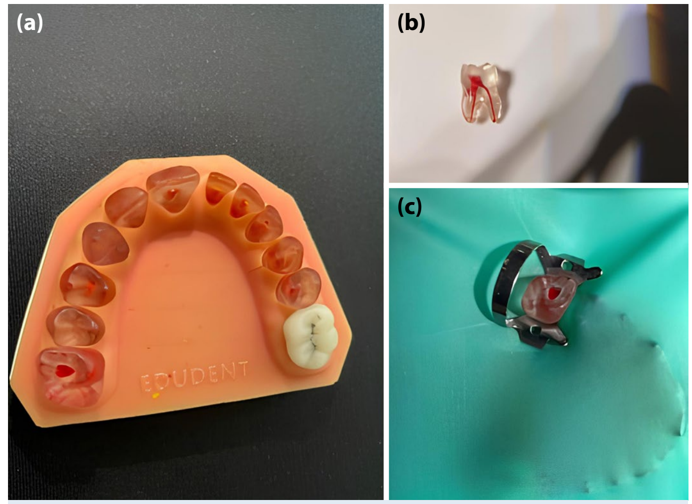

Figure 1. Printed tooth in study model **(a)**, printed tooth **(b)**, and tooth after root canal treatment **(c)**.

Materials and Methods

The research protocol received approval from the Pamukkale University Research Ethical Committee Institutional Review Board [(number: E-60116787-020-353837), (date 06.04.2023)]. Following the approval, a cone beam computed tomography (CBCT) scan was managed on a human mandibular first molar, and the resulting data files were formatted in standard triangle language. Subsequently, 3D tooth models (Edudent, Türkiye) were produced by a manufacturer that supplied these models for the experimental phase of the study (Fig. 1a–c).

Two printing methods, SLA and fused deposition modeling (FDM), were employed for different parts of the 3D models: SLA with a Formlabs FORM2 printer (USA) and FDM with a 3DGence Industry F340 printer (Poland). The FDM technology, utilizing acrylonitrile butadiene styrene, was used to print the mandible base for the dental patient simulator, whereas SLA technology was employed for the other components. Components including the alveolar part, teeth, and carious lesions of the mandible were fabricated using various types of resin such as elastic, rigid, white, and black resins. The replication of the pulp was achieved using an impression material. In this study, artificial intelligence–supported applications were not used.

The effect size was calculated using the G*Power 3.1 program (version 3.1.9.2; Heinrich Heine University, Düsseldorf, Germany). Based on the pilot study results, conducted in accordance with previous research,[13] the required sample size for our study was determined to be 24 to ensure reliable results. However, the study was ultimately conducted with a total sample size of 84. This calculation was based on a Type I error rate of 0.05 and a statistical power of 95%.

Information about the study's objectives and methodology was provided to 90 third-year dental students enrolled at Pamukkale University Faculty of Dentistry. All 84 dental students actively participated in the study. Each participant was required to perform a complete root canal treatment on 3D-printed tooth models, including access cavity preparation, root canal cleaning and shaping, obturation, and sealing, while following standard clinical protocols. Following the practical component, participants were administered a survey designed to gather their feedback.

The survey included questions on general demographics, the realism of the 3D dental models, the hardness and replication of pulp, and their suitability for access cavity preparation. It also assessed the models' effectiveness for various procedures, such as root canal filling, matrix band placement, and rubber dam application. Additionally, the survey evaluated the models' compatibility with endodontic procedures, the accuracy of working length determination, the risk of endodontic complications, and their compatibility with artificial jaw models. Overall educational quality, along with the advantages and disadvantages of the models, was also examined.

The survey employed a 5-point Likert scale, a commonly used tool in contemporary research. While Likert-type questions originally consisted of 5 options, they have since been adapted to include varying numbers of options, typically ranging from 3 to 7, with different labeling systems.[12] Our survey used a 5-point Likert scale for data collection, with responses ranging from "strongly approve" to "strongly disapprove." Respondents were asked to select one of the five available answers for each question.

Statistical Analysis

All statistical analyses were conducted using SPSS Statistics 25.0 software (IBM Corp., Armonk, NY, USA). Descriptive statistics were used to analyze the collected data. Continuous variables were presented as mean ± standard deviation (SD), and categorical variables were expressed as numbers and percentages. The Chi-square test was applied to compare categorical data, with the significance level set at 0.05.

Results

A total of 84 students participated in this study (45 women and 38 men, aged 20–24 years, with a mean age of 20.476±1.005). There was no significant effect of gender ($p>0.05$). All students had prior experience working with extracted human teeth. The majority, 80 students (95.23%), had successfully handled and filled more than six extracted teeth in their preclinic. By contrast, the remaining four students (4.77%) had notably fewer cavity preparation and filling experiences.

According to the students, 3D dental models were deemed proficient in accurately reproducing the anatomical characteristics of teeth (Fig. 2a). The replication of hard tissue features is perceived as the least strong aspect. In the questionnaire, we asked about the degree of hardness similar to real teeth; different from all other questions, the answer "I do not approve" comes first with a rate of 45.2% (Fig. 2b). A greater number of participants evaluated the replication of the pulp as either satisfactory or unsatisfactory in mimicking its natural counterparts.

The response concerning the appropriateness of access cavity preparation was "I approve" with a rate of 67.9% (Fig. 2c). Similarly, a high rate of "I approve" answers were received when asked about the suitability of artificial acrylic root canal preparation, rubber dam application, and determination of the localization of root canals (Fig. 2d–f; 63.1%, 47.6%, and 53.6%, respectively).

Inquiries directed toward students regarding their suitability for artificial root canal filling, cavity filling, and matrix band placement received similar rates of "I approve" answers (Fig. 2g–i). Interestingly, the answer "I'm undecided" tends to be slightly higher in questions concerning restorative parts.

Questions regarding the reduction of the risk of endodontic complications, determination of the working length of artificial root canals, and compatibility of tooth models with the artificial jaw models used received the answer "I approve" (Fig. 3a–c).

Based on the responses provided by the students, although it can be concluded that the education given with 3D dental models is on more equal terms, we cannot reach the idea that the education given with these teeth is of better quality because a group of students with a rate of 29.8% answered: "I am undecided." Nevertheless, the number of students who answered "I do not approve" and "I definitely disapprove" are 7.1% and 1.2%, respectively (Fig. 3d, e).

Every student responded to survey questions. The important advantages offered by 3D tooth models are that they represent the general anatomical features of the teeth realistically and are suitable for duplication and suitability for access cavity preparation and suitability for canal filling. The most important disadvantage is that artificial hard tissue is not suitable in comparison with original hard tissue.

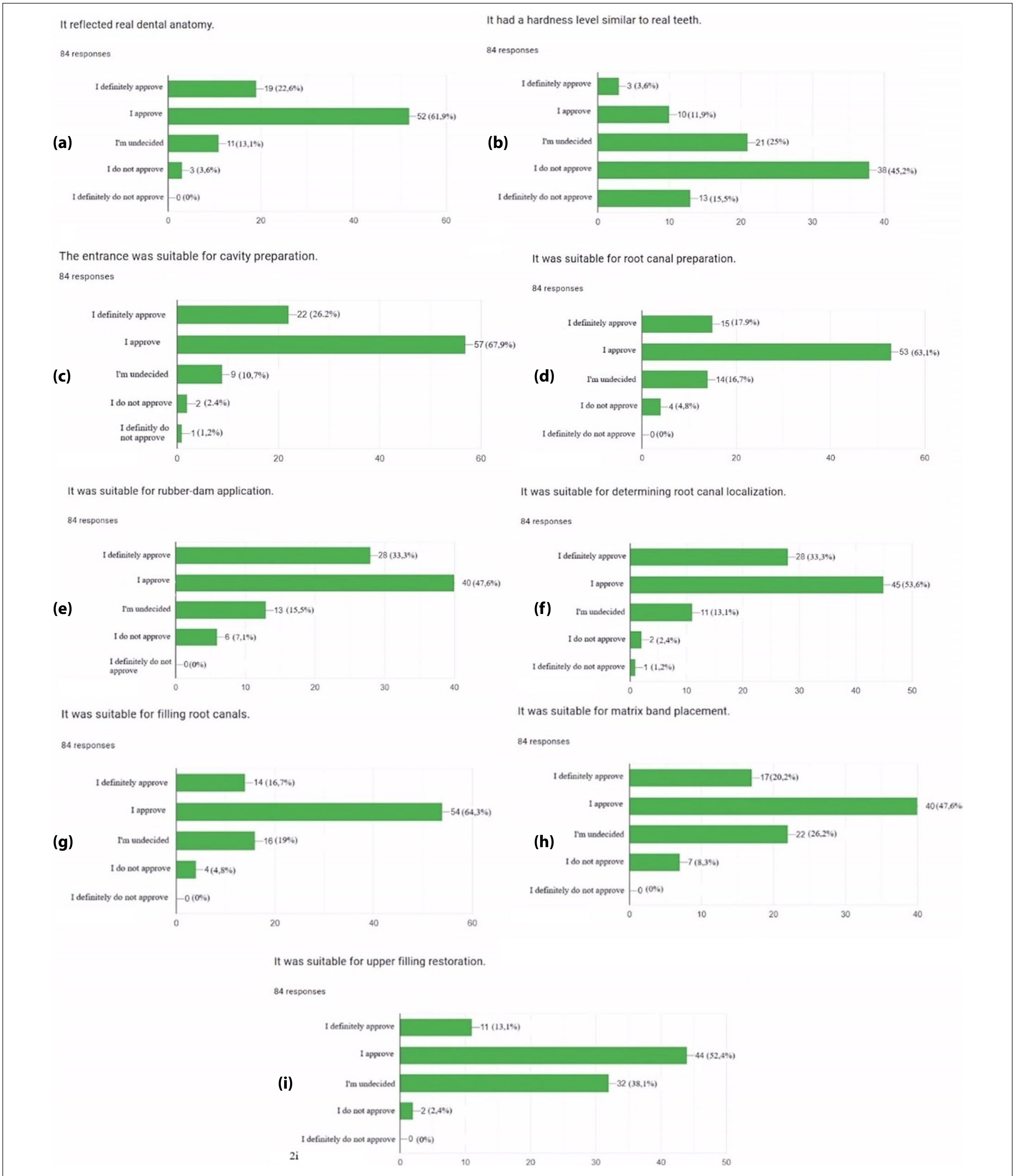

Figure 2. "It reflected real dental anatomy" **(a)**, "It had a hardness level similar to real teeth" **(b)**, "The entrance was suitable for cavity preparation" **(c)**, "It was suitable for root canal preparation" **(d)**, "It was suitable for rubber dam application" **(e)**, "It was suitable for determining root canal localization" **(f)**, "It was suitable for filling root canals" **(g)**, "It was suitable for matrix band placement" **(h)**, and "It was suitable for upper filling restoration" **(i)**.

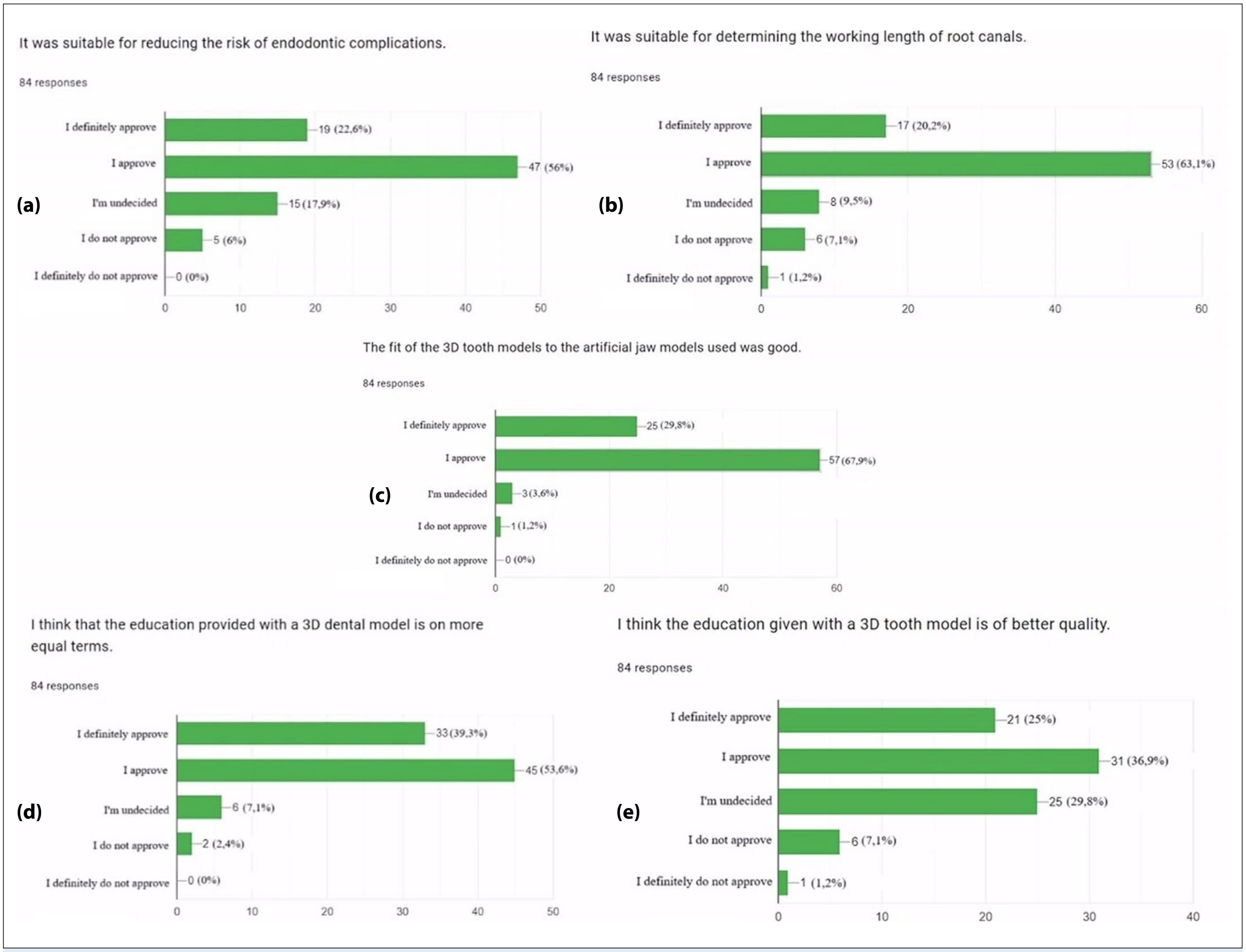

Figure 3. "It was suitable for reducing the risk of endodontic complications" **(a)**, "It was suitable for determining the working length of root canals" **(b)**, "The fit of the 3D tooth models to the artificial jaw models used was good" **(c)**, "I think that the education provided with a 3D dental model is on more equal terms" **(d)**, and "I think the education given with a 3D tooth model is of better quality" **(e)**.

Discussion

The students commonly employ either standard teeth models or extracted teeth at preclinic. However, they contend that the anatomical perfection of standard models disregards natural variability among patients' teeth.[14,15] Contrarily, the initial 3D model, replicating the mandible with teeth, accurately emulated patient-specific characteristics obtained from CBCT scans. This method facilitated a true-to-life anatomical reproduction, which was highly appreciated by the students.

Höhne et al.[14] carried out studies that evaluated the overall hardness of 3D-printed teeth models during prosthetic crown preparation, receiving an adequate rating from students. Interestingly, tactile perception garnered a slightly higher rating in the same evaluation.[16] In Reymus et al.'s[15] endodontic model, the overall hardness was compared to that of extracted teeth, which resulted in a lower rating that impacted the ease of preparation work. Conversely, Marty et al.'s[17] 3D model suggested an impractical pace of material extraction based on students' opinions. Notably, the original 3D tooth model received a high rating in terms of the overall hardness of the printing material.

In this study, a high rate of approval was received when asked about the model's suitability for root canal preparation, rubber dam application, and determination of the localization of root canals. Additionally, the answer to the question concerning suitability to access cavity preparation was received from 67.9% of the students. These answers are compatible with a study conducted in 2022 on the use of 3D artificial teeth for educational purposes in conservative dentistry. As shown in this study, the answer "I approve" to the question concerning the access cavity ranks first with 11 points. Particularly, the response rate in terms of rubber dam application coincides with the study conducted in Poland, in which the answer "I approve" received a high score of 13 points.[13]

In the question we asked about the degree of hardness similar to real teeth, unlike all other questions, the answer "I do not approve" comes first with a rate of 45.2%. This answer is similar to the answers in the study on the use of 3D tooth models produced with stereolithography technology in the applied training of endodontics, conducted in 2020.[18] Additionally, the findings were similar to those of a previous study on the use of 3D-printed teeth in endodontic courses.[19,20]

The application of SLA system–produced teeth models originated in the 1990s and was initially employed in medicine for surgical planning and crafting personalized implants. However, the utilization of 3D-printed teeth models in endodontics education presents an innovative approach, which leads to a limited number of published studies on this pioneering method.

Employing 3D-printed teeth models presents an effective solution for preclinical root canal training. These models accurately replicate the diverse root canals of different teeth, a property lacking in factory models. Importantly, they eliminate the risk of cross-infections associated with extracted teeth. A study by Tchorz et al.[21] compared the standard of root canal treatments applied by students on artificial and extracted teeth, which revealed more iatrogenic mistakes and inferior overall quality in the extracted teeth group. The authors argued that standard tooth models simplify root canal training due to their basic anatomy. By contrast, SLA-manufactured tooth models not only eliminate bio-hazards but also offer precise representations of anatomical variations.

The study is limited by the imperfect replication of tooth tissue properties in the material utilized for 3D models, lacking ideal similarity to actual density, hardness, and elasticity. Moreover, the uniform anatomy of teeth in the study overlooks the recognized broad variability, particularly in premolars and molars. Despite these limitations, working with 3D models provides students with valuable insights into fundamental principles and practical constraints of the procedure. Furthermore, the use of 3D-printed teeth models holds promise in complex clinical cases, which offers a potentially significant tool for mapping out personalized treatments as availability becomes more widespread.

Students who selected "I'm undecided" often mentioned that anatomical variability hindered a valid assessment of their individual performance. This finding aligns with a previous study on the production phase of 3D-printed teeth.[22] It was also observed that, given sufficient teeth and time, students expressed a desire for additional practice, which is consistent with findings from earlier studies on 3D-printed teeth.[23,24]

Conclusion

Practical courses during dental studies constitute the basic component of the education of future dentists. Students expressed a high level of satisfaction with the 3D tooth models, mostly because basic anatomical features were adequately replicated and the pulp chamber was well simulated.

The use of 3D models in endodontic education can be recommended as it has a noteworthy potential to enhance the overall quality of education at the preclinical stage with studies to achieve real tooth hardness, to remarkably reduce the risk of facing complications during real clinical work.

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