Duan *et al. BMC Medical Education* (2024) 24:913
https://doi.org/10.1186/s12909-024-05869-2

BMC Medical Education

RESEARCH

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Effect of 3D printed teeth and virtual simulation system on the pre-clinical access cavity preparation training of senior dental undergraduates

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Abstract

Background The objective of the present study was to evaluate the effect of 3D printed teeth and virtual simulation system on the pre-clinical access cavity preparation training of senior dental undergraduates.

Methods The 3D printed teeth were manufactured based on the micro-CT data of an extracted lower first molar. Ninety-eight senior dental undergraduate students were required to finish the access cavity preparation of lower first molar within 20 min on plastic and 3D printed teeth on the manikin system as well as on a virtual simulation machine respectively with randomly selected sequences. Expert dentists scored the operated teeth. The scores from the virtual simulation system were also recorded. All the scores were analyzed and compared. Following the procedure, two questionnaires were sent to students to further evaluate the feelings and optimal training sequence.

Results No significant differences were found between plastic and 3D printed teeth scores, while virtual simulation achieved a valid/invalid area removal ratio of 96.86% ± 5.08% and 3.97% ± 1.85%, respectively. Most students found plastic teeth training the easiest and favored the three-training combination (36.36%). 71.42% of the students thought the virtual simulation training should be put at the first place of the three trainings. Over 80% of students agreed with incorporating 3D printed teeth and virtual simulation into their routine training courses. In addition, the general advantages and disadvantages of the virtual simulation system and 3D printed teeth training received almost equal recognition by students.

Conclusions Virtual simulation system training + plastic teeth training + 3D printed teeth training might be the optimal training sequence. Virtual simulation system training could not completely replace the traditional training methods on the manikin system at the moment. With further modifications, 3D printed teeth could be expected to replace the plastic teeth for the pre-clinical access cavity preparation training.

†Mengting Duan and Silei Lv are co-first authors with equal contributions.

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Keywords 3D printing, Pre-clinical training, Virtual simulation system, Access cavity preparation, Dental, Undergraduate

Background

Effective pre-clinical training in access cavity preparation for senior dental undergraduates is essential for the transition from course studies to clinical practices [1]. Extracted natural teeth, commercial plastic teeth, 3D printed teeth and virtual simulation system have all been used for this training [2–4]. However, how these training methods would affect the training results remains unclear yet, let alone how these methods should be arranged for a better training based on students' feelings [5].

The traditional pre-clinical access cavity preparation training was normally performed on extracted natural teeth which could provide a good understanding on the anatomy of pulp chamber in teeth and a similar drill-through feeling in real clinical operations. However, the type of extracted teeth used for training was quite limited (wisdom teeth in most cases), and the diversity in the anatomy of extracted teeth would reduce the stability of training quality and objectivity of scoring by teachers [6, 7]. In addition, limited sources of extracted teeth and ethical considerations also hinder the large-scale application of extracted teeth in pre-clinical trainings [8, 9]. As a result, the commercial plastic blocks or plastic teeth, based on artificially designed models or drawings of average human tooth anatomy, were introduced for endodontic pre-clinical training [10, 11]. However, the artificial plastic teeth could not produce accurate pulp chamber anatomy related to different tooth types [12]. Therefore, an economic and accessible tooth model with accurate pulp chamber anatomy is necessary.

Recently, three-dimensional (3D) printed technology enables the production of anatomically matched artificial teeth with high tunability and repeatability [13–15]. Based on the cone beam computed tomography (CBCT) or high-resolution micro-computed tomography (microCT) scans, 3D printed teeth could precisely replicate the external and internal anatomy of the natural origin teeth [12]. Therefore, 3D printed teeth could provide good understanding on the pulp chamber anatomy of different tooth types and could be fabricated in large numbers. The assessment for the training quality would be more stable, repeatable and objective than extracted teeth [12]. Additionally, due to the transparent property of 3D printed teeth, students could observe the internal conditions of the teeth from different angles during the training to improve the understanding of operations [16].

Virtual simulation technology utilizes computer technology to create a simulated virtual environment with multiple perceptions such as visual, tactile, and auditory senses, and has been applied in dental training recently, such as caries removal, access cavity preparation, wisdom tooth extraction, crown and bridge preparation, oral and maxillofacial surgery and so on [17–19]. The virtual simulation is quite beneficial for students as it provides an optimal practice environment through its non-invasive, non-destructive, risk-free, and repeatable features [20]. It facilitates a smooth transition from the pre-clinical to the clinical stages, which is often considered by students as a stressful period [17].

At present, there is no comparative report on the effect of virtual simulation system, commercial plastic teeth and 3D printed teeth on the pre-clinical access cavity preparation training of senior dental undergraduates. In this study, senior dental undergraduates were asked to conduct access cavity preparation training on the plastic and 3D printed teeth as well as virtual simulation system. Then the effect of these three methods on the quality and feeling of the training was evaluated by scoring and questionnaires. The optimal combination of the methods was finally determined.

Methods

Demography of participants

Ninety-eight grade four dental undergraduate students (42 male and 56 female) with the age between 20 and 24 from the School of Stomatology, Wuhan University were invited to participate in this study and were all well-trained in using the virtual simulation systems before the study.

Fabrication of 3D printed teeth

A mandibular left first molar extracted due to periodontal disease with typical root canal and pulp chamber morphology, fully formed apex, no fractures or cracks, no signs of visible apical resorption was selected as the original template for 3D printing under the approval by the Ethics Committee of School and Hospital of Stomatology, Wuhan University. Then the molar was scanned using a micro-CT (μCT-50; Scanco Medical, Bassersdorf, Switzerland) with an isotropic resolution of 15 μm at 90 kV, 88 μA, 8 W, and 500-millisecond integration time. The segmented tooth was reconstructed using the medical imaging software Mimics 18.0 (Materialise NV, Leuven, Belgium), and exported into the stereolithography (STL) file. The STL data of the selected sample was then sent to the factory (Wuhan jiayi 3D technology application Co. Ltd, China) for 3D printing after the length, width, and height of the STL files being modified proportionally to fit in the dentition of a manikin system (Japan Sentian Co. Ltd, Japan).

Training protocol for pre-clinical access cavity preparation

All students (n=98) were required to finish the access cavity preparation on a commercial plastic lower first molar (Sanmenxia medical equipment Co. Ltd, China) and the 3D printed lower first molar on the manikin system as well as on a virtual simulation machine (Unidraw. Ltd, China, V1.0) within 20 min each with randomly selected sequences. The steps for access cavity preparation were based on the standard procedures [21], including: penetration of the pulp chamber roof, identification of all canal orifices, removal of the cervical dentin bulges, orifice and coronal flaring, straight-line access determination, visual inspection of the pulp chamber floor.

Scoring method for the access cavity preparation trainings

After trainings, the plastic and 3D printed teeth were collected and scored by two experienced dental teachers based on the criteria for access cavity preparation of Oral Practitioner Qualification Examination of China (Table 1) and the average was taken as the final score. To ensure the consistent and correct scoring results, one of the two scoring teachers had received standard scoring training and served as a scorer for the Oral Practitioner Qualification Examination of China. Before the scoring, the two teachers discussed each of the scoring standards and reached a consensus. The score of virtual simulation machine training was collected from the screenshots uploaded by the students, based on the proportion of valid/invalid area removal (the area removal in/out of the red frame on the screen shown in Fig. 1I), which were automatically given by the machine.

Questionnaire survey design

The students were then invited to complete two questionnaire surveys that were modified from published literatures [22, 23]. The questionnaire survey I included questions (shown in Supplementary file and Fig. 2 notes) on a comparison of undergraduates' subjective feelings towards the above three trainings, while questionnaire survey II (shown in Supplementary file) mainly included students' evaluations on the advantages and disadvantages of 3D printed teeth and virtual simulation system training. The survey was based on a voluntary basis, and all answers were entirely anonymous.

Statistical analysis

The data were analyzed using SPSS software (IBM, USA). The distribution of data was checked by Shapiro-Wilk test. As all the data violated the normal distribution, the non-parametric Wilcoxon Signed Ranks Test was used for analysis. P values less than 0.05 were considered statistical significance.

Results

3D printed teeth

The 3D printed teeth were manufactured and modified to fit in the dentition of manikin system as shown in Fig. 1e. The lingual, buccal, mesial and distal views of the 3D printed teeth and relevant STL images were shown in Fig. 1A-D and a-d.

Scores of access cavity preparation trainings

The total scores of the access cavity preparation on the plastic and 3D printed teeth showed no significant differences ($p>0.05$) in Table 1. However, when it came to the access cavity-related index (cavity location, cavity size and cavity outline) and the destruction of pulp chamber floor or wall, the scores of 3D printed teeth group were significantly higher than the plastic teeth group ($p<0.05$). Regarding the scores of the entrance of pulp chamber, detection of root canal orifice as well as the straight-line access determination, the plastic teeth group was higher than 3D printed teeth group ($p<0.05$). In addition, there

Table 1 Analysis of access cavity preparation on the plastic and 3D printed teeth

Items (scores)	Plastic teeth (scores)			3D printed teeth (scores)			*p* values
	Mean ± SD	Min	Max	Mean ± SD	Min	Max	
cavity location (10)	9.70 ± 0.54	8	10	9.85 ± 0.46	7	10	0.027
cavity size (8)	6.28 ± 1.25	3	8	7.05 ± 1.00	4	8	0.000
cavity outline (7)	6.76 ± 0.43	6	7	6.94 ± 0.23	6	7	0.000
drilling into the pulp chamber (10)	9.94 ± 0.51	5	10	9.13 ± 1.41	6	10	0.000
the adequate removal of pulp chamber roof (20)	15.96 ± 2.01	11	20	15.38 ± 3.43	7	20	0.677
the perforation of pulp chamber floor or wall (5)	5.00 ± 0.00	5	5	5.00 ± 0.00	5	5	-
the destruction of pulp chamber floor or wall (16)	13.30 ± 1.39	10	16	14.00 ± 0.76	12	16	0.000
smoothness (8)	7.26 ± 0.88	5	8	7.26 ± 0.92	4	8	0.694
detection of root canal orifice (8)	7.46 ± 0.73	4	8	6.91 ± 0.84	4	8	0.000
straight-line access determination (8)	7.31 ± 0.98	4	8	6.77 ± 0.93	4	8	0.000
total (100)	89.01 ± 4.59	71	97	88.29 ± 6.52	73	98	0.925

Note: Mean ± SD (means ± standard deviations), Min (minimum), Max (maximum)

-: The values in two groups were identical and statistical analysis was not performed

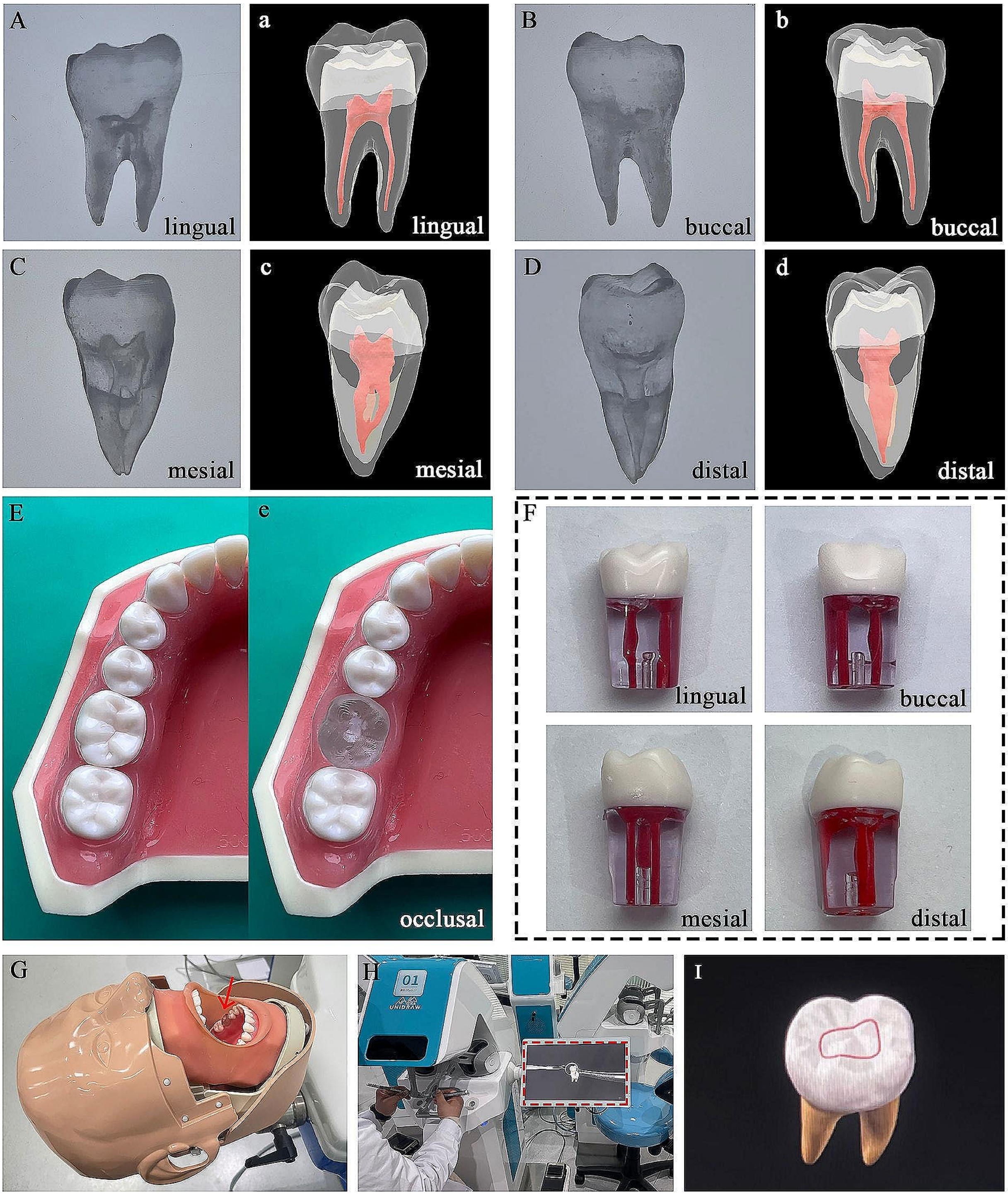

Fig. 1 Images of the 3D printed teeth, plastic teeth and virtual simulation machine. (**A-D**, **a-d**) Lingual, buccal, mesial and distal views of the 3D printed teeth (**A-D**) and STL image (**a-d**); (**E**, **e**) Occlusal views of the plastic teeth (**E**) and 3D printed teeth (**e**) fitted in the dentition of manikin system; (**F**) Lingual, buccal, mesial and distal views of the plastic teeth; (**G**) Manikin system; (**H**) Access cavity preparation on virtual simulation system; (**I**) Zoomed-in image of the screen in (**H**)

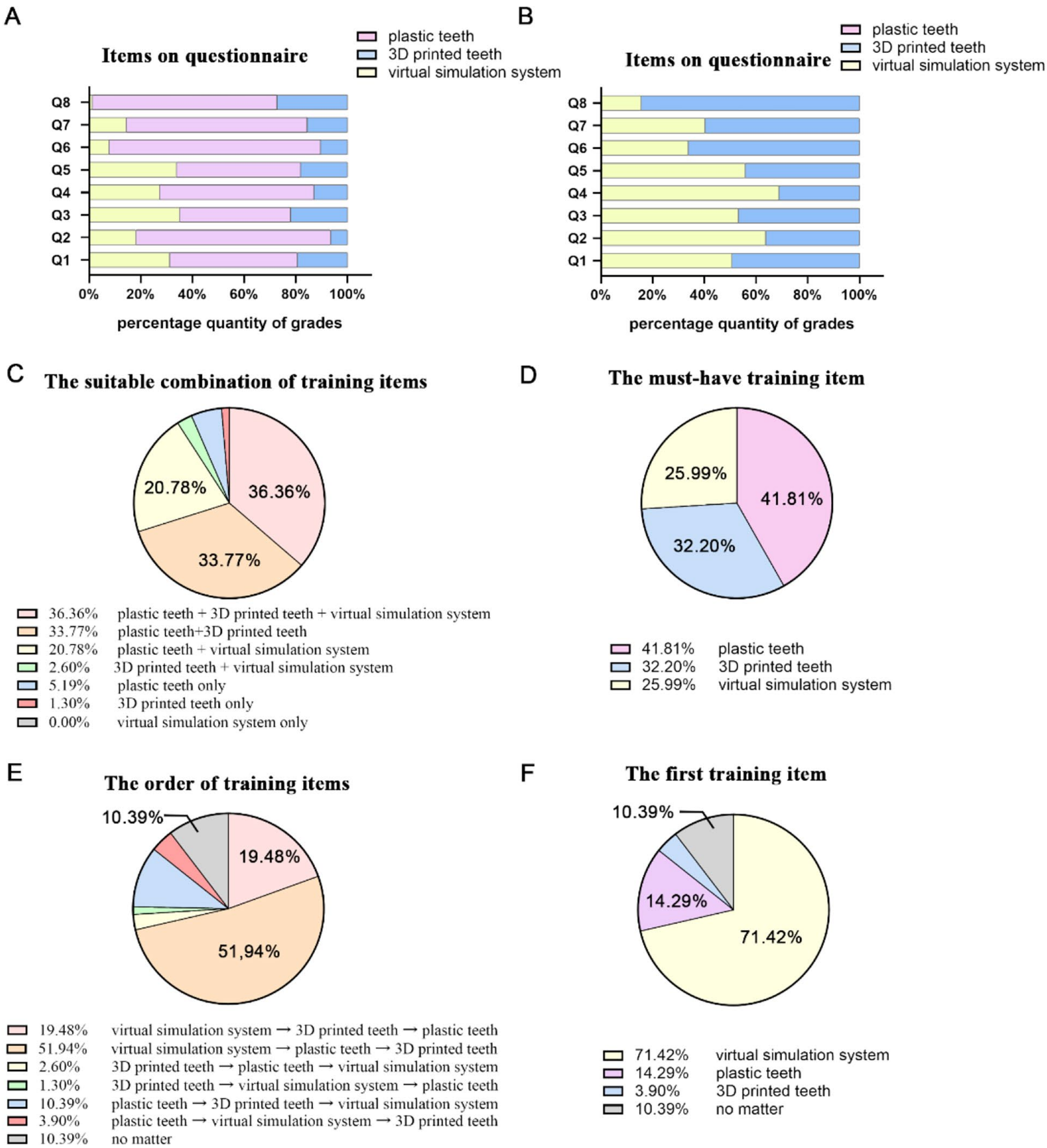

Fig. 2 Comparison of three trainings by questionnaire survey I. (**A**) Eight questions (Q1-Q8) of questionnaire I; (**B**) Further comparison after excluding the plastic teeth training from (**A**); (**C**) The most suitable combination of training items; (D)The must-have training item based on (**C**); (**E**) The most suitable order of the three training items; (**F**) The best training item for the first one based on (**E**)

Notes: Questions for questionnaire I. Q1: easier to drill into the pulp chamber; Q2: better feeling of drill-through the chamber; Q3: simpler to unroof the pulp chamber; Q4: easier to distinguish the pulp chamber floor; Q5: easier to create a straight path with no deflections; Q6: better drill feeling; Q7: more helpful in understanding the procedures; Q8: more similar to clinical practice was no pulp chamber floor or wall perforation in both trainings.

The scores of access cavity preparation on the virtual simulation system showed the valid area removal ratio was 96.86% ± 5.08%, while the invalid area removal ratio was 3.97% ± 1.85%.

Questionnaire survey

The questionnaires from 77 students were analyzed. The questionnaire survey I and the corresponding answers were shown in Fig. 2. Most of the students found the plastic teeth training to be the easiest, compared to the 3D printed teeth and virtual simulation system training. They reported that the plastic teeth were easier to drill into the pulp chamber (49.35%), provided a better feeling of drill (81.82%) and drill-through into the pulp chamber (75.32%), was simpler to unroof the pulp chamber (42.86%), easier to distinguish the pulp chamber floor (59.74%) and create a straight path (48.05%), more helpful in understanding the procedures (70.13%), and was more similar to clinical practice (71.43%). Additionally, virtual simulation training was superior to 3D printed teeth training in the drill-through feeling (63.64%), the pulp chamber unroof degree (53.25%), the pulp chamber floor discrimination (68.83%) as well as the straight path establishment (55.84%). While in the drill feeling (66.23%), procedure understanding (59.74%), and similarity to clinical practices (84.42%), 3D printed teeth training was better than the virtual simulation training.

In addition, 36.36% of the students redeemed the access cavity preparation training should include all three kinds of trainings, while 33.77% students thought plastic teeth training plus 3D printed teeth training would be enough. The most indispensable training was considered to be the commercial plastic teeth training (41.81%), followed by 3D printed teeth training (32.20%) (Fig. 2C, D).

As shown in Fig. 2E, the most favorite training sequence (51.94%) was the virtual simulation system training as the first, then the plastic teeth training, and finally the 3D printed teeth training, and 71.42% students thought that virtual simulation system training should be put in the first place of all three trainings (Fig. 2F).

The results of questionnaire survey II (Table 2; Fig. 3) demonstrated strong internal consistency, with Cronbach's alpha coefficients of 0.701. Additionally, the Kaiser-Meyer-Olkin value was 0.649, indicating high validity.

Table 2 Advantages and disadvantages of the virtual simulation system training and 3D printed teeth training (*n* = 77)

Questionnaire	Strongly agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly disagree (%)
advantages of 3D printed teeth training					
realistic	19.48%	35.06%	40.26%	5.19%	0.00%
no ethical issues	66.23%	27.27%	5.19%	1.30%	0.00%
repeatable	31.17%	19.48%	20.78%	23.38%	5.19%
root canal system could be directly observed	50.65%	29.87%	12.99%	6.49%	0.00%
available	33.77%	32.47%	23.38%	9.09%	1.30%
more dental options	59.74%	36.36%	3.90%	0.00%	0.00%
providing different root canal system in the same position	57.14%	38.96%	3.90%	0.00%	0.00%
helpful in improving clinical skills	40.26%	38.96%	16.88%	3.90%	0.00%
disadvantages of 3D printed teeth training					
poor drill feeling	48.05%	38.96%	10.39%	1.30%	1.30%
poor feeling of drill-through the chamber	40.26%	33.77%	16.88%	7.79%	1.30%
high cost and hard to popularize	24.68%	45.45%	20.78%	5.19%	3.90%
tedious production process	12.99%	50.65%	29.87%	3.90%	2.60%
affected by the solidification of the material	20.78%	49.35%	22.08%	5.19%	2.60%
advantages of virtual simulation system training					
safety	67.53%	31.17%	0.00%	0.00%	1.30%
easy to use	37.66%	35.06%	16.88%	7.79%	2.60%
similar to clinical practice	11.69%	20.78%	36.36%	22.08%	9.09%
repeatability	46.75%	45.45%	5.19%	0.00%	2.60%
objective scoring system	7.79%	18.18%	50.65%	16.88%	6.49%
wide coverage and suitable for multi-level students	29.87%	48.05%	14.29%	3.90%	3.90%
disadvantages of virtual simulation system training					
poor drill feeling	29.87%	42.86%	20.78%	6.49%	0.00%
inconvenient operation and unintuitive observation	24.68%	38.96%	16.88%	16.88%	2.60%
prone to dizziness and discomfort	15.58%	18.18%	18.18%	29.87%	18.18%
need special instruments and hard to popularize	28.57%	55.84%	11.69%	2.60%	1.30%
only provide a single standard model for a position	25.97%	49.35%	18.18%	6.49%	0.00%
imprecise scoring system	18.18%	61.04%	15.58%	3.90%	1.30%

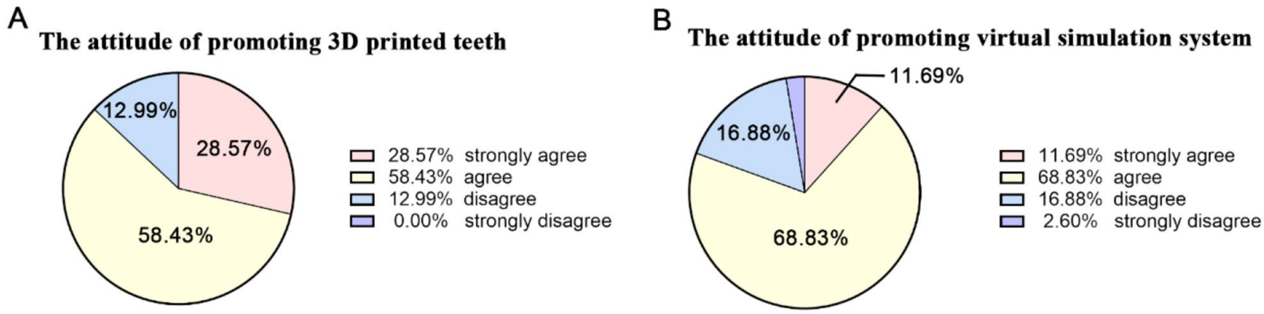

Fig. 3 Attitude comparison of promoting 3D-printed teeth training (**A**) and virtual simulation system training (**B**) (*n* = 77)

The percentage of 'disagree' (disagree + strongly disagree) was no more than 20%, except for the repeatability of 3D printed teeth training (28.57%), the similar to clinical practice (31.17%) and objective scoring system (23.38%) of virtual simulation system training, especially the prone to dizziness and discomfort (48.05%) of virtual simulation system training.

Additionally, the result in Fig. 3 showed that only 12.99% (0.00% strongly disagree) students disagreed the promoting 3D printed teeth training, and only 19.48% (2.60% strongly disagree) students disagreed the promoting virtual simulation system training in daily experimental course.

Discussion

Key findings

The commercial plastic and 3D printed teeth were found comparable in the total score of access cavity preparation. The 3D printed teeth seemed be able to produce a higher cavity-related quality, such as cavity location, size and outline, while the commercial plastic teeth brought a better access-related outcomes, such as the entrance of pulp chamber, detection of root canal orifice and straight-line access determination. As for the virtual simulation training, most students could remove more than 90% valid area during the access cavity preparation.

The questionnaire survey revealed that the plastic teeth could provide an easy feeling of access cavity preparation training for students. The virtual simulation system and 3D printed teeth could also provide good drill or drill-through feelings similar to clinical practice. Based on these feelings, students showed their favored training combinations. More than 70% students thought the virtual simulation training should be put at the first place of the three-training module. Over 80% of students agreed with incorporating 3D printed teeth and virtual simulation into their routine training courses. The most favored training sequence was "virtual simulation system training + plastic teeth training + 3D printed teeth training".

Comparison with previous studies

Currently, 3D-printed models and the virtual simulation platform have been widely used in dental education. Studies have shown that using 3D printed teeth in dental pre-clinical training, such as inlay preparation, root canal treatment, and caries removal, could enhance teaching efficiency and boost students' confidence [8, 24, 25]. This aligns with our findings, where only 3.90% students disagreed that 3D printed teeth were helpful in improving clinical skills (Table 2). Similar results were also noted in the training studies of virtual simulation system [26–28]. A study on access cavity preparation indicated that pre-clinical teaching effectiveness could be effectively improved through combining the virtual simulation system with the traditional manikin training system, and prioritizing virtual simulation training was also helpful, which was in line with our conclusions [3]. Interestingly, Ambika Sinha et al. [25] reported that 71.4% of students preferred 3D printed teeth over plastic ones in caries removal study. This differed from our results possibly due to the differences in the training purpose. Besides, the virtual simulation system is always favored for its objective scoring system, but less than 30% of students supported the idea in this study (Table 2) possibly due to the limited explanation of the "valid/invalid area removal ratio" scoring criteria [17, 20]. Additionally, 33.77% of the students agreed that the 3D display on the computer screen of virtual simulation system could cause unpleasant feelings such as dizziness and nausea, indicating the virtual simulation system might not be suitable for every student, which aligns with the findings of other researchers [20, 29].

Implications for practice

For the traditional access cavity preparation on the manikin system, incorporating 3D printed teeth into training could enhance visual understanding of real pulp chamber structures because the 3D printed teeth were made from the transparent liquid resin [8, 12]. However, commercial plastic teeth exhibited better tactile sense probably due to the difference in manufacturing materials. Therefore, it may be a good way at the moment to combine the 3D and plastic teeth in the access cavity preparation training. However, the present materials used for 3D printed teeth are normally soft with lower stiffness and tensile strength compared to plastic and natural teeth [8, 30]. If the material used for 3D printed teeth could be modified to simulate the natural teeth in physical characters, the plastic teeth may be replaced by the 3D printed teeth in the future training. What's more, the commercial plastic teeth have the pulp chamber and root canal labeled with red color, which makes the access entrance and canal orifice detection easier than the 3D printed teeth in this study. This merit could also be adopted by the 3D printed teeth.

For the virtual simulation system, the results indicated that it could not completely replace traditional trainings but only served as a supplement [31]. The reason for this conclusion is probably because the virtual simulation system cannot provide an environment and situation as that in the real clinical practice. The virtual simulation system would show the access cavity outline in the crown for students to prepare (Fig. 1I), which is impossible in the clinical situations. Despite this, the virtual simulation training is safe and repeatable without materials consumption. Besides, the drill-through feeling in the virtual simulation training is similar to that on the natural teeth. Therefore, the virtual simulation training could be used as the pre-training before the traditional trainings on the manikin system. In this study, most students also thought that virtual simulation training should be placed before traditional trainings probably due to the above features of virtual simulation system. As the plastic teeth are thought easy to operate and the 3D printed teeth are based on the structure of natural teeth, a sequence that begins with virtual simulation system training, followed by plastic teeth training, and then 3D printed teeth training was considered optimal for pre-clinical access cavity preparation training.

Limitations and future directions

One of the main limitations of this study is that the training evaluation was only performed on a specific tooth type and the student participants came from only a specific dental school. Futher studies using various tooth types and involving multiple dental schools are needed for a broader applicability of the findings. What's more, the long-term training effect was not tested in this study and whether the students could benefit from these training methods and combinations in their clinical practice remains unknown yet. As to the method used in this study, the 3D printed teeth require improvements in the properties of printing materials so that it is close to that of natural teeth. If so, the 3D printed teeth would very likely replace the commercial plastic and natural teeth in the future training courses. Virtual simulation system needs to be further refined to make it more user-friendly and comfortable, and provide a more practical scoring system as that on natural teeth or clinical situations [32]. Besides, the cost and time used for different training methods should also be considered and evaluated for future applications.

Conclusions

Based on the findings of this study, virtual simulation system training + plastic teeth training + 3D printed teeth training sequence was considered as the optimal sequence. Virtual simulation system training could not completely replace the traditional training on the manikin system at the moment. After further design modifications, 3D printed teeth could be expected to replace the plastic teeth for the pre-clinical access cavity preparation training.

Abbreviations

microCT	Micro-computed tomography
CBCT	Cone beam computed tomography
STL	Stereolithography
3D	Three-dimension
SD	Standard deviation
Min	Minimum
Max	Maximum
Q	Question

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12909-024-05869-2.

Supplementary Material 1

Acknowledgements

Not applicable.

Author contributions

Mengting Duan, Silei Lv: methodology, data acquisition, analysis and interpretation, writing - original draft preparation; Wei Fan and Bing Fan: conceptualization and design, funding acquisition, supervision and review of manuscript. All authors have read and approved the final manuscript for publication.

Funding

The research was funded by the Comprehensive Construction and Reformation Programme for the Undergraduate Education Quality of Wuhan University and the Top Youth Talent in Medicine Program of Hubei Province, China.

Data availability

All data generated or analyzed during this study are included in this published article.

Declarations

Ethics approval and consent to participate

The tooth selected for 3D printing template as well as the study was approved by the Ethics Committee of School and Hospital of Stomatology, Wuhan University. The informed consent of each student to participate this study has been obtained.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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Received: 21 May 2024 / Accepted: 6 August 2024
Published online: 23 August 2024

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