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Original Article

A New Self-Evaluation Approach for Practicing Access Cavity Preparation Using 3D-Printed Endodontic Models

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ABSTRACT

Emerging technologies can ease the transition from pre-clinical exercises to actual clinical practice. This study evaluated students' satisfaction with a novel approach for access cavity training. Students performed access cavity preparations on cost-effective, in-house 3D-printed teeth. Prepared teeth were scanned using an intraoral scanner and visualized through mesh processing software. The same software was then employed to align the students' work with the instructor's reference for self-assessment. Students completed a questionnaire to report their experiences with this learning method. From the instructors' viewpoint, the approach was simple, practical, and economical. Student responses were largely favorable: 73% considered scanning-based assessment more beneficial than visual inspection under magnification, and 57% felt it helped them better recognize errors and mistakes. However, some students noted that the 3D-printed material was too soft. Incorporating in-house 3D-printed teeth into pre-clinical training offers a practical solution to limitations associated with extracted teeth, including scarcity, variability, infection control issues, and ethical concerns. Additionally, intraoral scanning combined with mesh processing software may enhance students' self-assessment abilities.

Keywords: Intraoral scanner, Endodontics, Access cavity, 3D printing, Dental education

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Introduction

The main objective of root canal therapy is to treat or prevent apical periodontitis [1], a common dental condition in adults [2]. In Italy, where endodontics is not yet a fully established specialty, root canal procedures are often carried out by general dentists, who frequently achieve suboptimal results [3, 4]. Similar findings regarding the quality of treatments performed by general dentists have been reported in other countries [5-7], potentially due to insufficient training during undergraduate education [8].

Pre-clinical training is a crucial stage for dental students, allowing them to become proficient with techniques and procedures before entering clinical practice [9]. Given its importance, enhancing pre-clinical education is strongly encouraged, and emerging technologies can play a key role in this process [10]. The European Society of Endodontology (ESE) and the Association for Dental Education in Europe (ADEE) have jointly recommended the development of intelligent systems to support pre-clinical skills training and provide immediate performance feedback [11].

Traditionally, extracted human teeth have been widely used in pre-clinical endodontic training because they are free, present diverse anatomical variations and pathologies, and provide essential tactile feedback for developing manual dexterity and tactile sensitivity [12, 13]. Recent surveys report that 82.1%, 73%, and 100% of dental schools in Italy, the UK, and Spain, respectively, still use extracted teeth for training [14-16]. However, their use comes with limitations: improved oral health and alternative treatments have reduced the availability of suitable extracted teeth [17],

ethical concerns arise, and strict measures are needed to prevent cross-infection [13, 18]. Moreover, the natural variability of teeth can complicate both classroom exercises and the assessment of student performance [19].

To address these issues, a variety of artificial root canal models have been developed, ranging from resin blocks with different canal shapes to plastic typodonts [20, 21]. In particular, some companies now produce 3D-printed teeth derived from X-ray or micro-CT scans of extracted teeth [19]. Across medical fields, students have enhanced their skills using 3D-printed models that replicate patient tissue haptics [22], with successful applications reported in temporal bone surgery [23, 24], implant placement, and maxillary sinus floor augmentation [25].

In dentistry, 3D-printed models are commonly used for pre-clinical training in procedures such as caries removal, direct pulp capping, core build-up, and crown preparation [26]. The cost of these models depends on the tooth type and anatomical fidelity, and large quantities are required for repeated student training, making affordability a key factor [27]. The decreasing cost of 3D printers has enabled in-house production of tooth replicas [28], offering advantages such as unlimited availability and standardized anatomy [12].

Intraoral scanners (IOSs) are widely used to create detailed digital impressions [29], operating through light sources like lasers or structured light projected onto the scanned object, with imaging sensors capturing the reflected images. The scanning software processes these images into point clouds, which are then converted into 3D surface models (meshes) through triangulation [30]. Beyond clinical applications, IOSs have shown promise in dental education. Seet *et al*. demonstrated that IOSs can improve the assessment of student crown preparations by addressing limitations of conventional evaluation [31], while Park *et al*. highlighted the benefits of CAD/CAM-based learning software for objective pre-clinical prosthodontic assessment [32]. More recently, Choi *et al*. used IOSs as feedback tools for evaluating student access cavity preparations on 3D-printed teeth [33].

This study aims to present a novel learning method implemented in access cavity exercises at the Parma Dental School.

Materials and Methods

This study involved 19 fifth-year dental students enrolled in the Endodontics course at Parma University from September 2022 to January 2023. The undergraduate endodontic program includes 50 hours of theoretical lectures and 75 hours of hands-on pre-clinical training. During these practical sessions, students translate lecture concepts into practice by performing complete endodontic procedures—ranging from access cavity preparation to canal shaping, cleaning, and obturation—on extracted teeth under close tutor supervision. In contrast to previous academic years, the 2022–2023 course also incorporated exercises on four to five 3D-printed teeth produced in-house, alongside a comparable number of natural teeth.

To create replicas of teeth 1.1 and 3.6 that preserved both internal and external anatomical features, STL files freely available online [34] were used. These files were imported into PreForm software (Formlabs, Somerville, MA, USA), where custom 3D printing supports were designed to enable accurate fabrication **(Figure 1)**.

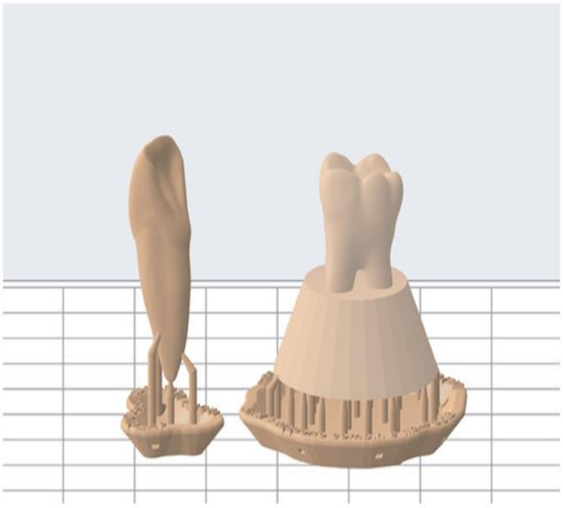


Figure 1. STL files imported into PreForm software with customized 3D printing supports.

The teeth were printed at a layer resolution of 100 µm using a Form 2 vat photopolymerization printer (Formlabs, Somerville, MA, USA) with Model V2 resin, chosen for its strength and precision suitable for dental simulation. After printing, the models were post-processed: first, they were immersed in 97 percent isopropyl alcohol for 10 minutes in the Form Wash system, and then cured for 80 minutes at 60 °C in the Form Cure unit. Following removal of the printing supports, the 3D-printed teeth were ready for practical use **(Figure 2)**.

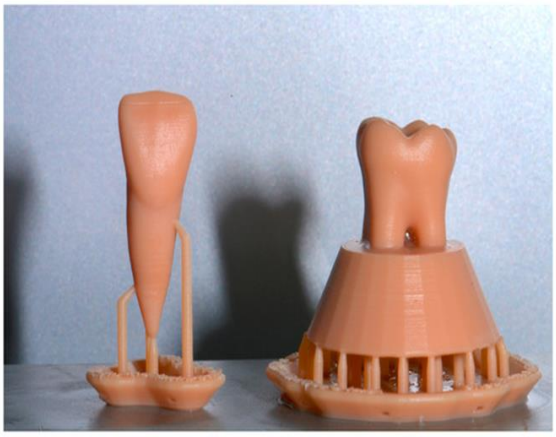


Figure 2. Replicas of teeth 1.1 and 3.6 following the post-curing procedure.

Students carried out access cavity preparations using both air-driven and electric handpieces, following standard clinical practice **(Figure 3)**.

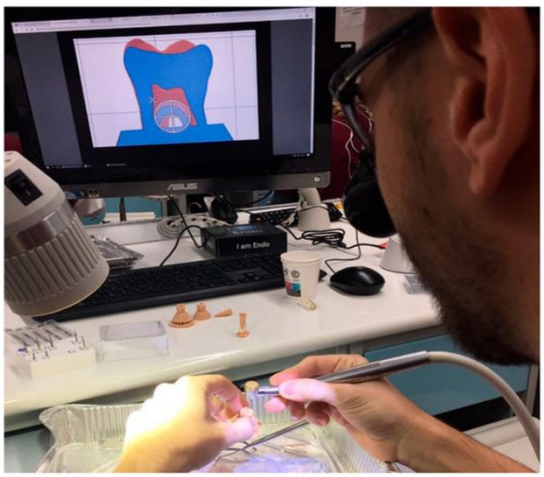
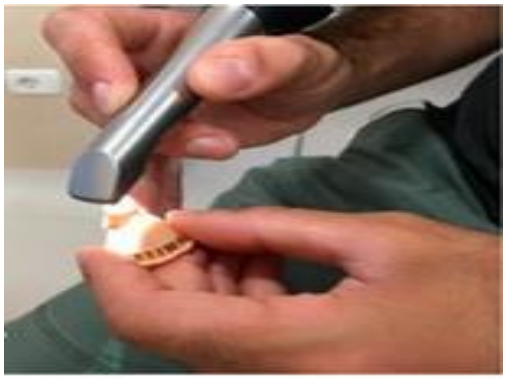


Figure 3. Students performing access cavity exercises on 3D-printed teeth during pre-clinical training.

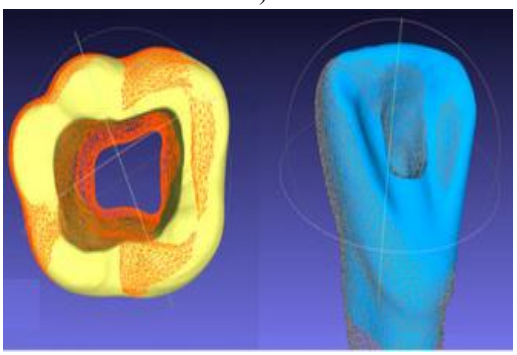
In contrast to exercises on natural teeth, students completed the training on 3D-printed teeth without direct tutor supervision. Evaluation of the prepared access cavities was conducted as follows: each tooth was scanned using the Omnicam system (Dentsply Sirona, Charlotte, NC, USA), and any voids or scanning errors in the resulting 3D model prompted a rescanning until accurate data were obtained. The scan files were exported as STL format and opened in Meshlab v.2022.02 (Visual Computing Lab, Pisa, Italy), an open-source platform that enabled students to manipulate the model—rotating, zooming, and inspecting it—to assess cavity size, shape, extent, completeness of deroofing, proper form, gouging, and the presence of perforations.

Meshlab also allowed alignment of the student-prepared model with a reference tooth prepared by the instructor, facilitating direct visual comparison and identification of differences **(Figure 4)**. Beyond visual assessment, the software enabled quantitative analysis of geometric deviations using the Hausdorff distance, a metric that measures the greatest distance from any point in one set to the closest point in another, effectively quantifying the dissimilarity between two point sets [35, 36]. The Hausdorff distance considers deviations in both directions, providing a comprehensive measure of how much the student's preparation differed from the ideal model.

To summarize the overall discrepancy, the root mean square (RMS) of the Hausdorff distances was calculated. RMS provides a statistical measure of the average magnitude of differences, accounting for both positive and negative deviations. This approach offered a precise, quantitative evaluation of the variation between the students' preparations and the teacher's model, complementing the visual inspection with objective metrics.



a)



b)

Figure 4. Digital scan of a prepared tooth (a) and its visualization using MeshLab software (b).

Upon completion of the course, and following approval from the local research ethics committee (protocol number 94637/2023), students' perceptions and satisfaction with the access cavity training were assessed through a voluntary questionnaire.

Participation was invited via a Google Form distributed by email, and students were informed about the study's purpose, the anonymity of responses, and that participation would not affect their course evaluations. The questionnaire explored topics such as challenges in obtaining extracted teeth, perceived differences between natural and 3D-printed teeth, the value of 3D-printed teeth for pre-clinical practice, and the usefulness of self-assessment through digital scanning and alignment software. Most questions utilized a 5-point Likert scale (1—strongly disagree to 5—strongly agree), while some closed-ended questions offered options such as "yes/no" or "less/equal/more." Open-ended questions gathered qualitative feedback on the advantages of natural versus artificial teeth and overall impressions of the training program.

Results and Discussion

From the instructors' viewpoint, the new learning method was practical, straightforward, and cost-effective. After preparing the STL files, printing each tooth required approximately 12 minutes, with resin costs of about 0.54 euros per tooth. Scanning each tooth took roughly one minute.

The RMS values quantifying deviations between student-prepared molars and the reference model averaged 0.269 ± 0.05 mm (n = 44, range 0.134–0.336 mm), while for incisors the mean RMS was 0.279 ± 0.07 mm (n = 44, range 0.07–0.396 mm). Considering all teeth together, the average RMS was 0.274 ± 0.06 mm (n = 88, range 0.07–0.396 mm).

The questionnaire achieved a 100% response rate, with all students completing every question. Overall, the feedback regarding the use of in-house 3D-printed teeth and intraoral scanning for access cavity training was strongly positive **(Figure 5)**.

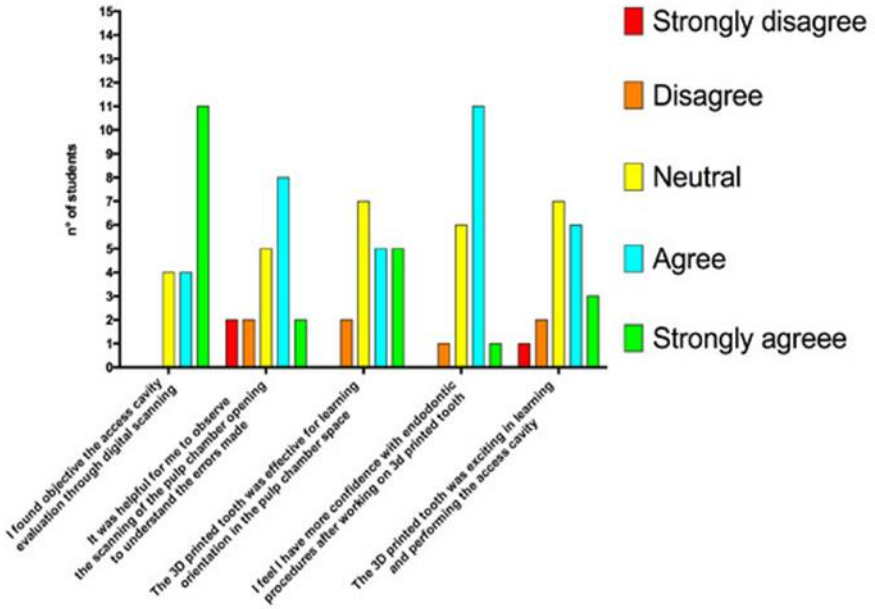


Figure 5. Student perceptions following access cavity exercises using in-house 3D-printed teeth and digital scanning.

Fifteen students (79%) agreed that observing the scanned pulp chamber opening helped them recognize their mistakes, while 14 students (74%) felt that analyzing the cavity digitally was more beneficial than direct visual inspection. Only 4 students disagreed with the statement that the digital scanning provided an objective evaluation of access cavities. A majority of students (16/19, 84%) reported that the pulp morphology of the 3D-printed teeth was easy to interpret, whereas three students (16 percent) found identifying anatomical landmarks for a proper opening challenging. Additionally, 11 students (58%) considered 3D-printed teeth more appropriate than natural teeth for practical examinations.

Students identified the primary limitation of 3D-printed teeth as the difference in tactile feedback compared to natural dentin **(Figure 6)**.

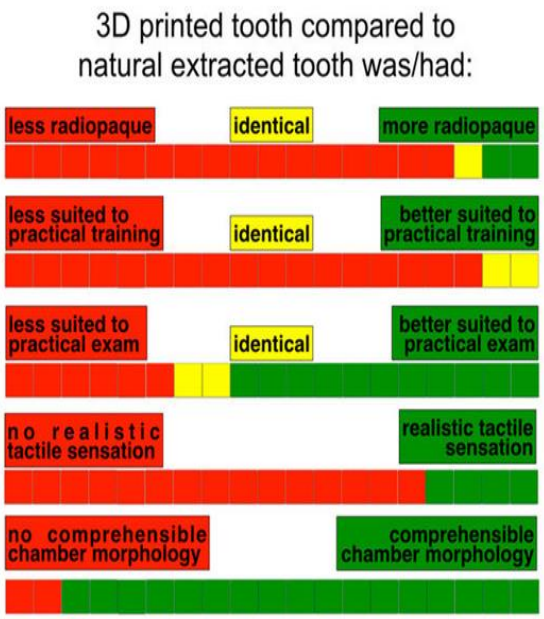


Figure 6. Student comparison of 3D-printed and extracted teeth based on questionnaire responses.

All students reported that the resin of the 3D-printed teeth felt softer than natural dentin, and 15 out of 19 students (79%) indicated that the printed teeth did not provide a realistic tactile experience during preparation. Only seven students (37 percent) agreed that 3D-printed teeth were helpful for developing fine sensitivity when using rotary instruments for access cavity preparation. A small portion (6/19, 32%) considered 3D-printed teeth a valid substitute for extracted human teeth in training exercises, whereas nine students (47%) found the printed teeth engaging and stimulating for learning and performing access cavities. Additionally, four students (21%) noted challenges in obtaining extracted teeth.

In open-ended responses, students highlighted several advantages of 3D-printed teeth for access cavity training. They valued their greater availability, absence of cross-infection risk, and reduced risk of fracture compared to natural teeth. The ability to repeat exercises on the same model was considered particularly useful for refining skills in the early learning stages, and having identical models allowed simultaneous practice for multiple students. Some students appreciated that standardized pulp chamber anatomy, without calcifications or variations, facilitated initial learning. One student remarked that printed teeth enable consistent assessment of student performance. For future improvements, many students suggested increasing the resin hardness to enhance tactile feedback and prevent the bur from catching, as well as introducing a wider variety of 3D-printed tooth types.

The primary goal of root canal therapy is the treatment or prevention of apical periodontitis [1, 37], which requires that every stage of the procedure be executed correctly [38]. Among these steps, the access cavity is particularly critical, demanding precision and care, as errors at this stage can compromise subsequent management of the root canal system [39]. Creating an access cavity has been reported as a stressful task for dental students [40] and is frequently associated with iatrogenic errors, such as untreated or inadequately cleaned, shaped, and filled canals [41]. Poorly performed access cavities are a common cause of treatment failure, highlighting the need for effective pre-clinical training methods, for which emerging technologies can be highly beneficial.

In this study, we present a novel learning approach implemented at the Dental School of Parma that combines in-house 3D-printed teeth with intraoral scanning (IOS) for access cavity exercises. While the use of 3D-printed teeth in endodontic education is not new [27, 41–43], recent advances have introduced commercially produced models capable of closely replicating dental anatomy [19]. However, their high cost often limits their availability for large-scale student training. The decreasing costs of in-house 3D printing now allow dental schools to produce models independently, including those that are not commercially available or are prohibitively expensive [28, 34, 44, 45]. Typically, the workflow involves converting DICOM data from CBCT or microCT scans of natural teeth into STL files, followed by extensive refinement and smoothing using specialized software before printing [46, 47]. This process can be time-consuming and represents a major limitation of custom model production.

For this preliminary study, we opted to use freely available STL files to assess the feasibility of printing and to gather initial student feedback, with plans to create models from natural tooth scans in future courses. Students also expressed interest in having additional tooth types produced. According to their responses, the 3D-printed teeth accurately represented pulp morphology and provided identifiable anatomical landmarks for conventional access cavity preparation. However, consistent with prior reports [27, 48–50], the resin's mechanical properties were softer than natural dentin, limiting realistic tactile feedback during the use of rotary instruments. One potential solution, proposed by Robberecht *et al.*, involves producing ceramic-based models with hydroxyapatite to mimic dentin hardness [51, 52], though the complexity of manufacturing restricts widespread adoption. A more practical approach, already partially explored by some

manufacturers [19], is to develop novel resins and advanced post-printing methods to achieve mechanical properties closer to natural teeth.

Following access cavity exercises, students used an IOS to acquire digital impressions of their prepared teeth. These scans were processed in MeshLab, a free STL visualization software, which allowed students to manipulate the models—rotating them 360 degrees and zooming in for detailed inspection. Furthermore, the software enabled alignment of student-prepared cavities with an ideal model created by the instructor, instantly highlighting deviations in shape, size, and extent. Iatrogenic errors such as incomplete deroofing, gouging, or perforations could be easily identified. By employing the Hausdorff distance function within MeshLab, discrepancies between student and reference models could also be quantified. In future work, we plan to evaluate whether RMS values derived from these measurements can serve as reliable proxies for instructor assessments, potentially supporting both self-evaluation and formal examination grading.

Students reported high satisfaction with the new self-assessment method, likely reflecting not only the immediate visual feedback provided but also the general enthusiasm of dental students for digital dentistry [53]. Commercial digital evaluation platforms, such as PrepCheck® (Dentsply Sirona©, Bensheim, Germany), Dental Teacher™ (KaVo©, Biberach, Germany), and Compare© (Planmeca©, Helsinki, Finland), offer feedback on student prosthetic preparations by comparing them with reference scans [54–56]. To our knowledge, only one previous study explored the use of IOS as a learning tool in preclinical endodontic training: Choi *et al*. [33] evaluated student experiences using commercial 3D-printed teeth, an IOS, and custom software called 3D Dental Align. Despite differences in protocols—including commercial versus in-house printed teeth, Emerald versus Omnicam IOS, and 3D Dental Align versus Meshlab software—both approaches received similarly positive student feedback.

In the present study, we opted for in-house 3D-printed teeth to reduce costs and ensure an unlimited supply. Although 3D Dental Align is specifically designed to streamline workflows for both instructors and students, aligning models using Meshlab was more complex; however, all students successfully completed the task under supervision. The Omnicam 2.0 was used because it was readily available in our clinical department, and previous studies suggest it may offer greater accuracy than Emerald IOS (Planmeca, Helsinki, Finland) [57]. Future research should examine how IOS reliability influences access cavity evaluation.

Conclusion

Traditional use of extracted teeth in dental education faces limitations, including reduced availability and ethical concerns. Emerging technologies, particularly 3D printing, offer a practical alternative by providing accessible, anatomically realistic models. These tools enable educators to circumvent the constraints of conventional teaching methods.

Our findings indicate that integrating 3D printing with IOSs and mesh processing software enhances pre-clinical training by facilitating more efficient and objective assessment of student performance. Further studies are needed to fully validate this innovative approach and compare its effectiveness to traditional training methods.

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Conflict of Interest: None

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Ethics Statement: None

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