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**Evaluating the effectiveness of a preclinical practice of tooth preparation using digital training system**

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**Evaluating the effectiveness of a preclinical practice of  
tooth preparation using digital training system: a  
randomized controlled trial**

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Review

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## Introduction

Current dental practice is characterized by a growing need for knowledge and multidisciplinary collaboration (1, 2), so educational institutes focus on promoting dentists' competences to successfully deal with the challenges of daily practice (3). It is very important for the dental undergraduates to transfer theoretical medical knowledge and relevant material science for training operative skills and performing preclinical and clinical practices (4, 5).

The dental preclinical education involves the various practical tasks, in which the practical course is about the 'shows how' (6, 7). The instructors show the students how to perform the practical tasks on the manikin head, and then the students exercise with the guidance of the instructors. Therefore, it is necessary to have adequate resources of instructors for the students clearly observing the instructor's operation and being instructed in a timely manner (8). The costs of adequate manpower, the demand for sufficient training and time allocation are high for the dental institutes. On the other hand, most of the dental practices require precise operation within restricted time, so it is not enough to evaluate the practical outcomes just via the subjective observation, particularly the evaluation of preparation of the prosthesis in the phantom Model (9). Recently, witnessed a rapid advance of digital technologies in dentistry in recent decades since the Computer Aided Design and Computer Aided Manufacture (CAD/CAM) was first introduced into dentistry in the 1970s (1). The development of digital technologies such as virtual reality simulation (VRS) system, three-dimensional imaging, and computer-assisted tracking provides digital alternatives for existing work practices in dental profession (2). New digital technologies have changed dentistry by replacing many traditional techniques with its standardized chain of automated production, which has been shown with improved quality and precision as well as enhanced efficiency (1, 3-5).

As a result of continual developments in digital dental technology, dental education has started to use digital technologies in various preclinical trainings in recent decades (6, 7). Of these, digital training system used in

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3 restorative dental training has shown its potential in replacing the traditional  
4 apprentice style of preclinical training through demonstrating restorative dental  
5 techniques on the phantom head and checking students' practical work by trainers.  
6 This may generate high inter-and intra-individual differences in the students'  
7 evaluation results (1, 3, 4). Digital training systems, however, provide favorable  
8 special features such as accurate measurement and instant calculation, which might  
9 be more suitable to dental students in their preclinical training compared with  
10 traditional method (8). It can provide students with a virtual learning environment  
11 for students to observe and receive instant and objective visual feedback based on  
12 predefined assessment criteria within the system. This could improve students'  
13 self-assessment skills which will be beneficial to their life-long learning (9-11).

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23 ~~The development of digital technologies such as virtual reality system,~~  
24 ~~three dimensional imaging, and computer assisted tracking provides digital~~  
25 ~~alternatives for existing work practices in dental profession(2). New digital~~  
26 ~~technologies have already been omnipresent in many aspects of the dental workflow~~  
27 ~~(1, 3, 4). Due to the specialties of the digital technologies, including accurate~~  
28 ~~measurement and efficient calculation, they might be suitable to the dental students~~  
29 ~~and their preclinical training (7-9). One digital evaluation system used commonly in~~  
30 ~~restorative dental preclinical training is the DentSim (Image Navigation, New York,~~  
31 ~~NY), which is a preclinical simulator that provides real-time image processing with~~  
32 ~~the use of three-dimensional graphics and VRS (12). The DentSim unit includes a~~  
33 ~~manikin head and torso, KaVo dentoform, dental handpiece, light source, infrared~~  
34 ~~camera, and software. The students are able to see the illustration of their preparation~~  
35 ~~in real-time on the monitor. It is believed that if students see illustrations of their~~  
36 ~~procedures, they can possibly understand inadequacies in their skills in an objective~~  
37 ~~and visual way (13, 14). This may result in high effectiveness for technical training.~~

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Gluch et al. (15) and Stewart et al. (16) suggested that the DentSim technology based  
on the ~~virtual reality (VR)~~VRS system could improve the student learning abilities  
and operating skills in the dental practical course. However, Quinn et al. (17)  
compared the dental preclinical training via the VRS system ~~to~~with conventional

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3 instruction, and thought that VRS should not be used without supplemental faculty  
4 instruction. Although another study indicated that there were no statistical differences  
5 in the quality of the tooth preparations between using computer-assisted simulation  
6 system and non-computer-assisted system, the students with non-computer-assisted  
7 system received five times more instructional time from faculty than ~~did those trained~~  
8 using computer-assisted ~~students system~~. The authors ~~concluded that while~~ suggested  
9 the need for further ~~study was needed~~ studies to assess VRS technology as this  
10 decreased faculty time in instruction which could have meaningful impact on the  
11 dental curriculum (18, 19).  
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16 Although the DentSim system can provide the students with the real-time  
17 illustrations of their procedures and inadequacies of their skills in an objective and  
18 visual way, the students' assessment abilities of the practical task might not be  
19 improved. This might be due to the fact that the DentSim system has no peer  
20 assessment and feedback functions. So we developed a new digital training system for  
21 the preclinical practice. Except for the Real-time Dental Training and Evaluation  
22 System (RDTES) similar to the DentSim system, the Online Peer-Review System  
23 (OPRS) with the peer assessment and feedback platform was added to the new digital  
24 system. By virtue of the OPRS, the students can assess their own and peers' practical  
25 tasks online and obtain instant feedback about their operation and assessment results.  
26 This may help increasing students' ability of self-assessment/assessment and  
27 operating skills.  
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41 In this study, therefore, we aimed to evaluate the effectiveness of a preclinical  
42 training using digital evaluation system to improve dental students' practical skills on  
43 ceramic crown preparation compared with using traditional method. Additionally, the  
44 present study was aimed to explore the association between the students' outcomes of  
45 crown preparation and their attitudes towards the digital training method.  
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## Materials and Methods

### *Participants*

This prospective cohort study took place in the fourth year of the undergraduate program within the preclinical course of prosthodontics at the School of Stomatology of Nanjing Medical University in ~~Nanjing~~, China. All fourth-year dental students (28 males, 38 females) were invited and they all consented to participate in the study. A sample of 66 fourth-year undergraduates (28 males, 38 females) with no experience in operative dentistry was recruited in this study for performing the practical task: preparation for ceramic crown of the upper left central incisor. The mean age of the students was 22.11 (range 21–24) years. All 66 dental students had been trained in other preclinical tooth preparation courses with the traditional method which included the dental cavity preparation of upper first molar and the metal crown preparation of lower first molar prior to the study experiment.

~~The participants provided informed written consent, and the study followed the Declaration of Helsinki and the guidelines of the Ethics Review Committee of Affiliated Stomatological Hospital of Nanjing Medical University with regard to medical protocols and ethics (PJ2016-032-001).~~

### *Study design and interventions*

The participating students were randomly allocated into two groups: practiceexperimental group (n = 33), and control group (n = 33). The demographic parameters of the students were shown in Table 1. Both groups were instructed to prepare the ceramic crown of upper left central incisor using two different methods. All students had attended the theory course didactic lecture of preparing the ceramic crown before performing attending this practical course.

In the control group, the students were instructed to complete the practical task with the traditional training method according to the pre-defined criteria of preparation for the ceramic crown (Table 2). The instructors (prosthodontics specialists) showed the students demonstrated the practical procedures of ceramic crown

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3 preparation on the phantom model. The instructors corrected the students' mistakes  
4 during the practical course, and assessed their tooth preparation results. At the end of  
5 the practical course, the essentials of this practical task were summarized by the  
6 instructors based on the students' results and feedback, and then were provided to the  
7 students. The process of the practical course using traditional method was shown in  
8 Figure 1. The flow of the practical process was showed in the Figure 1.

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14 The students in practicexperimental group were trained with a digital training  
15 method. Firstly, they were provided with standard videos showing how to perform the  
16 practical steps on the Online Peer-Review System (OPRS, Nanjing Bootsoft Software  
17 Company, Nanjing, China). The standard videos involved two parts: extraoral and  
18 intraoral views of the whole practice procedure based on the pre-defined criteria  
19 (Figure S1) . The students would learn the essentials of the practical task via  
20 watching the standard videos many times before performing the practice. Then they  
21 were requested to prepare the ceramic crown of upper left central incisor on the  
22 phantom model under the guidance of the Real-time Dental Training and Evaluation  
23 System (RDTEs, Suzhou Digital-health Care Company, Suzhou, China). Each  
24 student's practice videos were captured by the RDTEs, including the extraoral view  
25 via the camera and the intraoral view via the optical position sensor system (NDI  
26 Polaris) and virtual reality simulation system (Figure S2) . When the students finished  
27 their practices in the phantom model, the RDTEs would ~~automatically~~ assess the  
28 operations and model results instantly based on the predefined assessment criteria  
29 ~~(Figure S3)~~ . The subjects' own practice videos were uploaded to the OPRS by  
30 themselves via their own online student accounts ~~(Figure S4)~~ . The instructor selected  
31 and assessed one student's videos online as the "gold standard exemplar". The "gold  
32 standard exemplar" videos were assigned to each student as a reference for assessing  
33 their peers' practical results. Moreover, the OPRS randomly assigned 2 or 3 subjects'  
34 videos to each subject in order to test their peer assessment and self-assessment  
35 abilities. All students of the practicexperimental group were blinded to the tasks for  
36 assessment. They evaluated the assigned videos online according to the assessment  
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3 criteria ~~(Figure S5)~~, and then obtained the assessment results of their own tasks from  
4 others ~~(Figure S6)~~. The whole practical course lasted one week, including learning the  
5 standard videos, ~~preforming~~ performing the practices, assessing their peers' tasks, and  
6 obtaining the feedback of their own tasks. The intervention process of the  
7 ~~practice~~ experimental group was shown in the Figure 1.  
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### 12 13 14 *Assessment of practical test models*

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17 A week later when all students of both groups finished the practical training, a  
18 practical test of a ceramic crown preparation of upper left central incisor in the  
19 phantom models was implemented ~~for~~ by each subject in order to test their learning  
20 achievements. The subjects all used the ~~same~~ identical operative armamentarium and  
21 phantom heads, and were allocated the same time for tooth preparation in identical  
22 situation. Two experienced instructors (prosthodontics specialists with more than 10 years  
23 of clinical experience) who were calibrated prior to the study, independently assessed  
24 each practical test model and operation under the prior described criteria (Table 2),  
25 and then repeated the evaluation two weeks later. They were blinded to the group  
26 status to prevent information bias.  
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### 38 *Questionnaire*

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40 The questionnaire was comprised of six items for the participating students ~~of~~ in the  
41 ~~practice~~ experimental group, which were used to illustrate their attitudes towards the  
42 digital training method using the OPRS and RDTES (Table 3). ~~Particularly, these~~  
43 ~~items were chosen to demonstrate the essential features of the practical task and~~  
44 ~~feedback~~. A modified Likert scale was used in this questionnaire, with four instead of  
45 five possible degrees to prompt a stated opinion rather than a neutral attitude (20).  
46 The degrees ranged from 'I disagree', 'I partially disagree', 'I agree' to 'I strongly  
47 agree', which were respectively marked with the points of -2, -1, +1 and +2. The sum  
48 of the questionnaire points per subject in the ~~practice~~ experimental group was obtained,  
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and we computed the correlation between the total scores of practical task results and the questionnaire items in the practi~~ee~~experimental group.

### ***Statistical analyses***

Data were analyzed using the statistical software program SPSS ver.16.0 (IBM Corporation, Armonk, NY). The demographic data of the two groups were compared using Student's t-tests. The scores of the practical results of the practi~~ee~~experimental and control groups were tested for normal distribution and variance homogeneity (Kolmogorov–Smirnov test, Levene test). Student's t-tests or Wilcoxon signed rank tests were conducted to compare differences of the assessment results between the two groups, including the total score and every component score. We calculated the Pearson's correlation coefficient for the scores of practical results and the questionnaires per subject in the practi~~ee~~experimental group and computed the statistical significance of the value. The level of significance was  $p < 0.05$ .

Furthermore, inter-rater and intra-rater reliabilities between two instructors for assessment of the practical tasks were calculated using the Intra-class Correlation Coefficient (ICC). ICC values of  $> 0.75$  were considered to indicate good interrater or intra-rater reliability.

### ***Ethical considerations***

The participants provided informed written consent, and the study followed the Declaration of Helsinki and the guidelines of the Ethics Review Committee of Affiliated Stomatological Hospital of Nanjing Medical University with regard to medical protocols and ethics (PJ2016-032-001).

### **Results**

The subjects of the practi~~ee~~experimental group ( $n = 33$ ) included 14 men-male and 19 women-female students, whose age ranged from 22 to 24 years old (mean = 22.18 years). Similarly, there were also 14 men-male and 19 women-female students in the

control group (n = 33), whose age ranged from 21 to 23 years old (mean = 22.04 years). There were no statistically significant differences between the subjects of the practiseexperimental and control groups in terms of demographic parameters (P > 0.05). The intra-rater reliabilities of the instructor A (ICC = 0.896) and instructor B (ICC = 0.935) were good, so was the inter-rater reliability of two instructors (ICC = 0.928).

### ***Differences in the ceramic crown preparation between the practiseexperimental and control groups***

According to the final assessment of practical test conducted by the instructors, the results of preparation for the ceramic crown differed significantly between the practiseexperimental and control groups (Table 4). The scores of the practical task in the practiseexperimental group were statistically significantly higher compared with those of the control group (P = 0.003). Among the three extraoral items of assessment criteria, the scores of two items were significantly higher in the practiseexperimental group than the control group, including operating position (P = 0.003), grip manner and support (P = 0.032). Furthermore, there were three out of twelve intraoral items, of which the scores were also significantly higher in the practiseexperimental group, such as crown reduction (P = 0.003), taper of axial surfaces (P = 0.004), and damage of adjacent teeth (P = 0.038). Although the rest of fifteen items did not statistically differ between the two groups, the scores of ten items were also higher in the practiseexperimental group than the control group (Table 4).

### ***Questionnaires from the students in the practiseexperimental group***

The questionnaires consisting of six items were answered by the 33 students enrolled in the practiseexperimental group. The responses of the students to the six items were shown in Figure 2 and Table S1. Nearly ~~ninety-seven percent~~ 97% (32) of the students agreed or strongly agreed that they could better improve their ability of preparation for the ceramic crown via the digital training method compared with the traditional

method. ~~Only one student partially disagreed with this statement.~~ Twenty-seven (81.82%) out of 33 students agreed or strongly agreed that watching the standard videos on the OPRS could make it easier for them to understand the essentials of the practical task compared with the traditional method of directly observing instructor's demonstration. A minority of the students (18.18%) disagreed or partially disagreed with this statement. Nearly ~~ninety-four percent~~94% (31) of the students agreed or strongly agreed that assessing their own and others' tasks could help them understand the essentials of the practical task better. The results showed 72.73% (24), 54.44% (18) and 36.36% (12) of the students strongly agreed that the digital training method with OPRS and RDTES could respectively improve their self-learning, assessment, and self-assessment abilities of the practical task.

According to the correlation analysis between the scores of practical results and the questionnaires in the practiceexperimental group, the total scores of practical results were significantly positively correlated with the points of the questionnaires (Pearson's correlation coefficient = 0.798,  $P < 0.001$ ).

## Discussion

Digital dental technologies and devices, as parts of digital dentistry, incorporated digital or computer controlled components (18). Digital technologies applied to the dental practice could contribute to better and faster diagnosis, patient communication and dental student education (21). Among these dental technologies, the virtual reality simulation system was mostly used in the preclinical course of dental practices. The advantages involved effective learning and low-cost training even without an instructor's presence, possibility of repeating various dental operations, as well as evaluating student performance objectively (4, 11, 22).

In the previous studies, the virtual reality simulation system ~~could have been shown with enhance~~enhancement in the capability of evaluating students' preparations using computer tracking system. The students learned at a faster rate, developing their skills in significantly less time (15, 21). Our findings are consistent with these results~~The results were consistent with our findings~~, which showed the

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3 scores of the practical task in the ~~practi~~practi~~ee~~ee~~experimental~~ group were statistically  
4 significantly higher than those of the control group (Table 4). Two extraoral items of  
5 assessment criteria, of which the scores were significantly higher in the  
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7 ~~practi~~practi~~ee~~ee~~experimental~~ group than the control group, were operating position (~~P=~~P=~~0.003~~)  
8 and grip manner and support (~~P=~~P=~~0.032~~). It suggested that observing own extraoral  
9 practical video or the others could make it easier to improve operating position and  
10 instrument gripping manner. In the traditional training method, it was hard for the  
11 instructors to observe the whole operation of each student and ~~correct every mistake~~  
12 ~~immediately provide an instant feedback~~, particularly with a large number of the  
13 students (15, 16). In addition, the students could not ~~see~~see ~~assess~~ their own operating  
14 position with the traditional method during the whole operation, so they ~~did~~did ~~would~~ not  
15 know whether their own performances ~~was~~was ~~were~~ good or poor. Watching own  
16 extraoral videos, is like observing own operation from the viewpoint of outsiders,  
17 which made it more objective and more direct for the students to assess and correct  
18 their positions and grip manners.  
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31 Among fifteen intraoral items, there were three items significantly higher  
32 favoring using the RDTES than the traditional instruction, including crown reduction  
33 (~~P=~~P=~~0.003~~), taper of axial surfaces (~~P=~~P=~~0.004~~), and damage of adjacent teeth (~~P=~~P=~~0.038~~).  
34 Evaluating the three items was based on the precise values of assessment  
35 criteria (Table 2). It was difficult for the dental beginners to estimate the precise  
36 values due to their lack of practical experience. The RDTES based on the virtual  
37 reality simulation could provide the students with precise and objective measured  
38 values, which were more accurate and more sensitive than visual observational values.  
39 The digital dental system made it more accessible for the beginners to ~~master~~master ~~grasp~~  
40 the technical skills of precise crown reduction and taper of axial surfaces at the first  
41 time of ceramic crown preparation. The aforementioned factors may explain the  
42 reasons of the better test outcomes of the ~~practi~~practi~~ee~~ee~~experimental~~ group than the control.  
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53 According to the questionnaire results of this study, a vast majority of the  
54 students in the ~~practi~~practi~~ee~~ee~~experimental~~ group thought that using the digital training  
55 system could better improve their ability of preparation for the ceramic crown  
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3 compared with using the traditional method (Figure 2). All students agreed or strongly  
4 agreed that the digital training with OPRS and RDTES could improve their  
5 self-learning, assessment, and self-assessment abilities of the practical task. With the  
6 help of the OPRS, watching the standard videos and assessing own and peers'  
7 practical tasks online made it easier for the students to understand the essentials of the  
8 practical task. The Online Peer-Review System could provide the students with  
9 self-learning platform and allow them to learn the essentials of the practice without  
10 limitation of time and space. This new learning manner could improve the efficiency  
11 of self-learning, as well as save the resources of instructors and costs. On the other  
12 hand, the OPRS allowed the students to assess their own operating progress and the  
13 progress of their fellow students (23, 24). By judging their peers, students might gain  
14 insight into their own performance through reflection (25-27). It helped increasing  
15 students' ability of self-assessment/assessment and operating skills (28). The use of  
16 peer assessment by students may also alleviate the burden on the instructors (29). In  
17 addition, the OPRS provided instant feedback about the preclinical practices from the  
18 students' operation and assessment results, and thus better instructed the students in  
19 the future exercises (30). On account of these aforementioned characteristics and  
20 advantages OPRS possessed, the practical outcomes and operating skills of students  
21 were increased. This viewpoint was also proved by the positive correlation between  
22 the scores of practical results and the questionnaires in this study.

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25 However, this digital training system also had limitations. Because of the optical  
26 position sensor ~~embedded~~~~imbedded~~ into the handpiece, some students complained  
27 that the handpiece was ~~so~~ heavy and big that the accuracy of the operation might be  
28 compromised. Also for this reason, the students might not get used to the standard  
29 handpiece used in the clinical reality when beginning to perform clinical practice on  
30 the real patients. It was necessary to reduce weight and size of the special handpiece  
31 to as same as possible with the standard handpiece for the clinical practice in the  
32 future.  
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## Conclusions

The results of this study suggested that the digital training system with the OPRS and RDTES have demonstrated some promising features for students' training of ceramic crown preparation was suitable for the preclinical course of dental practice. It might be a good alternative to the traditional training method in the ceramic crown preparation, in terms of improving operating skills, peer-assessment and self-assessment skills as well as enhancing self-learning experience. Using the digital training system could better improve the dental students' abilities of tooth preparation than using the traditional training method with regard to operating skills, peer assessment, self-assessment and self learning.

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## Conflict of interest

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## References

1. van Noort R. The future of dental devices is digital. Dent Mater 2012; 28: 3-12.

2. van der Zande MM, Gorter RC, Aartman IH, Wismeijer D. Adoption and use of digital technologies among general dental practitioners in the Netherlands. *PLoS One* 2015; 10: e0120725.
3. Lebus A, Lai B, Emami E, Feine JS. New technologies in health care. Part 1: A moral and ethical predicament. *J Can Dent Assoc* 2008; 74: 631-5.
4. Flores-Mir C, Palmer NG, Northcott HC, Huston C, Major PW. Computer and Internet usage by Canadian dentists. *J Can Dent Assoc* 2006; 72: 145.
5. Beuer F, Schweiger J, Edelhoff D. Digital dentistry: an overview of recent developments for CAD/CAM generated restorations. *Br Dent J* 2008; 204: 505-11.
6. Al-Jewair TS, Qutub AF, Malkhassian G, Dempster LJ. A systematic review of computer-assisted learning in endodontics education. *J Dent Educ* 2010; 74: 601-11.
7. Welk A, Splieth C, Seyer D, Rosin M, Siemer M, Meyer G. German dental faculty attitudes towards computer-assisted simulation systems correlated with personal and professional profiles. *Eur J Dent Educ* 2006; 10: 87-95.
8. Sharaf AA, AbdelAziz AM, El Meligy OA. Intra- and inter-examiner variability in evaluating preclinical pediatric dentistry operative procedures. *J Dent Educ* 2007; 71: 540-4.
9. Flores-Mir C, Palmer NG, Northcott HC, Khurshed F, Major PW. Perceptions and attitudes of Canadian dentists toward digital and electronic technologies. *J Can Dent Assoc* 2006; 72: 243.
10. John JH, Thomas D, Richards D. Questionnaire survey on the use of computerisation in dental practices across the Thames Valley Region. *Br Dent J* 2003; 195: 585-90.
11. Schleyer TK, Thyvalikakath TP, Spallek H, Torres-Urquidy MH, Hernandez P, Yuhaniak J. Clinical computing in general dentistry. *J Am Med Inform Assoc* 2006; 13: 344-52.
12. Hamil LM, Mennito AS, Renne WG, Vuthiganon J. Dental students' opinions of preparation assessment with E4D compare software versus traditional methods. *J Dent Educ* 2014; 78: 1424-31.
13. Rees JS, Jenkins SM, James T, Dummer PM, Bryant S, Hayes SJ, et al. An initial evaluation of virtual reality simulation in teaching pre-clinical operative dentistry in a UK setting. *Eur J Prosthodont Restor Dent* 2007; 15: 89-92.
14. Kikuchi H, Ikeda M, Araki K. Evaluation of a Virtual Reality Simulation System for

- 1  
2  
3 Porcelain Fused to Metal Crown Preparation at Tokyo Medical and Dental University. *Journal*  
4 *of Dental Education* 2013; 77: 782-92.
- 5  
6  
7 15. Gluch JI, Stewart CL, Buchanan JA, Hammrich PL. Virtual reality technology in  
8 preclinical laboratory: differential student responses based on learning styles. *J Dent Educ*  
9 1999; 63: 58.
- 10  
11  
12 16. Stewart DL, Gluch JI, Hammrich PL, Buchanan JA. Virtual reality technology versus  
13 traditional preclinical lab: perceptions of first-year dental students. *J Dent Educ* 1999; 63: 74.
- 14  
15  
16 17. Quinn F, Keogh P, McDonald A, Hussey D. A study comparing the effectiveness of  
17 conventional training and virtual reality simulation in the skills acquisition of junior dental  
18 students. *European Journal of Dental Education* 2003; 7: 164-9.
- 19  
20  
21 18. Jasinevicius TR, Landers M, Nelson S, Urbankova A. An evaluation of two dental  
22 simulation systems: virtual reality versus contemporary non-computer-assisted. *J Dent Educ*  
23 2004; 68: 1151-62.
- 24  
25  
26 19. Quinn F, Keogh P, McDonald A, Hussey D. A pilot study comparing the effectiveness of  
27 conventional training and virtual reality simulation in the skills acquisition of junior dental  
28 students. *European Journal of Dental Education* 2003; 7: 13-9.
- 29  
30  
31 20. Norman G. Likert scales, levels of measurement and the "laws" of statistics. *Adv Health*  
32 *Sci Educ Theory Pract* 2010; 15: 625-32.
- 33  
34  
35 21. Prithviraj DR, Bhalla HK, Vashisht R, Sounderraj K, Prithvi S. Revolutionizing  
36 restorative dentistry: an overview. *J Indian Prosthodont Soc* 2014; 14: 333-43.
- 37  
38  
39 22. Bhambhani R, Bhattacharya J, Sen SK. Digitization and its futuristic approach in  
40 prosthodontics. *J Indian Prosthodont Soc* 2013; 13: 165-74.
- 41  
42  
43 23. Saedon H, Saedon MH, Aggarwal SP. Workplace-based assessment as an educational  
44 tool: Guide supplement 31.3--viewpoint. *Med Teach* 2010; 32: e369-72.
- 45  
46  
47 24. Spencer J. Learning and teaching in the clinical environment. *BMJ* 2003; 326: 591-4.
- 48  
49  
50 25. Plasschaert AJ, Manogue M, Lindh C, McLoughlin J, Murtomaa H, Nattestad A, et al.  
51 Curriculum content, structure and ECTS for European dental schools. Part II: methods of  
52 learning and teaching, assessment procedures and performance criteria. *Eur J Dent Educ* 2007;  
53 11: 125-36.
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55  
56 26. Kramer GA, Albino JE, Andrieu SC, Hendricson WD, Henson L, Horn BD, et al. *Dental*



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2  
3 student assessment toolbox. J Dent Educ 2009: 73: 12-35.

4  
5 27. Clark JD, Robertson LJ, Harden RM. Applying learning outcomes to dental education.

6  
7 Br Dent J 2004: 196: 357-9.

8  
9 28. Speyer R, Pilz W, Van Der Kruis J, Brunings JW. Reliability and validity of student peer  
10 assessment in medical education: a systematic review. Med Teach 2011: 33: e572-85.

11  
12 29. Gordon MJ. A review of the validity and accuracy of self-assessments in health  
13 professions training. Acad Med 1991: 66: 762-9.

14  
15 30. Macluskey M, Hanson C, Kershaw A, Wight AJ, Ogden GR. Development of a  
16 structured clinical operative test (SCOT) in the assessment of practical ability in the oral  
17 surgery undergraduate curriculum. Br Dent J 2004: 196: 225-8.  
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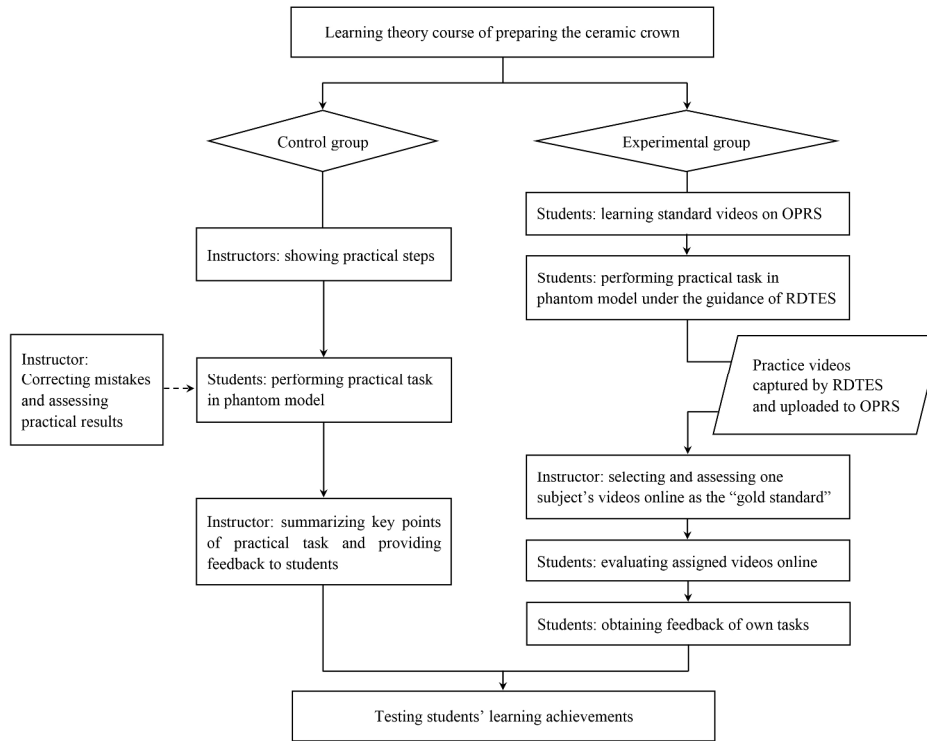


Figure 1. The flow diagram of the practical process in the control and experimental groups. The left part showed the practical procedure in the control group via the traditional training method. The right part showed the practical procedure in the experimental group via the digital training system.

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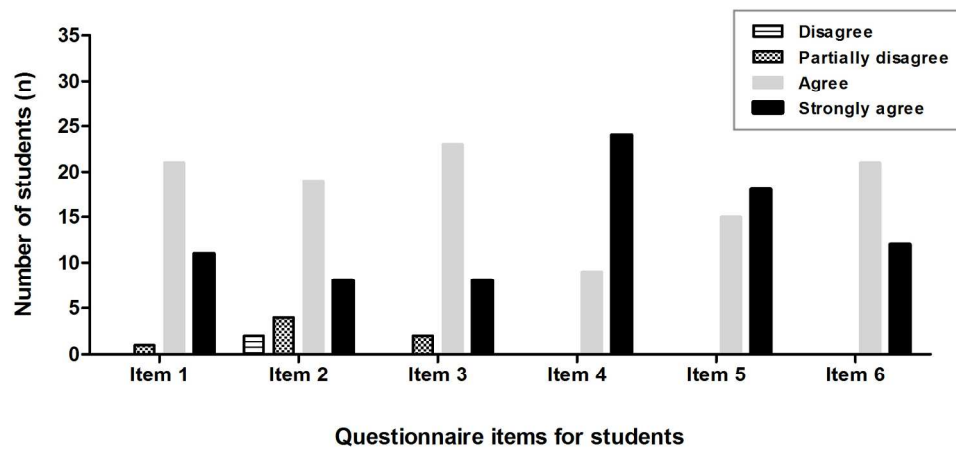


Figure 2. Students' attitudes towards the digital training method using the OPRS and RDTES. Six items involved in the questionnaire were answered with four possible degrees, including 'I disagree', 'I partially disagree', 'I agree' and 'I strongly agree'. The numbers of the students choosing four different degrees were counted, respectively.

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Table 1. Demographic characteristics of the subjects.

Group	<del>Practice</del> <u>Experimenta</u> l Group (n = 33)	Control Group (n = 33)
- Gender		
Males, n (%)	14 (42.42)	14 (42.42)
Female, n (%)	19 (57.58)	19 (57.58)
- Age, years	22.18 ± 0.48	22.04 ± 0.34
- Race, n (%)		
Mongoloid	33 (100)	33 (100)

Table 2. The pre-defined criteria of preparation for the ceramic crown.

	Items of the assessment criteria	Score
Extraoral	Extra 1 Operating position: 45° angle between upper occlusal plane and horizon; operator located at the right rear of the head-simulator, 11 or 12 o'clock.	5
	Extra 2 Grip manner and support: gripping the handpiece as holding the pen; stabilizing the support	10
	Extra 3 Instrument selection: preparing the contact area by TR11, the axial surface by TR13, the cingulum by flame-shaped drill	5
Intraoral	Intra 1 Patient-friendly <u>approach</u> : operating gently; avoiding tissue damages	5
	Intra 2 Water cooling, grinding discontinuously	5
	Intra 3 <u>Preparation s</u> Sequence: incisal edge → labial surface → proximal surface → lingual surface → cervix → refinement	5
	Intra 4 Operating procedure: preparing guidance grooves → grinding off dental hard tissue between the grooves → opening the contact area between the adjacent teeth	10
	Intra 5 Refinement and occlusal examination	5
	Intra 6 Smooth and obtuse line angles	5
	Intra 7 <u>Preparation reduction: Incisal-incisal</u> reduction with 2.0 mm; <del>Labial</del> labial, lingual and proximal reduction with 1.5-2.0 mm. Maintaining the lingual form of the crown.	10
	Intra 8 No undercut of axial surfaces	10
	Intra 9 Ideal taper of axial surfaces (2-5°)	5
	Intra 10 Shoulder <u>width and position</u> : fillet or retuse shoulder with 1.0 mm width; on or above the gingiva margin with 0.3-0.5 mm	5
	Intra 11 Continuous and smooth cervical margin of tooth	5
	Intra 12 No damage of adjacent teeth	10

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Total	100
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For Peer Review

Table 3. The questionnaire items for the students concerning their opinions on the benefits and drawbacks of using the OPRS and RDTES.

Items	Contents
Item 1	I have improved the ability of <del>the preclinical practice preparation for the ceramic crown</del> via the digital method better <del>than via</del> <u>compared with</u> the conventional method.
Item 2	Watching the standard videos on the OPRS makes it easier for me to understand the essentials of the practical task <u>compared with the conventional method.</u>
Item 3	Assessing my and other tasks helps me understand the essentials of the practical task better <u>compared with the conventional method.</u>
Item 4	The digital method with OPRS and RDTES can improve my self-learning of the practical task <u>better compared with the conventional method.</u>
Item 5	The digital method with OPRS and RDTES can improve my evaluation ability for the practical task <u>better compared with the conventional method.</u>
Item 6	The digital method with OPRS and RDTES can improve my self-evaluation ability for the practical task <u>better compared with the conventional method.</u>

Table 4. ~~Comparing~~ Comparison of the results of the ceramic crown preparation between the ~~practice~~ experimental and control groups.

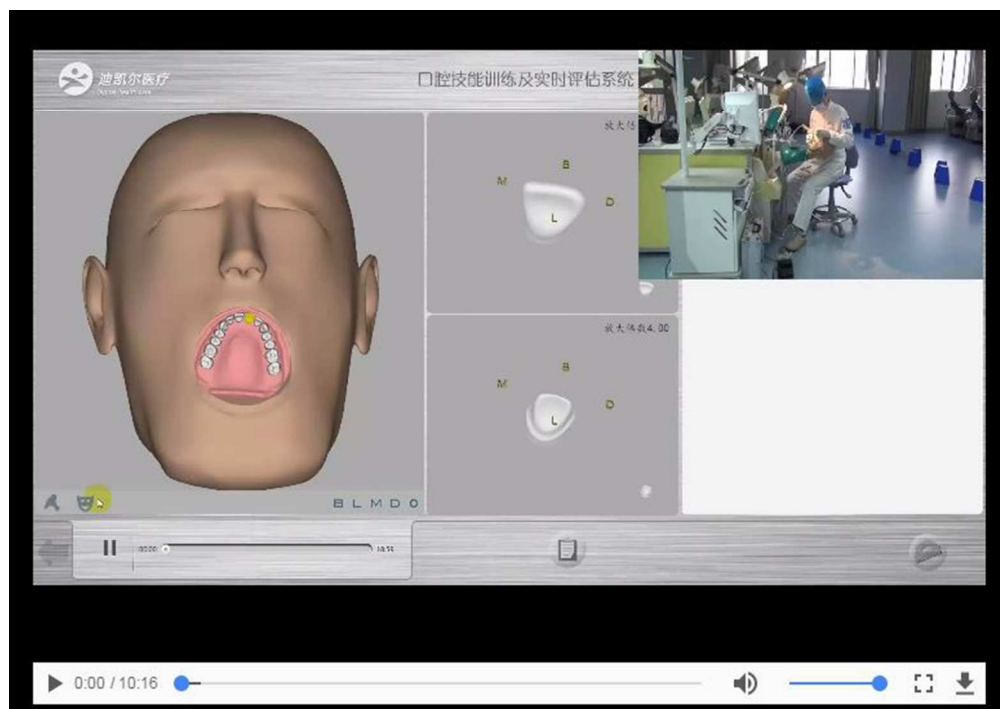
	<u>Scoring items</u>	<u>Score</u>	<u>Experimental group</u>	<u>Control group</u>	<u>t</u>	<u>P value</u>
			<u>Mean (SD)</u>	<u>Mean (SD)</u>		
<u>Extraoral</u>	<u>Extra 1: Operating position</u>	<u>5</u>	<u>4.98 (0.09)</u>	<u>4.80 (0.33)</u>	<u>3.067</u>	<u>0.003*</u>
	<u>Extra 2: Grip manner and support</u>	<u>10</u>	<u>9.97 (0.12)</u>	<u>9.85 (0.29)</u>	<u>2.198</u>	<u>0.032*</u>
	<u>Extra 3: Instrument selection</u>	<u>5</u>	<u>4.97 (0.12)</u>	<u>4.91 (0.20)</u>	<u>1.512</u>	<u>0.135</u>
<u>Intraoral</u>	<u>Intra 1: Patient-friendly approach</u>	<u>5</u>	<u>4.95 (0.15)</u>	<u>4.85 (0.29)</u>	<u>1.863</u>	<u>0.067</u>
	<u>Intra 2: Cooling and grinding</u>	<u>5</u>	<u>4.88 (0.22)</u>	<u>4.83 (0.24)</u>	<u>0.807</u>	<u>0.423</u>
	<u>Intra 3: Preparation sequence</u>	<u>5</u>	<u>4.83 (0.30)</u>	<u>4.80 (0.30)</u>	<u>0.409</u>	<u>0.684</u>
	<u>Intra 4: Operating procedure</u>	<u>10</u>	<u>9.39 (0.63)</u>	<u>9.29 (0.61)</u>	<u>0.691</u>	<u>0.492</u>
	<u>Intra 5: Refinement and occlusal examination</u>	<u>5</u>	<u>4.67 (0.30)</u>	<u>4.65 (0.48)</u>	<u>0.155</u>	<u>0.877</u>
	<u>Intra 6: Line angles</u>	<u>5</u>	<u>3.88 (0.59)</u>	<u>3.74 (0.60)</u>	<u>0.933</u>	<u>0.355</u>
	<u>Intra 7: Preparation reduction</u>	<u>10</u>	<u>7.55 (1.02)</u>	<u>6.77 (0.98)</u>	<u>3.133</u>	<u>0.003*</u>
	<u>Intra 8: Undercut of axial surfaces</u>	<u>10</u>	<u>7.74 (0.96)</u>	<u>7.03 (1.92)</u>	<u>1.902</u>	<u>0.062</u>
	<u>Intra 9: Taper of axial surfaces</u>	<u>5</u>	<u>3.68 (0.61)</u>	<u>3.15 (0.81)</u>	<u>2.993</u>	<u>0.004*</u>



<u>Intra 10: Shoulder</u>					
<u>width and position</u>	<u>5</u>	<u>3.45 (0.67)</u>	<u>3.32 (0.51)</u>	<u>0.932</u>	<u>0.355</u>
<u>Intra 11: Cervical</u>					
<u>margin of tooth</u>	<u>5</u>	<u>3.36 (0.69)</u>	<u>3.27 (0.65)</u>	<u>0.552</u>	<u>0.583</u>
<u>Intra 12: Damage</u>					
<u>of adjacent teeth</u>	<u>10</u>	<u>8.38 (0.65)</u>	<u>8.02 (0.74)</u>	<u>2.114</u>	<u>0.038*</u>
<u>Total</u>	<u>100</u>	<u>86.70 (4.17)</u>	<u>83.29 (4.81)</u>	<u>3.077</u>	<u>0.003*</u>

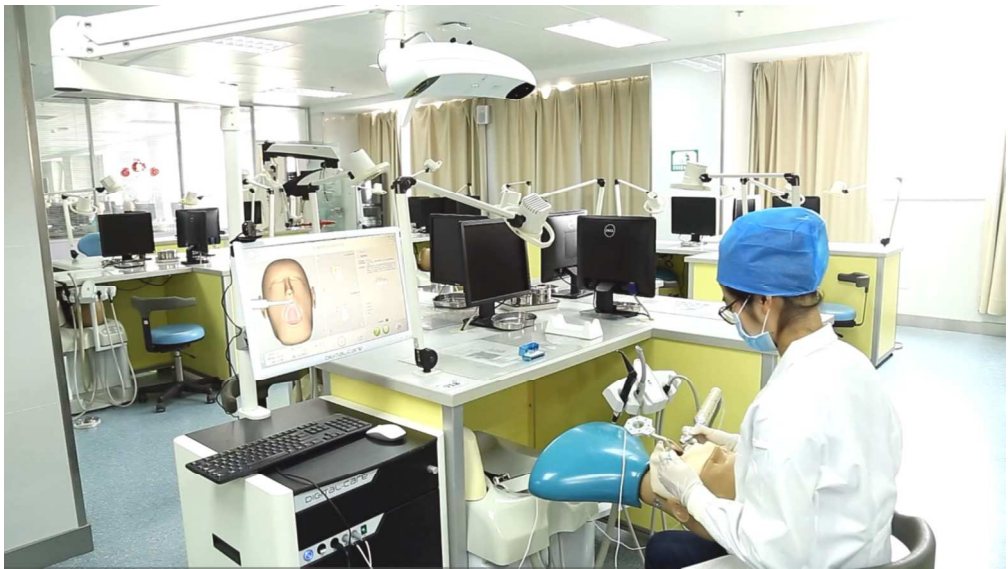
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Figure S1. The standard videos showing how to perform the practical steps on the ~~Online Peer Review System (OPRS)~~OPRS, including. The left and right parts were respectively intraoral and extraoral views of the whole practice procedure captured by the ~~Real-time Dental Training and Evaluation System (RDTES)~~. The students would learn the essentials of the practical task via watching the standard videos.

Figure S2. Preparing the ceramic crown of upper left central incisor on the phantom model under the guidance of the ~~Real-time Dental Training and Evaluation System (RDTES)~~RDTES. Each student's practice videos were captured by the RDTES, including the extraoral view via the camera and the intraoral view via the optical position sensor system and virtual reality system.

Figure S3. The procedure and result evaluation of the practical task by the RDTES. When the students finished their practices in the phantom model, the RDTES would automatically assess the operations and model results based on the predefined assessment criteria. The left part provided the scores of the procedure and result evaluation. The right part was the report card of the practical model results.

Figure S4. The student's practice videos captured by the RDTES. The right part was the extraoral view via the camera and the left part was the intraoral view via the optical position sensor system and virtual reality system. The subjects' own practice videos were uploaded to the OPRS by themselves via their own accounts.

Figure S5. The students evaluating the assigned videos online according to the assessment criteria. All students of the practice group were blinded to the tasks for assessment of the assigned videos. The right part showed the standard videos of the practical task as a reference. The left part showed the assigned videos for the peer assessment.

Figure S6. The feedback of students' own tasks from peer assessment on the OPRS.

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3 All students of the practice group evaluated the assigned videos online according to  
4 the assessment criteria, and then obtained the assessment results of their own tasks  
5 from others on the OPRS. The first and second columns were respectively the serial  
6 number and item content. The third column was the result of peer assessment. The  
7 green marker represented the good result of peer assessment, and the red one  
8 represented poor result.  
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For Peer Review