BMC Oral Health

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Comparing digital real-time versus virtual simulation systems in dental education for preclinical tooth preparation of molars for metal-ceramic crowns

Tianyu Tang[1], Xingxing Li[1], Yunhong Lin[1] and Caojie Liu[1,2*]

Abstract

Purpose This study aimed to compare the effectiveness of the Real-time Dental Training and Evaluation System (RDTES) and Virtual Simulation System (VSS) with the Traditional Head-Simulator (THS) method in teaching molar preparation for metal-ceramic crowns in preclinical dental education.

Methods Undergraduate students were divided into four groups: No Additional Training (NAT), THS, RDTES, and VSS. The primary outcomes measured were artificial and machine scoring of tooth preparations, with additional anonymous surveys assessing student feedback.

Results Both RDTES and VSS groups demonstrated significantly higher tooth preparation scores compared to the NAT group, with RDTES showing superior performance in machine scan scoring. Linear regression analysis revealed a clear positive correlation between scoring and scoring improvement for both artificial and machine assessments. Student surveys indicated RDTES was rated higher in accuracy, feedback quality, skill improvement, and teaching effectiveness.

Conclusions RDTES and VSS significantly enhance students' mastery of molar tooth preparation, with RDTES providing more precise guidance on tooth preparation volume. These systems show broad application prospects and development potential in dental education.

Keywords Dental Education, Real-time Dental Training, Virtual Simulation, Tooth Preparation, Metal-ceramic Crowns

Introduction

In the field of dental education, prosthodontics is a subject that closely integrates theory with practice. Especially, dental preparation is a crucial component in the teaching of prosthodontics [1]. The traditional educational model, which encompasses demonstration teaching, practice on head-simulator [1, 2], and clinical internships, has been the classic approach in dental education. As dentists trained under this traditional model, we acknowledge its irreplaceable advantages in the current stage. However, while this traditional teaching method can simulate clinical operation to some

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extent, it still suffers from several drawbacks, including relatively low efficiency, heavy reliance on the individual skills of the teacher, limited teaching resources and duration, insufficiently intuitive information for students, and unclear feedback on teaching outcomes [3, 4].

With the rapid advancement of information technology, traditional educational models are increasingly being challenged by the digital and artificial intelligence revolution [5–7]. Digital teaching has emerged as a new trend in the field of dental education, with the advent of virtual simulation teaching systems and digital real-time assessment systems providing new methods and tools for prosthodontics preclinical training [2, 8].

Current research primarily focuses on the development and application of virtual simulation teaching systems and digital real-time assessment systems, as well as comparative studies with traditional teaching methods [9–11]. Research findings indicate that these systems can offer more realistic and vivid teaching environments, which are conducive to enhancing students' operational skills and learning interest [12, 13]. Moreover, these systems can provide real-time operational feedback and assessments, aiding teachers in promptly understanding students' learning progress and adjusting teaching strategies accordingly [10, 11].

Several renowned dental institutions and research organizations have actively explored the application of virtual simulation technology in dental education, achieving notable results. For instance, the Academic Centre for Dentistry in Amsterdam (ACTA), the School of Dentistry at the University of Leeds in the UK and the University of Hong Kong in China have conducted a series of teaching experiments using virtual simulation systems, effectively improving students' operational skills and providing valuable experience for dental education [12, 14–18]. Despite these achievements, the quantity and quality of existing research still need to be enhanced. Further large-sample comparative studies are required to verify the universality and reliability of the application effects of virtual simulation digital real-time assessment systems. Additionally, lack of reliable research and evaluation on digital real-time assessment systems makes it even more challenging to conduct a direct comparison of the teaching effectiveness and student feedback between digital real-time assessment systems, virtual simulation systems, and traditional head-simulator [9, 12]. There is still an urgent need for further exploration and improvement in how to better integrate these systems into dental education, which remains an unanswered question.

Therefore, this study aims to introduce Real-time Dental Training and Evaluation System (RDTES) and Virtual Simulation System (VSS), comparing their effectiveness with Traditional Head-Simulator (THS) methods in the teaching of molar preparation, in order to address current issues in teaching. This research is of significant importance to the reform and development of dental education. By comparing the effects of different teaching methods, it can provide more scientific and rational teaching approaches for dental education, enhancing teaching quality. Moreover, the introduction of RDTES and VSS can promote the informatization and intelligent development of dental education, providing strong support for the cultivation of high-quality dental talents.

Methods

Research subjects' characteristics

This study was conducted among undergraduate students from the School of Stomatology at Kunming Medical University in the class of 2021. The specific experimental process is depicted in the flow chart (Fig. 1). After receiving a lecture on the chapter of tooth preparation, 114 undergraduate students were given instructions on the required metal ceramic crown preparation according to the 8th edition of the undergraduate textbook "Prosthodontics" (People's Medical Publishing House, China) [19] and a demonstration of mandibular first molar tooth preparation on head-simulators (NISSIN, NL-2000) and standard dental models (NISSIN, D16HD-500H(GSF)-MF) by teachers. Students practiced molar crown preparation on head-simulators for 3 h before assessment. Subsequently, all students were evaluated on PFM crown preparation using standardized typodont right mandibular first molars (A5SAN-500; Nissin Dental Products, Inc) as the baseline [15, 16].

Baseline and group strategy

Five experienced teachers blindly scored the prepared molars according to Table 1 and conducted machine scan scoring through a digital oral teaching internship evaluation system (NISSIN, Fair Grader 2000 PLUS). We selected the interval scoring range from 12.5% to 87.5%. With artificial scoring between 65 and 80 points and machine scoring between 30 and 50 points, totaling 63 students met the inclusion criteria. After fully explaining the purpose, process, schedule, and potential benefits of this teaching research, we obtained informed consent from 61 students to be included in this study.

Using the simple random number table method, 48 students were selected and assigned to four groups: No Additional Training (NAT), Traditional Head-Simulator (THS), Real-time Dental Training and Evaluation System (RDTES), and Virtual Simulation System (VSS). All four groups had open access to head-simulators without additional training. The THS group received 12 supervised sessions on head-simulators guided by an experienced teacher, Dr. Tang. The RDTES and VSS groups

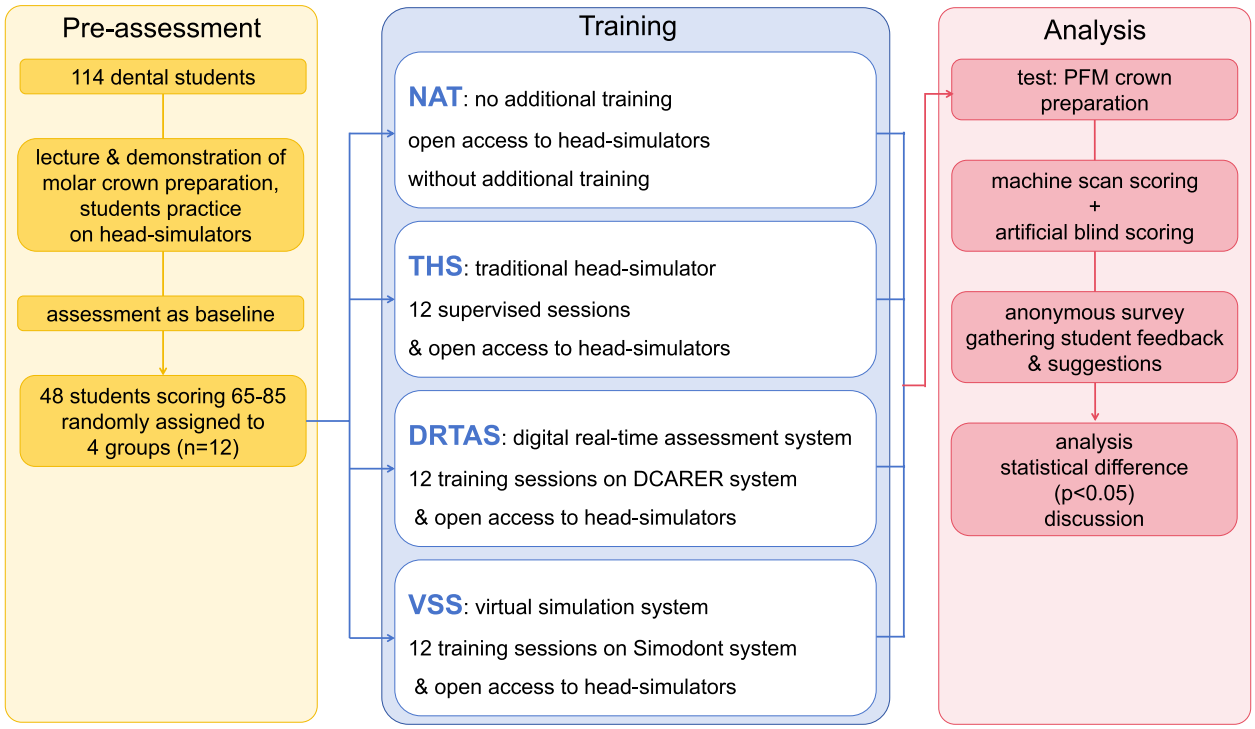

Fig. 1 Flow chart of the research

Table 1 Scoring items of the tooth preparation of the mandibular first molars for metal-ceramic crowns

Items	Score
Occlusal Surface Reduction	5
Occlusal Surface Morphology	10
Functional Cusp Bevel	5
Buccal Surface	5
Lingual Surface	5
Proximal Surface	5
Adjacent Tooth	5
Marginal Ridge Position	5
Marginal Ridge Continuity	10
Buccolingual Convergence	10
Mesiodistal Convergence	10
Axial Surface Angle Rounding	10
No Feather Edges	5
No Undercuts	5
Polishing	5
Total	100

underwent 12 training sessions on Real-time Dental Training and Evaluation System (DCARER) or Simodont Dental Trainer (NISSIN), respectively, with teacher (Dr. Liu) providing technical support but no additional guidance.

Application of RDTES and VSS

The operation of RDTES is similar to that of traditional head-simulators (Fig. 2). After routine calibration, tooth preparation practice can commence. The difference lies in its capability to possess a real-time digital assessment system consistent with navigational oral implant surgery. When operators perform tooth preparation on a simulated head model, the navigator can closely monitor the movement of the turbine handpieces and promptly convert the actual amount of tooth preparation into digital information. During the practice phases, it can intuitively remind operators whether the preparation amount of the tooth surface meets the requirements, and whether there are any areas with high contour points or excessive preparation. In the examination phase, it can directly provide a score once the student has completed the operation.

VSS is a completely virtual teaching system, significantly differing from traditional simulated head model teaching methods (Fig. 3). This system does not use actual turbines and simulated teeth. Instead, students engage in virtual practice throughout the process. They observe the preparation of virtual teeth through a screen and receive tactile feedback from the handle that simulates the sensation of cutting tooth hard tissue accompanied by the sound effect of the turbine working. After the operation is completed, the system will also provide

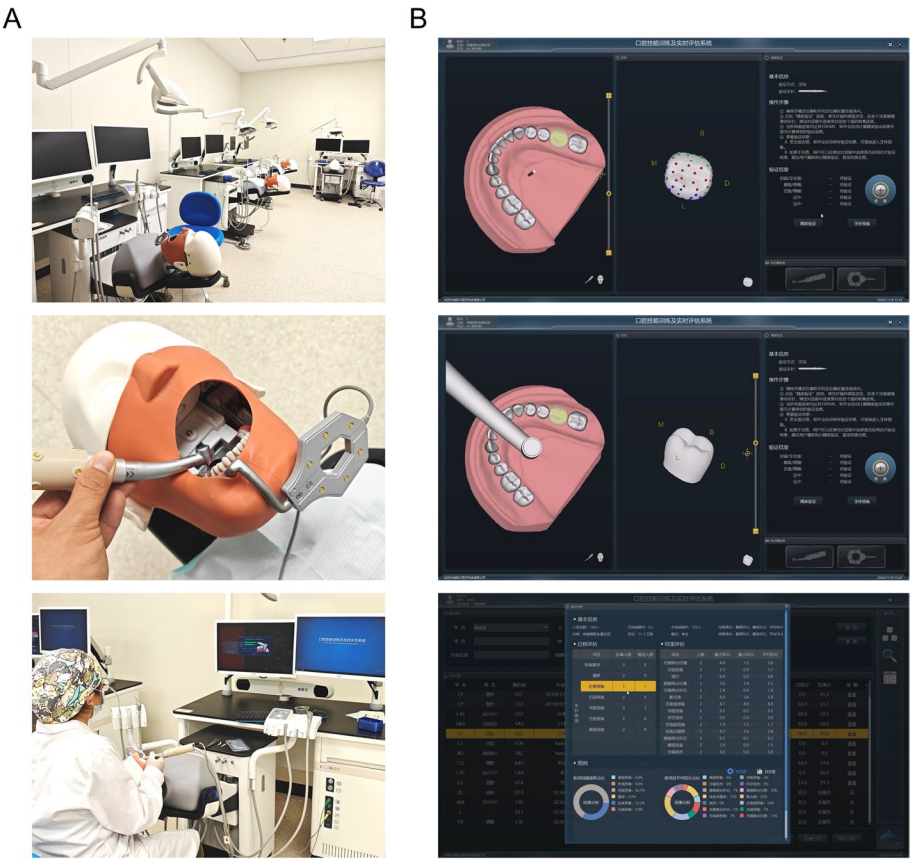

Fig. 2 Application of RDTES. **A** Demonstration of RDTES and operation methods. **B** Real-time assessment displayed on the computer screen during the operation process of RDTES, and scoring upon completion

a corresponding score based on whether the preparation amount is qualified.

Scoring and surveys

After 6 weeks of training, the four groups of students were tasked with completing the preparation of a right mandibular first molar PFM crown within a 30-min time limit using standardized typodont right mandibular first molars (A5SAN-500; Nissin Dental Products, Inc) [15, 16]. Five experienced teachers blindly scored the prepared extracted teeth of the students according to Table 1 and conducted machine scan scoring through a digital oral teaching internship evaluation system (NISSIN, Fair Grader 2000 PLUS). Statistical methods were used to analyze and evaluate the artificial scoring and machine scoring separately. Then, the improvement value of each student was analyzed and evaluated by subtracting their baseline score from their final score. The correlations between each pair were also calculated.

At the end of the course, anonymous surveys were conducted to collect students' subjective evaluations on the use of various teaching systems, including the ease of use of the equipment and the quality of interactive feedback. These were used to assess student satisfaction with the teaching methods and whether they believe these teaching methods can significantly improve their tooth preparation skills.

Statistical analyses

All data were calculated as the mean ± standard deviation (SD). Statistical differences were analyzed via Student's t test for independent sample tests or one-way ANOVA with Tukey's post hoc tests for multiple comparisons. Simple linear regression was used to conduct the correlation analysis. A p value < 0.05 was considered statistically significant.

Results

Firstly, regarding artificial subjective scoring (Fig. 4A), the tooth preparation scores of the 3 training groups were significantly higher than those of the NAT control group, with statistically significant differences ($p < 0.05$). Among the 3 training groups, pairwise comparisons showed small differences without statistical significance

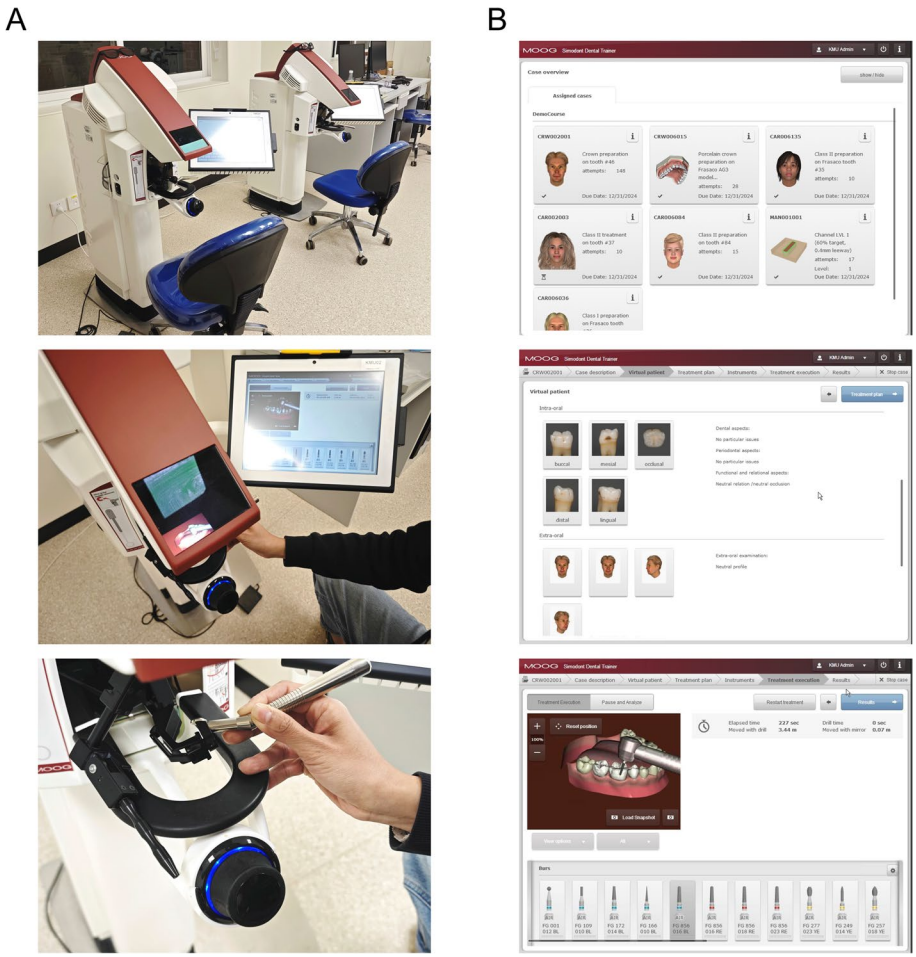

Fig. 3 Application of VSS. **A** Demonstration of VSS and operation methods. **B** The virtual patient information presented by VSS, and the virtual real-time tooth preparation progress displayed on the VSS screen during the operation process

($p > 0.05$). After subtracting the artificial scoring baseline, the improvement in artificial scoring showed the same trend, with all 3 training groups demonstrating a more significant enhancement compared to the NAT group, and these differences were statistically significant ($p < 0.05$). However, pairwise comparisons among the 3 training groups revealed small differences without statistical significance ($p > 0.05$).

In terms of machine scan scoring (Fig. 4B), the tooth preparation scores of the 3 training groups were significantly higher than those of the NAT control group, with statistically significant differences ($p < 0.05$). Notably, the RDTES group scored higher than the other 2 training groups, and these differences were statistically significant ($p < 0.05$). After subtracting the machine scoring baseline, the comparison of machine scoring improvement showed that all 3 training groups had a more significant enhancement compared to the NAT group, with statistically significant differences ($p < 0.05$). However, pairwise comparisons among the 3 training groups revealed small differences without statistical significance ($p > 0.05$).

We conducted simple linear regression to test for a clear correlation between scoring and scoring improvement (Fig. 4C) to examine the reliability of the scoring system and the aforementioned results. Both the artificial scoring and artificial scoring improvement ($R^2 = 0.6226$) and the machine scoring and machine scoring improvement ($R^2 = 0.7111$) showed a clear positive correlation and were statistically significant ($p < 0.05$).

Using simple linear regression to test for a clear correlation between artificial scoring and machine scoring (Fig. 4D) to assess the consistency of these two evaluation methods, however, both the artificial scoring and machine scoring ($R^2 = 0.1013$) and the artificial scoring improvement and machine scoring improvement ($R^2 = 0.02349$) showed a poor correlation.

In the analysis of the anonymous survey questionnaires from students in the RDTES and VSS groups

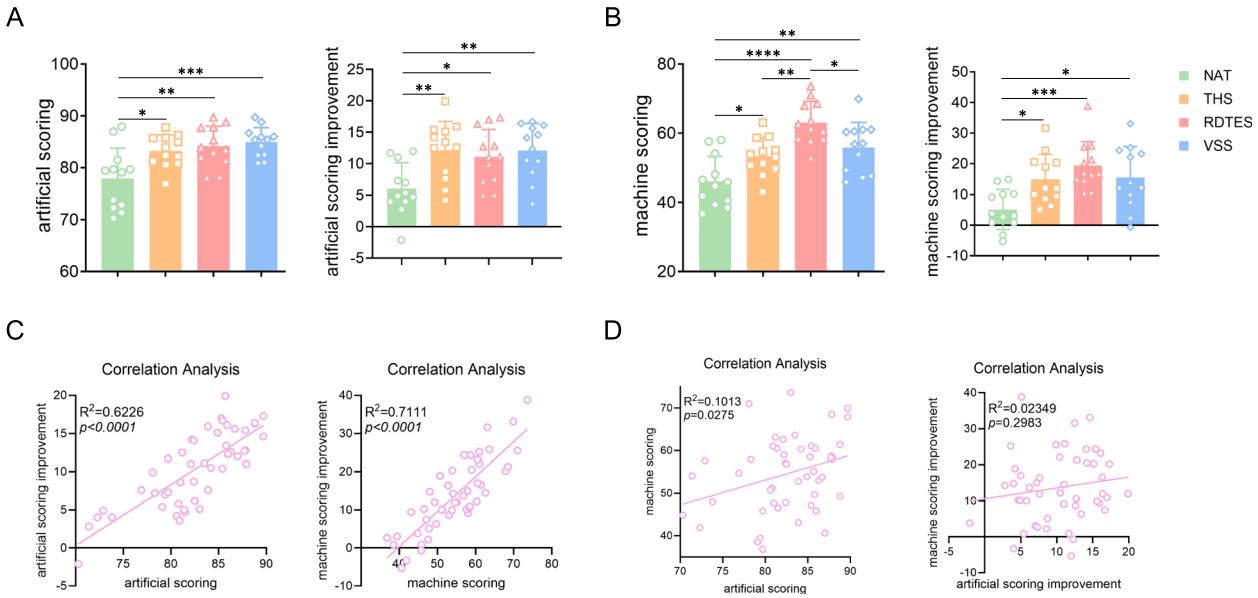

Fig. 4 Analysis of artificial and machine scoring. **A** Comparing the artificia scoring and artificial scoring improvement among the 4 groups ($n = 12$). **B** Comparing the machine scoring and machine scoring improvement among the 4 groups ($n = 12$). **C** Simple linear regression for correlation analysis between scoring and scoring improvement ($n = 48$). **D** Simple linear regression for correlation analysis between artificial scoring and machine scoring ($n = 48$). Data are shown as the mean ± S.D.; *p* value by one-way ANOVA with Tukey's post hoc tests for multiple comparisons

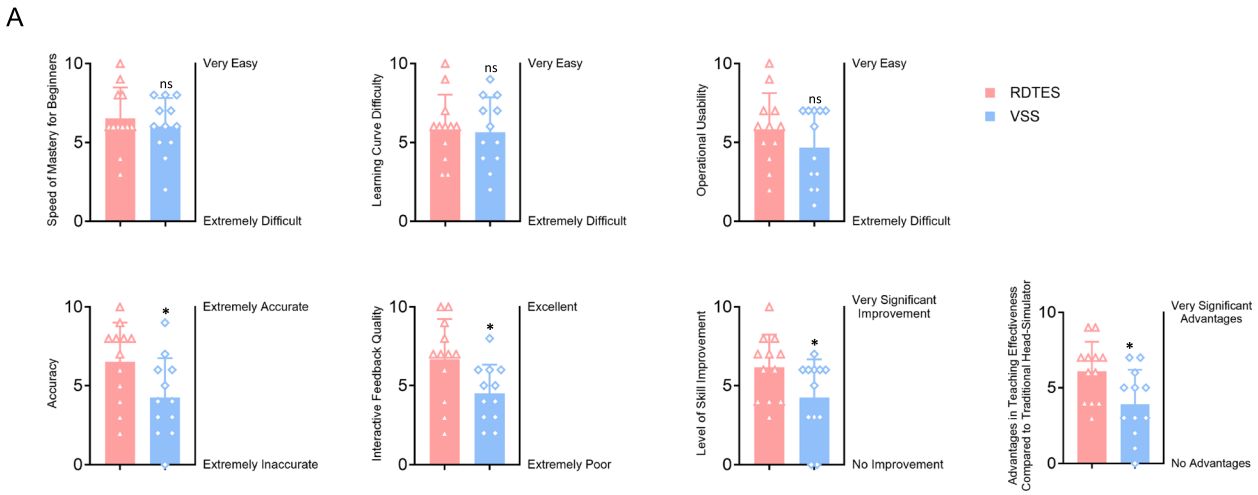

Fig. 5 Analysis of the anonymous survey questionnaires from students in the RDTES and VSS groups. **A** Comparing the subjective feedback of students in the RDTES and VSS groups ($n = 12$). Data are shown as the mean ± S.D.; *p* value by by two-tailed Student's *t* test

(Fig. 5), we found that students generally believed there was no significant difference between these 2 digital systems in terms of Speed of Mastery for Beginners, Learning Curve Difficulty, and Operational Usability ($p < 0.05$). However, in terms of Accuracy, Interactive Feedback Quality, Level of Skill Improvement, and Advantages in Teaching Effectiveness Compared to THS, students generally had a better subjective experience during the training process with RDTES, and the differences were statistically significant ($p < 0.05$).

Discussion

Exquisite tooth preparation skills are one of the cornerstones of prosthodontics. In the classic preclinical training model, students primarily rely on repeated tooth

preparation practice on resin teeth using head-simulators, and improve their tooth preparation operations and skills through one-on-one evaluation and feedback from teachers. This classic training model is effective but relatively inefficient. In Chinese dental schools, 1–2 laboratory teachers usually face 30–40 students [20–22]. Typically, students have to complete the entire preparation of a resin tooth before receiving a delayed evaluation of the final result from the teacher. Mistakes made during their operation and insufficiencies in the amount of preparation are difficult to be pointed out in a timely manner. At the same time, the teacher's guidance often depends on their clinical and teaching experience, which is somehow subjective and personal, and thus may inevitably be accompanied by a certain degree of subjective bias. Therefore, digital, objective measurement of the amount of preparation can well compensate for this and provide students with timely and accurate references.

Regarding artificial and machine scoring, the tooth preparation scores of the 3 training groups were significantly higher than those of the NAT control group, and in pairwise comparisons among the 3 training groups, the RDTES group and VSS group were not inferior to the classic THS group. This suggests that we can to some extent consider that, after receiving standardized lecture and head-simulator demonstration, students trained through RDTES or VSS, are not inferior in tooth preparation level to students guided by the classic THS. Furthermore, we can to some extent consider that both RDTES or VSS training can partially replace the workload of the teacher's chair-side guidance, both under the evaluation of subjective artificial scoring system and the objective machine scan scoring system [23].

Especially, in Fig. 4B, the RDTES group scored higher than the other 2 training groups by machine scanning. This is due to the working characteristics of RDTES, which uses a navigator to monitor in real-time, calculates the differences between the tooth preparation amount and the standard preparation, and provides immediate and rapid feedback to the operating student, helping them to make adjustments in time and further strengthening the requirements for the amount of preparation on the occlusal surface and each axial surface [11, 13]. The scoring logic of machine scan scoring also emphasizes precise control of the amount of preparation. The significant higher machine scoring of students trained through the RDTES group indicates that RDTES can indeed help students to better grasp the amount of tooth preparation [24–26].

Additionally, in Fig. 4D, we found through simple linear regression that there is no clear linear correlation between artificial scoring and machine scoring. In machine scan scoring, the machine mainly emphasizes the amount of preparation and lacks evaluation of form and details. In subjective artificial scoring, attention is also focused on the occlusal surface form, functional cusp bevel, shoulder platform form and continuity, axial surface angle rounding, no thin edges, no undercuts, polishing, and many other morphological details that affect the quality of tooth preparation and the service life of crowns [22, 27]. When evaluating the amount of preparation, teachers rely more on their clinical experience and may not be sensitive enough to excessive preparation, leading to a certain degree of bias in their scoring results [4, 26].

On this basis, we would like to discuss the advantages and disadvantages of these two digital systems. The main advantage of RDTES is its timely and rapid feedback, which is helpful for students to initially grasp the amount of tooth preparation. It also saves on teacher labor costs, allowing students to practice and improve based on the feedback from the digital system without depending on teacher guidance, and their training time is relatively more flexible. According to the survey feedback, students have a good subjective feeling during practice. However, RDTES also has the following shortcomings: the system emphasizes the amount of preparation but lacks guidance on form and preparation details, such as axial surface angle rounding, shoulder platform smoothness, polishing, etc. There are also inconveniences in its use, including: the weight of the turbine is too large; preparation operation easily blocks the navigator, also as know as its recognition module, affecting real-time assessment effects, especially in the posterior tooth area; a long time is needed for each use for debugging, which consumes actual practice time, etc [13, 20, 21].

VSS also has its unique advantages. VSS is very environmentally friendly, generating almost no resource consumption except for electricity, and also not producing aerosols and other air pollutants when cutting simulated teeth; VSS is also very safe, not using turbines, avoiding operational risks during practice by beginners; after the practice module, the VSS system will also give corresponding scores. However, the shortcomings of VSS are also repeatedly mentioned by students in the questionnaire: VSS feedback has a significant delay, leading to a poor subjective feeling during practice; although VSS tries to simulate the feeling of cutting tooth hard tissue, there is still a big gap from reality; in addition, VSS also has the disadvantages of poor precision and poor interactive feedback quality during the training process, but it cannot be denied that compared with the NAT control group, students' tooth preparation level has indeed significantly improved after receiving VSS training [2, 9, 28].

The use of RDTES and VSS can fully save teacher labor costs and improve the tooth preparation level of practitioners; however, because they emphasize the amount of

preparation and lack guidance on form and details, they are not yet able to replace the teacher's chair-side guidance at this stage. It is possible to consider a combination of the two or three, with teachers conducting standardized lectures and head-simulator demonstrations, students practicing extensively on RDTES and VSS to fully master the requirements for tooth preparation, and then teachers providing chair-side guidance on tooth preparation details.

This study also has certain shortcomings. In order not to affect students' normal teaching and subsequent clinical practice, all students in this study underwent standardized lectures and head-simulator demonstrations in the initial stage, so there is no group that only uses RDTES or VSS, which may not fully reflect the potential of RDTES and VSS in tooth preparation teaching. However, considering educational equity, we cannot deprive the experimental group students of the right to use head-simulators for practice. It should be declared that, to fully ensure educational equity, after this study, we opened RDTES and VSS to all 114 students included or not included in this study, giving every student the opportunity to experience digital real-time and virtual simulation systems.

In the future, with continuous technological advancements and deepening applications, the application of virtual simulation teaching systems and digital real-time assessment systems in dental education will become more extensive and profound. On one hand, these systems will become more intelligent and personalized, capable of providing precise teaching guidance and feedback based on the actual situation and learning needs of students. On the other hand, these systems will be combined with other teaching methods to form a diversified teaching model, better meeting the needs of dental education. For example, RDTES can be considered for use in more aspects of dental teaching, including: cavity preparation for caries, root canal treatment, surgical block anesthesia, implant placement, orthodontic bracket positioning, etc [2, 8].

In addition, with the continuous development of virtual reality, augmented reality and other technologies, the immersion and reality of virtual simulation teaching systems will be further improved, enabling students to obtain a more realistic operational experience and learning effects in the virtual environment. Students' subjective evaluation of different teaching methods, including equipment ease of use, interactive feedback quality, and feelings about skill improvement, is also an important part of teaching effect evaluation. Future research should pay more attention to this aspect of survey and analysis in order to better meet students' learning needs and improve teaching quality.

Conclusion

The Real-time Dental Training and Evaluation System (RDTES) and the Virtual Simulation System (VSS) both significantly enhance students' mastery of molar tooth preparation, particularly in the precise guidance of tooth preparation volume provided by RDTES. These two systems hold broad application prospects and substantial development potential in dental education. Moving forward, it is essential to further strengthen related research and practical application, continually refining and optimizing these systems to advance innovation and development in dental education.

Acknowledgements

We thank Yan Liang, Lin Dai, Ting Zhou and the undergraduate class of 2021 from the Affiliated Stomatology Hospital of Kunming Medical University, for their support and assistance during the conduct of this teaching research project. We appreciate the equipment, consumables, and financial support provided by the Affiliated Stomatology Hospital of Kunming Medical University in the course of carrying out this teaching research project.

Authors' contributions

T.T.: Conceptualization (supporting), Investigation (equal), Validation. L.X.: Project Administration (equal), Resources (equal), Supervision (equal), Writing-Review & Editing. L.Y.: Project Administration (equal), Resources (equal), Supervision (equal). L.C.: Conceptualization (lead), Data Curation, Formal Analysis, Funding Acquisition, Investigation (equal), Visualization, Writing-Original Draft Preparation.

Funding

This research was supported by the National Natural Science Foundation of China (NSFC grant number 82401049), the Undergraduate Education and Teaching Reform Project of Kunming Medical University (grant number 2024-JY-Y-142) and the Yunnan Provincial Department of Education Science Research Fund (grant number 2024 J0273).
The funding for this project was entirely derived from the research grants of the corresponding author, Dr. Caojie Liu. There was no involvement of any commercial company's support. There are no commercial conflicts of interest.

Data availability

All data underlying the findings and outcome are presented as part of the article and no supplementary source data are required.

Declarations

Ethics approval and consent to participate

The study was approved by the Medical Ethics Committee of the Affiliated Stomatological Hospital of Kunming Medical University (KYKQ2024MEC0156). The study adhered to the Declaration of Helsinki.
Prior to the conduct of this teaching research project, informed consent was obtained from the undergraduate students participating in the study. This study does not involve clinical patient experiments or animal experiments. The research is a teaching research project that only involves the introduction of new digital teaching methods as supplements in the undergraduate prosthodontics experimental course, without affecting the overall undergraduate teaching schedule and teaching quality, and without involving disputes over teaching fairness.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Received: 19 February 2025 Accepted: 12 May 2025
Published online: 27 May 2025

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