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Short Communication

Students' perspectives on 3D-printed-simulated-caries teeth in transition to operative practice

Jiachen Lin [a], Emma Brooke Rooney [b], Nadia Irene Hossain [a], Supattriya Chutinan [a*]

[a] *Department of Restorative Dentistry and Biomaterials Sciences, Harvard School of Dental Medicine, Boston, MA, USA*
[b] *Boston College, Boston, MA, USA*

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Abstract The transition from pre-clinical to clinical operative dentistry requires effective training tools; however traditional typodont teeth often fall short in simulating clinical scenarios such as caries preparation. This study evaluated the perspectives of 71 third-year dental students from the classes of 2024 and 2025 at Harvard School of Dental Medicine on the use of 3D-printed caries teeth as a preparatory tool. Students participated in case-based collaborative learning and operative exercises using these models, with pre- and post-surveys capturing feedback on realism, usability, and educational impact. Statistical analysis revealed significantly increased confidence in modifying cavity preparations, understanding caries removal principles, selecting burs, using hand instruments, and differentiating carious from sound tooth structures. Students also reported improved comfort in designing cavity preparations and reduced reliance on instructors. These findings demonstrate that 3D-printed teeth effectively enhance students' skills and confidence, making them valuable tools for pre-clinical dental education and improved learning outcomes.

* Corresponding author. Department of Restorative Dentistry and Biomaterials Sciences, Harvard School of Dental Medicine, 188 Longwood Avenue, Boston, MA, 02115, USA.
E-mail address: supattriya_chutinan@hsdm.harvard.edu (S. Chutinan).

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Introduction

Pre-clinical exercise is a crucial learning process for developing hand skills and applying didactic knowledge in the operative curriculum. Traditionally, students practice using typodont plastic teeth, which have limitations in mimicking natural tooth structure and caries lesions. This can create challenges when dealing with caries lesions in a live patient and increase stress in dental students, further hindering their pre-clinical training and educational progress.[1]

Several technologies, such as haptics and virtual/augmented reality, have been introduced to simulate caries lesions in operative exercises.[2,3] However, these methods have limitations in providing tactile sensation and ergonomics training. The use of extracted human teeth may pose risks of possible infection, altered textures after disinfection, and ethical and legal concerns surrounding the practice.[4]

The application of 3D-printed technology has been gaining attention in dental education, offering an alternative in the pre-clinical setting.[5] This technology showed a positive outcome in training students for deep caries removal and vital pulp therapy,[6] and can simulate caries layers as well as pulpal structures.[7] With the ability to mimic human caries teeth, dental students may be better prepared to treat live patients.

This study aimed to evaluate the effects of 3D-printed caries teeth on the students' critical thinking and comfort levels during their transition from pre-clinical to clinical operative training. We hypothesized that there would be no significant difference in comfort levels before and after completing the 3D-printed teeth exercises.

Materials and methods

The Harvard University Faculty of Medicine Office of Human Research Administration approved this study as exempt (Protocol #IRB15-3845-3). Seventy-one predoctoral dental students (33 from class of 2024 and 38 from class of 2025) participated in a case-based collaborative learning (CBCL) session and a 3D-printed teeth lab exercise as part of the operative curriculum.

Before the CBCL session, students completed a voluntary 11-question "Pre-survey" questionnaire. The CBCL session involved analyzing caries clinical cases (case-description, photos, and radiographs), engaging in small groups discussion, and presenting findings in class, as described in the previous study.[8] Following the session, students engaged in a hands-on lab exercise. In groups of four, they reviewed lab instructions, analyzed two caries cases with radiographs and clinical photos (Fig. 1A and B), individually outlined tooth preparations, and discussed their designs within the group. Students then performed tooth preparations on two 3D-printed teeth (Frasaco: ANA-4 ZSDPK 300 V1, Practicon Inc., Greenville, NC, USA) that matched the cases discussed. These teeth featured layers simulating enamel, dentin, and caries lesions, with visible pulp when overprepped, as well as occlusal or interproximal caries (Fig. 1C). After completing the preparations, students compared their designs within groups before proceeding to restoration. Faculty members were available to address questions. A "Post-survey" was distributed at the end of the lab session to assess students' comfort level with restorative tooth preparations.

The pre- and post-survey each consisted of 11 identical questions rated on a five-point Likert scale (1 = disagree to 5 = agree). The post-survey included an additional question for students to provide feedback on their overall experience (Appendix 1). Hard copies of the surveys and written consent forms were distributed before the CBCL session and after the lab exercise.

Data were entered into Microsoft Excel (Microsoft Corp., Redmond, WA, USA) and analyzed using SPSS 29.0.1.0 (International Business Machines Corp., Armonk, NY, USA). Frequency distributions and means for all ordinal variables were calculated. Mann–Whitney U tests determined statistically significant differences in confidence levels before and after the exercises. All statistical tests were two-sided, with significance set at $P < 0.05$.

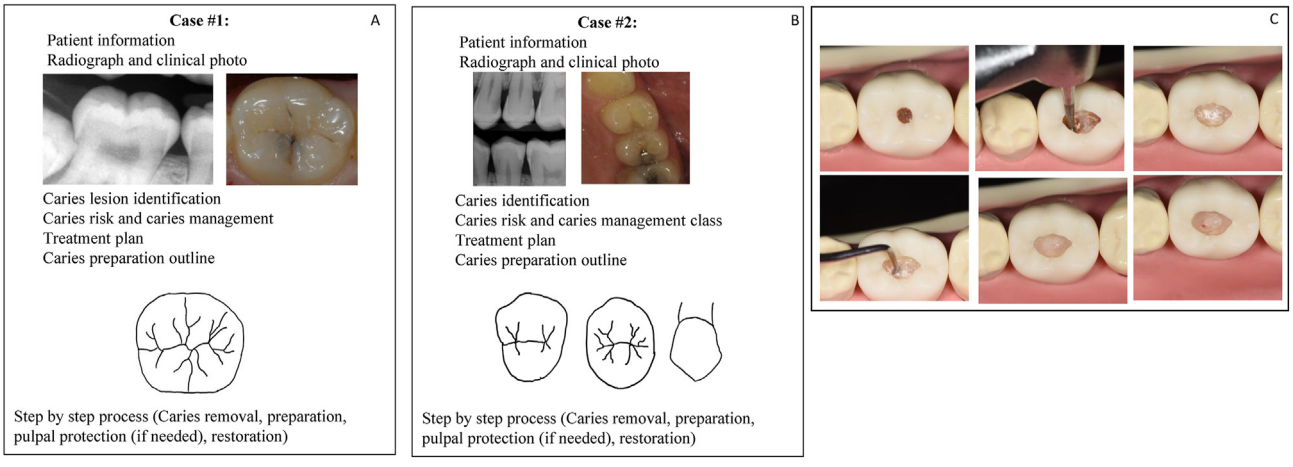

Figure 1 A, B shows case workflow with radiographs and clinical photos to mimic caries in typodont (radiographs and clinical photos not of typodont. No radiographs were taken of typodont teeth). C shows photos of 3D printed-simulated caries tooth preparations.

Results

The pre-survey response rates were 100 % for the class of 2024 and 87 % for the class of 2025, while the post-survey rates were 97 % and 74 %, respectively. One post-survey response from the class of 2025 was excluded due to incomplete answers.

The frequency distributions of participants' responses regarding their comfort level in tooth preparation are presented in Table 1. The Mann–Whitney test revealed significant increases in students' confidence after completing the exercises. Confidence improved in modifying cavity preparations to remove caries ($z = -5.53$, $P < 0.001$), understanding caries removal principles ($z = -2.32$, $P = 0.020$), and selecting appropriate burs ($z = -3.20$, $P = 0.001$). Students also reported greater comfort using hand instruments ($z = -4.51$, $P < 0.001$), mentally designing cavity preparations ($z = -4.97$, $P < 0.001$), and differentiating carious tissue from sound tissue by tactile ($z = -5.97$, $P < 0.001$) or by color ($z = -5.12$, $P < 0.001$). There was also a significant decrease in reliance on clinical instructors during initial preparations ($z = -2.83$, $P = 0.005$) and an increase in confidence for future caries removal ($z = -4.30$, $P < 0.001$).

Short-answer responses highlighted the perceived value of the CBCL session and 3D-printed teeth exercises. Students appreciated collaborating with peers on clinical cases and practicing non-ideal preparations. One student stated, "I really appreciated this session. Working on non-ideal preps was helpful. I'm still working on my tactile sensation of caries." The majority of students expressed a desire for additional sessions with more teeth to practice on in the future.

Discussion

The results of this study illustrate that the use of 3D-printed teeth in predoctoral dental education improved the overall comfort level after the pre-clinical operative exercises. Specifically, nine out of eleven survey questions showed significant improvements. Therefore, we reject the null hypothesis and confirm that our results are statistically significant.

Statements 1, 7, and 8, which addressed tooth preparation modifications, indicated significant improvement. Using 3D-printed simulated caries teeth may help students critically think about tooth preparation design when caries are present. Consistent with our findings, a previous study

Table 1 Combined responses of the classes of 2024 and 2025 to pre- and post-activities survey analyses.

Statement description	Survey type	Response scale					*P*-value
		1 Disagree	2 Somewhat disagree	3 Neutral	4 Somewhat agree	5 Agree	
1: I feel comfortable modifying my cavity prep to remove caries	Pre-survey	12.12 %	37.9 %	22.72 %	22.72 %	4.54 %	<0.001***
	Post-survey	0.0 %	1.7 %	28.3 %	56.7 %	13.3 %	
2: I feel comfortable self-evaluating my preparation.	Pre-survey	3.0 %	10.6 %	25.8 %	47.0 %	13.6 %	0.337
	Post-survey	0.0 %	8.3 %	21.7 %	55.0 %	15.0 %	
3: I understand the principle of caries removal.	Pre-survey	0.0 %	1.5 %	16.7 %	54.5 %	27.3 %	0.020*
	Post-survey	0.0 %	1.7 %	5.0 %	45.0 %	48.3 %	
4: I understand the principle of cavity preparation.	Pre-survey	0.0 %	1.5 %	9.1 %	56.1 %	33.3 %	0.390
	Post-survey	0.0 %	1.7 %	6.7 %	50.0 %	41.7 %	
5: I feel comfortable selecting the bur for the preparation of any restoration.	Pre-survey	3.0 %	13.6 %	21.2 %	40.9 %	21.2 %	0.001***
	Post-survey	0.0 %	3.3 %	10.0 %	45.0 %	41.7 %	
6: I feel comfortable using hand cutting instruments in caries removal and cavity preparation.	Pre-survey	6.1 %	27.3 %	30.3 %	24.2 %	12.1 %	<0.001***
	Post-survey	0.0 %	1.7 %	23.3 %	48.3 %	26.7 %	
7: I feel comfortable mentally designing a cavity preparation when encountering a carious tooth.	Pre-survey	12.1 %	33.3 %	34.8 %	18.2 %	1.5 %	<0.001***
	Post-survey	0.0 %	6.7 %	38.3 %	50.0 %	5.0 %	
8: I will need minimal consultation with the clinical instructor during my first cavity preparation.	Pre-survey	47.0 %	27.3 %	21.2 %	4.5 %	0.0 %	0.005**
	Post-survey	21.7 %	38.3 %	21.7 %	16.7 %	1.7 %	
9: I feel comfortable differentiating the carious part from the sound tooth structure tactilely.	Pre-survey	25.8 %	34.8 %	28.8 %	10.6 %	0.0 %	<0.001***
	Post-survey	5.0 %	8.3 %	31.7 %	40.0 %	15.0 %	
10: I feel comfortable differentiating the carious part from the sound tooth structure by color.	Pre-survey	12.1 %	33.3 %	31.8 %	21.2 %	1.5 %	<0.001***
	Post-survey	3.3 %	8.3 %	23.3 %	43.3 %	21.7 %	
11: I feel comfortable removing caries during my clinical operative procedure in the future.	Pre-survey	16.7 %	30.3 %	33.3 %	16.7 %	3.0 %	<0.001***
	Post-survey	1.7 %	11.7 %	36.7 %	38.3 %	11.7 %	

Notes. N = 66. *$P < 0.05$. **$P < 0.01$. ***$P \leq 0.001$.

illustrated that 3D-printed teeth allowed more than half of the students to achieve adequate outcomes in caries removal and cavity preparation depth.[7] Additionally, another study showed that 3D-printed simulations of deep caries reduced students' stress and anxiety, leading to increased confidence.[6] This increase in confidence could sharpen critical thinking skills and potentially result in better clinical performance.

Additionally, statements 3, 9, 10, and 11, which related to the principle of caries removal, differentiating caries from sound tooth structure, showed significant improvements in comfort levels. The 3D-printed teeth allowed students to gain hands-on experience in caries removal by replicating the feel and manifestation of caries lesions. These teeth mimic natural caries lesions, requiring force similar to that needed for caries removal in extracted teeth.[9] Thus, with 3D-printed teeth, students could improve their tactile skills and apply appropriate force to remove caries. Furthermore, another study showed that 94 % of participants found the texture of caries lesions in 3D-printed teeth realistic, and 97 % agreed that the shade of the caries was adequate.[10] These studies show the advantages of 3D-printed caries teeth and support their use in pre-clinical operative exercises.

Relatedly, Statements 5 and 6 were statistically significant and addressed the use of rotary and hand-cutting instruments. These findings indicated that 3D-printed caries teeth allowed students to effectively select and use several types of instruments, attributed to the teeth's multilayered structure and varying textures and hardness.[9] As a result, students reported greater comfort using various operative instruments.

Statements 2 and 4 showed no statistically significant improvement. Statement 2 pertained to self-assessment skills, which students had already developed prior to this exercise as a part of the operative curriculum. Statement 4 suggested that students already possessed proficient knowledge of cavity preparation before the exercises, as 89.4 % and 91.8 % of students selected 4 or 5 in the pre-and post-surveys, respectively.

Limitations of this study include a smaller sample size as only two classes (classes of 2024 and 2025) from the same institution were surveyed. Future studies should increase the sample size and include multiple institutions. Furthermore, the effectiveness of 3D-printed teeth in pre-doctoral education in this study was assessed based on students' perceptions, which focused on qualitative data. Future research could include a control group to evaluate the effectiveness of 3D-printed teeth quantitatively.

Despite these limitations, the study had several strengths, including a high post-survey retention rate. Additionally, comments from statement 14 in the questionnaire illustrated positive feedback from the students, such as "[I] liked practicing with fake caries tooth," "[I] would've loved to have more than one caries removal exercise. It was very different from what we have been doing," and "We should do this more!" These responses support the use of 3D-printed teeth in dental education. Similar studies in UK universities found that 71.4 % of students agreed that 3D-printed teeth would better prepare the students for clinical practice, and 57.1 % agreed that it would reduce their stress and anxiety when treating their first caries patient.[7]

The study revealed that 3D-printed caries teeth could serve as a valuable learning tool to enhance students' experience of caries removal and increase their comfort levels when transitioning from pre-clinical to clinical settings.

Declaration of competing interest

Authors have no conflict of interest to declare.

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Appendix 1

Pre-Survey:

Please rate the following statements on a scale of 1—5.

1. I feel comfortable modifying my cavity prep to remove caries.	1 2 3 4 5
2. I feel comfortable self-evaluating my preparation.	1 2 3 4 5
3. I understand the principle of caries removal.	1 2 3 4 5
4. I understand the principle of cavity preparation.	1 2 3 4 5
5. I feel comfortable selecting the bur for the preparation of any restoration.	1 2 3 4 5
6. I feel comfortable using hand cutting instruments in caries removal and cavity preparation.	1 2 3 4 5
7. I feel comfortable mentally designing a cavity preparation when encountering a carious tooth.	1 2 3 4 5
8. I will need minimal consultation with the clinical instructor during my first cavity preparation.	1 2 3 4 5
9. I feel comfortable differentiating the carious part from the sound tooth structure tactilely.	1 2 3 4 5
10. I feel comfortable differentiating the carious part from the sound tooth structure by color.	1 2 3 4 5
11. I feel comfortable removing caries during my clinical operative procedure in the future.	1 2 3 4 5

1: Disagree; 2: Somewhat disagree; 3: Neutral; 4: Somewhat agree; 5: Agree.

Post-Survey:

Same previous 11 questions with an additional short-answer question:

12. Please give feedback on the overall case-based interactive activities.

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