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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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 Wedelich (9) wi~~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

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

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

instruction, and thought that VRS should not be used without supplemental faculty instruction. Although another study indicated that there were no statistical differences in the quality of the tooth preparations between using computer-assisted simulation system and non-computer-assisted system, the students with non-computer-assisted system received five times more instructional time from faculty than ~~did~~those trained using computer-assisted ~~students~~system. The authors ~~concluded that while~~suggested the need for further ~~study was needed~~studies to assess VRS technology as this decreased faculty time in instruction which could have meaningful impact on the dental curriculum (18, 19).

Although the DentSim system can provide the students with the real-time illustrations of their procedures and inadequacies of their skills in an objective and visual way, the students' assessment abilities of the practical task might not be improved. This might be due to the fact that the DentSim system has no peer assessment and feedback functions. So we developed a new digital training system for the preclinical practice. Except for the Real-time Dental Training and Evaluation System (RDTES) similar to the DentSim system, the Online Peer-Review System (OPRS) with the peer assessment and feedback platform was added to the new digital system. By virtue of the OPRS, the students can assess their own and peers' practical tasks online and obtain instant feedback about their operation and assessment results. This may help increasing students' ability of self-assessment/assessment and operating skills.

In this study, therefore, we aimed to evaluate the effectiveness of a preclinical training using digital evaluation system to improve dental students' practical skills on ceramic crown preparation compared with using traditional method. Additionally, the present study was aimed to explore the association between the students' outcomes of crown preparation and their attitudes towards the digital training method.

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: ~~practice~~experimental 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 (prosthetics specialists) ~~showed the students~~demonstrated the practical procedures of ceramic crown

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

The students in ~~practice~~experimental group were trained with a digital training method. Firstly, they were provided with standard videos showing how to perform the practical steps on the Online Peer-Review System (OPRS, Nanjing Bootsoft Software Company, Nanjing, China). The standard videos involved two parts: extraoral and intraoral views of the whole practice procedure based on the pre-defined criteria （Figure S1）. The students would learn the essentials of the practical task via watching the standard videos many times before performing the practice. Then they were requested to prepare 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, Suzhou Digital-health Care Company, Suzhou, China). 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 (NDI Polaris) and virtual reality simulation system（Figure S2）. When the students finished their practices in the phantom model, the RDTES would ~~automatically~~ assess the operations and model results instantly based on the predefined assessment criteria ~~（Figure S3）~~. The subjects' own practice videos were uploaded to the OPRS by themselves via their own online student accounts~~（Figure S4）~~. The instructor selected and assessed one student's videos online as the "~~gold standard~~exemplar". The ~~"~~"~~gold standard~~exemplar~~"~~" videos were assigned to each student as a reference for assessing their peers' practical results. Moreover, the OPRS randomly assigned 2 or 3 subjects' videos to each subject in order to test their peer assessment and self-assessment abilities. All students of the ~~practice~~experimental group were blinded to the tasks for assessment. They evaluated the assigned videos online according to the assessment

criteria ~~(Figure S5)~~ , and then obtained the assessment results of their own tasks from others ~~(Figure S6)~~ . The whole practical course lasted one week, including learning the standard videos, ~~preforming~~ performing the practices, assessing their peers' tasks, and obtaining the feedback of their own tasks. The intervention process of the ~~practice~~experimental group was shown in the Figure 1.

Assessment of practical test models

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

Questionnaire

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

and we computed the correlation between the total scores of practical task results and the questionnaire items in the ~~practice~~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 ~~practice~~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 ~~practice~~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 ~~practice~~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 ~~practice~~experimental 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 ~~practice~~experimental 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 ~~practice~~experimental and control groups (Table 4). The scores of the practical task in the ~~practice~~experimental 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 ~~practice~~experimental 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 ~~practice~~experimental 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 ~~practice~~experimental group than the control group (Table 4).

Questionnaires from the students in the ~~practice~~experimental group

The questionnaires consisting of six items were answered by the 33 students enrolled in the ~~practice~~experimental 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 ~~practice~~experimental 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

scores of the practical task in the ~~practice~~experimental group were statistically significantly higher than those of the control group (Table 4). Two extraoral items of assessment criteria, of which the scores were significantly higher in the ~~practice~~experimental group than the control group, were operating position ~~(P = 0.003)~~ and grip manner and support ~~(P = 0.032)~~. It suggested that observing own extraoral practical video or the others could make it easier to improve operating position and instrument griping manner. In the traditional training method, it was hard for the instructors to observe the whole operation of each student and ~~correct every mistake immediately~~provide an instant feedback, particularly with a large number of the students (15, 16). In addition, the students could not ~~see~~ assess their own operating position with the traditional method during the whole operation, so they ~~did~~ would not know whether their own performance~~s~~ was~~were~~ good or poor. Watching own extraoral videos, is like observing own operation from the viewpoint of outsiders, which made it more objective and more direct for the students to assess and correct their positions and grip manners.

Among fifteen intraoral items, there were three items significantly higher favoring using the RDTES than the traditional instruction, including crown reduction ~~(P = 0.003)~~, taper of axial surfaces ~~(P = 0.004)~~, and damage of adjacent teeth ~~(P = 0.038)~~. Evaluating the three items was based on the precise values of assessment criteria (Table 2). It was difficult for the dental beginners to estimate the precise values due to their lack of practical experience. The RDTES based on the virtual reality simulation could provide the students with precise and objective measured values, which were more accurate and more sensitive than visual observational values. The digital dental system made it more accessible for the beginners to ~~master~~ grasp the technical skills of precise crown reduction and taper of axial surfaces at the first time of ceramic crown preparation. The aforementioned factors may explain the reasons of the better test outcomes of the ~~practice~~experimental group than the control.

According to the questionnaire results of this study, a vast majority of the students in the ~~practice~~experimental group thought that using the digital training system could better improve their ability of preparation for the ceramic crown

compared with using the traditional method (Figure 2). All students agreed or strongly agreed that the digital training with OPRS and RDTES could improve their self-learning, assessment, and self-assessment abilities of the practical task. With the help of the OPRS, watching the standard videos and assessing own and peers' practical tasks online made it easier for the students to understand the essentials of the practical task. The Online Peer-Review System could provide the students with self-learning platform and allow them to learn the essentials of the practice without limitation of time and space. This new learning manner could improve the efficiency of self-learning, as well as save the resources of instructors and costs. On the other hand, the OPRS allowed the students to assess their own operating progress and the progress of their fellow students (23, 24). By judging their peers, students might gain insight into their own performance through reflection (25-27). It helped increasing students' ability of self-assessment/assessment and operating skills (28). The use of peer assessment by students may also alleviate the burden on the instructors (29). In addition, the OPRS provided instant feedback about the preclinical practices from the students' operation and assessment results, and thus better instructed the students in the future exercises (30). On account of these aforementioned characteristics and advantages OPRS possessed, the practical outcomes and operating skills of students were increased. This viewpoint was also proved by the positive correlation between the scores of practical results and the questionnaires in this study.

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

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

The authors received no financial support and declare no potential conflicts of interest with respect to the authorship and/or publication of this article.

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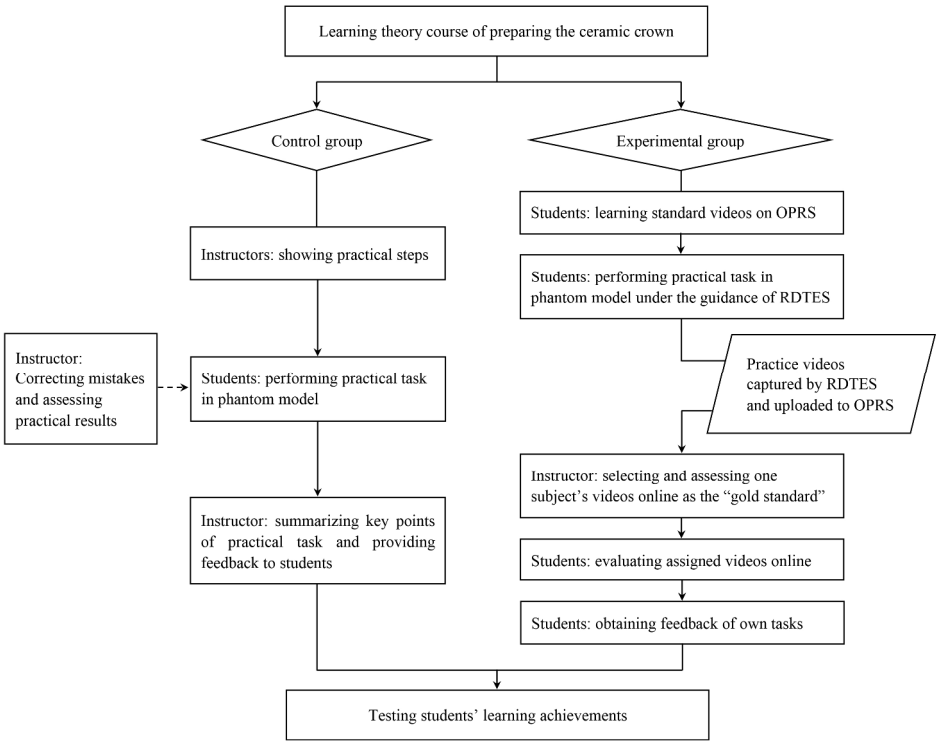


Figure 1. The flow diagram of the practical process in the control and experimental groups. The left part showed the practical procedure in the control group via the traditional training method. The right part showed the practical procedure in the experimental group via the digital training system.

263x209mm (300 x 300 DPI)

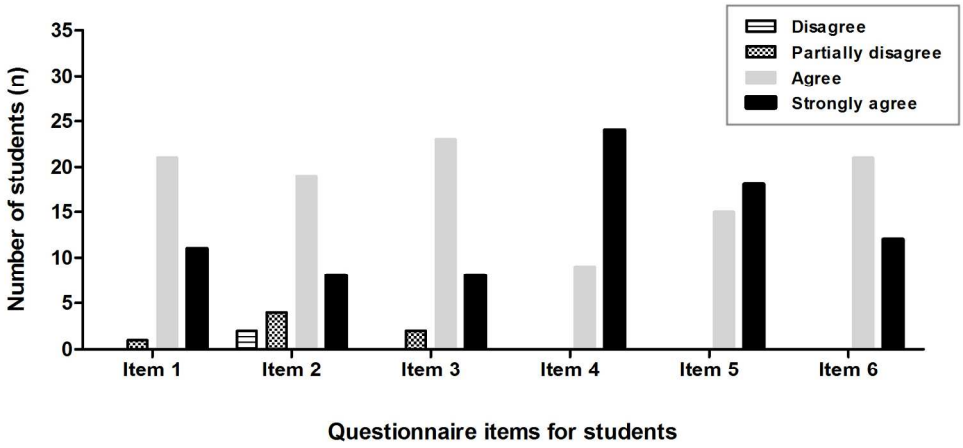


Figure 2. Students' attitudes towards the digital training method using the OPRS and RDTES. Six items involved in the questionnaire were answered with four possible degrees, including 'I disagree', 'I partially disagree', 'I agree' and 'I strongly agree'. The numbers of the students choosing four different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

187x88mm (300 x 300 DPI)

Table 1. Demographic characteristics of the subjects.

Group	~~Practice~~Experimental 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 approach: operating gently; avoiding tissue damages	5
	Intra 2	Water cooling, grinding discontinuously	5
	Intra 3	Preparation ~~s~~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	Preparation reduction: ~~Incisal~~ incisal reduction with 2.0 mm; ~~Labial~~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 width and position: 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

Total	100

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

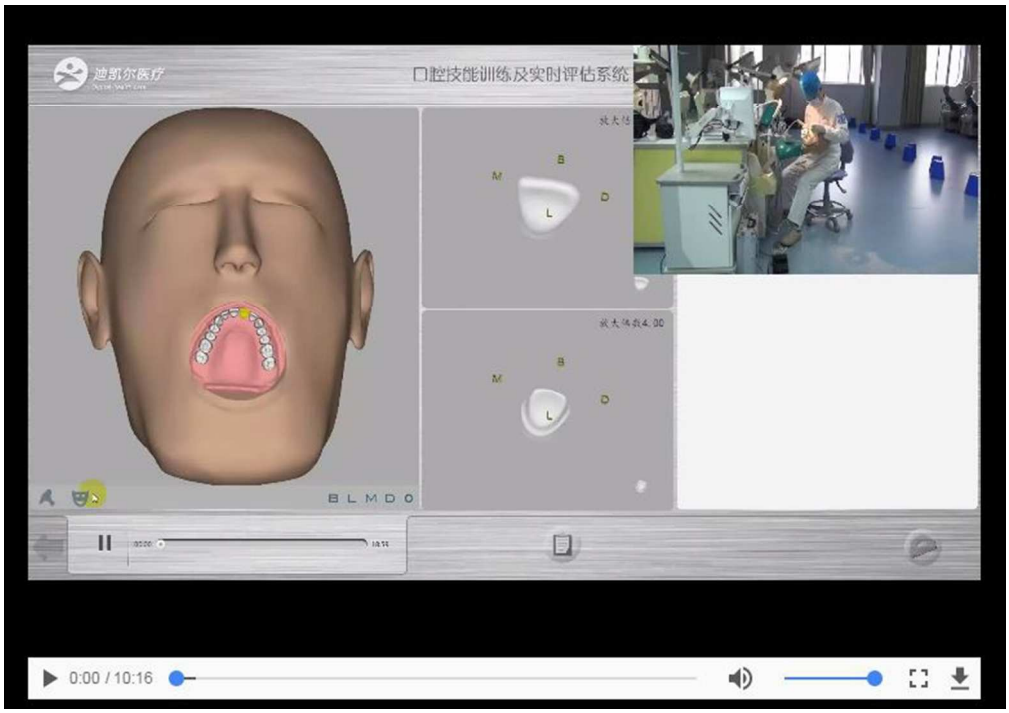
Items	Contents
Item 1	I have improved the ability of the preclinical practice~~preparation for the ceramic crown~~ via the digital method better ~~than via~~compared with the conventional method.
Item 2	Watching the standard videos on the OPRS makes it easier for me to understand the essentials of the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

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

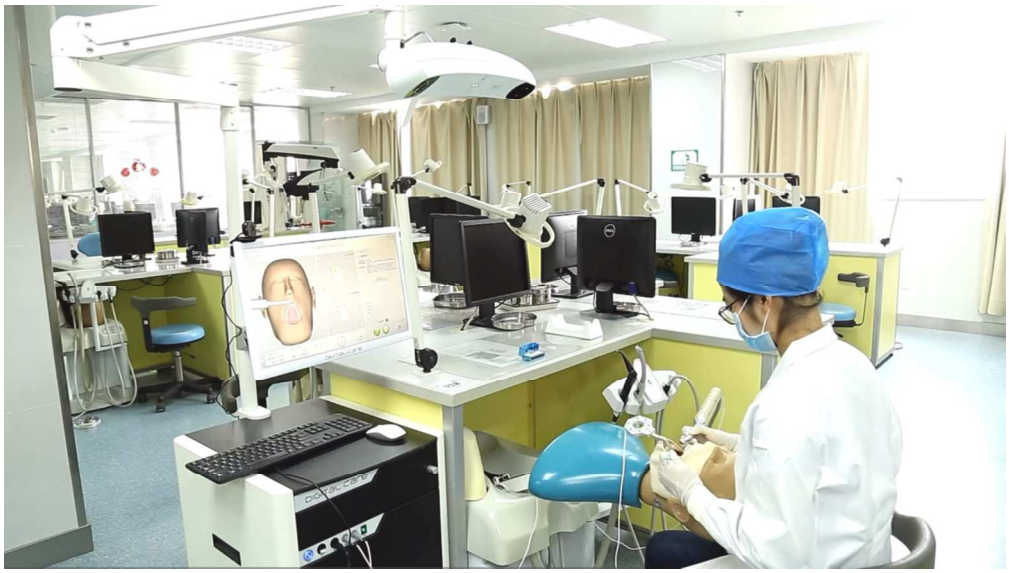
	Scoring items	Score	Experimental group Mean (SD)	Control group Mean (SD)	t	P value
Extraoral	Extra 1: Operating position	5	4.98 (0.09)	4.80 (0.33)	3.067	0.003*
	Extra 2: Grip manner and support	10	9.97 (0.12)	9.85 (0.29)	2.198	0.032*
	Extra 3: Instrument selection	5	4.97 (0.12)	4.91 (0.20)	1.512	0.135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

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

* $P < 0.05$



205x144mm (96 x 96 DPI)



338x190mm (144 x 144 DPI)

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.~~

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