Evaluation of a Virtual Reality Simulation System for Porcelain Fused to Metal Crown Preparation at Tokyo Medical and Dental University


Abstract: The use of virtual reality simulation (VRS) is a new teaching modality in dentistry, and there is scope for further research evaluating its use under different educational programs. The purpose of this study was to evaluate how VRS with or without instructor feedback influenced students' learning and skills related to porcelain fused to metal (PFM) crown preparation. In this study, forty-three dental students in their fifth year of study at Tokyo Medical and Dental University, Tokyo, Japan, were divided into three groups: the first group used VRS with instructor feedback (DSF) (n=15), the second group used VRS without instructor feedback (DS) (n=15), and the third group neither used features of VRS (NDS) (n=13) nor received the instructor's feedback. All the students performed PFM crown preparation under the same setup once a week for four weeks. Total scores, preparation time, and twelve evaluation items were compared among the three groups and four experiments. The total scores of students in the DSF and DS groups were significantly higher than those in the NDS group. The presence of the instructor did not result in significant difference when VRS was used for training, while it shortened the preparation time at early stages. The results of this study suggested that the use of the VRS system improved student training for PFM crown preparation.

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DentSim (Image Navigation, New York, NY) is a preclinical simulator that provides real-time image processing with the use of three dimensional (3D) graphics as a VRS. The DentSim unit includes a manikin head and torso, KaVo dentoform, dental handpiece, light source, infrared camera, and software. 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 objectively and visually, leading to high effectiveness for technical training.

Many studies have examined the training effectiveness and objectivity of evaluation of the VRS system. Leblanc et al. suggested that student performance was improved by the use of VRS at an early stage, while Fakhry et al., Steinberg et al., and Marras et al. referred to the improvement in learning effectiveness using visual information. Esser et al. and Welk et al. suggested that instruction using VRS could improve the interest and desire to learn in many students. Esser et al. similarly referred to the value of education using VRS and raised issues concerning the conventional curriculum.

While a large number of previous studies have compared VRS to the traditional bench type training laboratories, few have evaluated the actual effect of instructions provided by VRS or provided by VRS in addition to a human instructor on the student training under the same setup. Yasukawa reported that instructor feedback improved the Class II cavity preparation technique; however, no study has evaluated VRS training for porcelain fused to metal (PFM) crown preparations and the effect of instructor’s feedback.

Therefore, the purpose of this study was to evaluate how VRS influenced students’ techniques for crown preparation by comparing total scores, preparation time, and scores of specific items. The specific aim of the study was to determine whether there were differences among the group that used VRS with feedback from an instructor, the group that used VRS without feedback from an instructor, and the group that did not use VRS and received no feedback from an instructor. Total scores, preparation time, damage to mesial adjacent tooth, damage to distal adjacent tooth, occlusal reduction, wall incline, retention, resistance, wall smoothness, margin location, chamfer width, interproximal clearance, finish line continuity, and undercut as evaluated by the VRS were compared.

Materials and Methods

The equipment used is shown in Figures 1 and 2. A VRS program, the DentSim was used for preparation and evaluation of students’ preparations. PFM crown preparation Version A10 was selected in the system. The DentSim unit combines a dentoform integrated with seven tracking light emitting diodes (LEDs), standard jaw and standard turbine 650B LUX-3 (KaVo Dental GmbH, Germany) with sixteen tracking LEDs, dual Charge Coupled Device (CCD) infrared tracking camera, the computer that includes tracking software and the DentSim software, and a monitor. When a student starts preparation, the overhead camera tracks the LED light on the mannequin, and the computer calculates the positional relation between the dentoform and the turbine and projects the illustrations on the monitor. While preparing a tooth, the system immediately notifies the student about any incorrect preparation procedures such as damage to the adjacent tooth. The preparation is analyzed by the DentSim, comparing the student’s preparation to the preparation that has previously been defined according to certain standards and criteria depending on the doctrine selected by the instructor. The system can be switched to evaluation mode, which shows error messages, error details, graphic presentation, and points lost.

In November 2010, all sixty-seven students in their fifth year in the Faculty of Dentistry, Tokyo Medical and Dental University, were invited to participate in this study during a large-group session. The purpose and details of the study were explained verbally and in writing by one of the authors (HK). The students were informed that they would be divided into three groups at random and were given details of difference between the three groups. Forty-five volunteered; however, two students (male) dropped out of the study after the first experiment due to schedule conflicts. Therefore, forty-three students (twenty-one males and twenty-two females) participated in the study. The study protocol was approved by the Institutional Review Board of the Faculty of Dentistry, Tokyo Medical and Dental University (approved on November 5, 2010; No. 591). Six months before the experiment, the students had all done a full cast crown preparation of the left mandibular first molar with dentoforms once in their prosthetic practice class. All students performed PFM crown preparation of the artificial left mandibular first molar (KaVo Dental GmbH, Germany).
The students were randomly assigned to one of three groups: the first group used the DentSim with the instructor’s feedback (DSF) (n=15), the second group used the DentSim without the instructor’s feedback (DS) (n=15), and the third group received neither DentSim nor the instructor’s feedback (NDS) (n=13). In group DSF and group DS, students were able to see the VRS monitor during preparation procedures and switch to evaluation mode while preparing. The students in group NDS used the VRS unit, but they were able to see only a static standard shape of the prepared tooth on the monitor and a preparation tooth model. As feedback in DSF, the instructor gave only the information obtained on the VRS evaluation mode to the students, but no technical advice. The same person provided all instructions to the students. The instructor was the only person who could start up and set the VRS, so that students could not use it by themselves except for the experiments. To prevent the students assigned to group NDS from being at an educational disadvantage, all students gave feedback on PFM crown preparation using the VRS evaluation mode and performed the preparation again after completion of the study and data collection.

The instructor explained the anatomical characteristics of the left mandibular first molar and gave a ten-minute instruction about PFM crown preparation to all students in all groups, as well as directions using VRS to students in group DSF and group DS. Reference models and figures of PFM crown preparation were also presented to the students in all groups.

All students prepared a PFM crown preparation once a week for four weeks (referred to as Ex. 1 to Ex. 4, respectively) in the same setting as the initial experiment with the DentSim unit. Since there was only one VRS unit available in the facility, the experiments were carried out with one student at a time. All experiments took place during regular and after hours. The experiment lasted one month. It was started after the students completed their practice classes and before the start of clinical training. During the period of this experiment, the students did not
perform any crown preparations in clinical training or receive any additional practice.

The VRS was used to collect and analyze the data from the three groups. Consequently, all groups could be compared based on the same assessment. The parameters for evaluation were not customized for this study. The maximum score of 100 was decreased with the sum of error scores. The prepared artificial teeth were scored using twelve items in the DentSim evaluation system: the selected doctrine tested damage to mesial adjacent tooth, damage to distal adjacent tooth, occlusal reduction, wall incline, retention, resistance, wall smoothness, margin location, chamfer width, inter-proximal clearance, finish line continuity, and undercut. Preparation time included the time needed for preparation and feedback from the instructor and switching to evaluation mode or preparation mode. Students could spend as long as they wanted for preparation.

Wall incline is an index for evaluation of the taper. The DentSim specifies a taper of 3° to 6° and scores an excessive or short taper of >15° and >8° as -2 and -1, respectively, with evaluation of three or four sites of a single wall. The presence of undercut was evaluated, and significant was evaluated as Fail. Incorrect occlusal reduction was also evaluated as Fail for either overreduction or insufficient reduction (<1 mm). When undercut or occlusal reduction error was found, the score dropped to -41 points; however, to compare scores among evaluation items, -41 points was replaced with zero so that statistical analysis could be performed. For the damage to mesial or distal tooth, three points were reduced when the bur touched the adjacent tooth and ten points were reduced when the adjacent tooth was actually ground.

Total scores, total time, margin location scores, and wall incline scores for each evaluation item were compared among group DSF, group DS, and group NDS, using two-way analysis of variance (ANOVA) and a t-test with a Bonferroni correction. Damage to adjacent tooth, occlusal reduction scores, wall smoothness scores, resistance scores, chamfer width scores, inter-proximal clearance scores, finish line continuity scores, and retention scores were evaluated by Wilcoxon rank sum test with a Bonferroni correction. The presence of undercut case was evaluated by chi-square

Figure 2. PFM crown preparation using the DentSim
analysis with a Bonferroni correction. P-values of 0.05 or smaller were considered significant in all tests. The data were analyzed using the Statistical Package for Social Science (SPSS Version 11 for Windows, SPSS, Chicago, IL, USA) for statistical procedures.

Results

The total scores are presented in Figure 3. Total scores in group DSF and group DS were significantly higher than those in group NDS (p<0.05) at Ex. 2, Ex. 3, and Ex. 4. Total scores tended to increase with experience (from Ex. 1 to Ex. 4) in group DSF and group DS. In contrast, there was no significant difference in total scores in group NDS between experiments. The results for preparation time are presented in Figure 4. In Ex. 1, preparation time in group DS was significantly longer compared to group NDS (p<0.05). Moreover, preparation time in group NDS was significantly shorter compared to group DSF and group DS in Ex. 3 and Ex. 4 (p<0.05).

The scores for each item are shown in Figures 5-7. The percentage of undercut case is shown in Figure 8. Scores for wall incline in group DSF and group DS were significantly higher than those in group NDS in all experiments (p<0.05). Scores for occlusal reduction in Ex. 3 and Ex. 4 in group DSF and group DS were significantly higher than that in group NDS (p<0.05). In group DSF and group DS, scores tended to increase with significant differences, but there was no significant difference between experiments in group NDS.

The percentage of undercut cases differed between group NDS and groups DS or DSF (p<0.05). In group DSF, undercut was found in 40 percent of preparations at Ex. 1, in 13 percent at Ex. 2, in 6 percent at Ex. 3, and in none at Ex. 4, showing that undercut cases decreased with experience. Similarly, in group DS, undercuts were found in 46 percent of preparations at Ex. 1, in 33 percent at Ex. 2, and in 6 percent at both Ex. 3 and Ex. 4. However, in group NDS, undercuts were found in 77 percent, 84 percent, 84 percent, and 53 percent of preparations at Ex. 1 through Ex. 4, respectively.

Damage to mesial and distal adjacent teeth did not differ significantly among the three groups in any experiments (p>0.05). However, in the case of mesial adjacent teeth, there were significant differences between Ex. 1 and Ex. 3 in group DS and group NDS (p<0.05). Damage to distal adjacent teeth in group DS significantly decreased with experience (p<0.05). Scores for margin location in group DSF and group DS were significantly higher than those in group NDS.

Figure 3. Average of total scores for PFM crown preparation in each weekly experiment in each experimental group

Note: Total scores were addition of each evaluation item. Data are represented as mean±SD.
Figure 4. Average time required for PFM crown preparation in each weekly experiment in each experimental group

Note: Data are represented as mean±SD.

in Ex. 4 (p<0.05). Scores for chamfer width, wall smoothness, finish line continuity, inter-proximal clearance resistance, and retention were not different among the groups and did not significantly change with experience in any of the three groups (p>0.05).

Discussion

The use of VRS in dental education has increased over the last decade.24,27 As reported in previous studies, VRS can provide advantages such as self-evaluation, objective evaluation, and faster acquisition of skills.18,22,27 Our study clearly indicated the efficacy of instructions provided by VRS on the quality of preparations performed by the students. Students who used the simulations earned higher total scores and needed longer time to prepare a tooth than students who did not use the DentSim VRS. Scores for occlusal reduction and wall incline were higher in the DentSim groups than the non-DentSim groups. Regardless of the instructor feedback, students using VRS were able to prepare PFM crowns with fewer undercuts than those not assisted by VRS.

The higher scores in group DSF and group DS compared to group NDS indicate the effectiveness of technical training with VRS, because students in group DSF and group DS were able to see their preparation visually and quantitatively. The result that there was no difference in total scores between group DSF and group DS suggests that real-time error messages and instructions provided by VRS during the preparation as well as the comparison with the standard preparation in the evaluation mode were adequate.

In this regard, it has been reported that, with the use of VRS, students may need less supervision, and fewer instructors would be needed for the training process and feedback evaluations.28 Rees et al. found that the DentSim could be used for training without an instructor and had the advantage of allowing students to review self-preparation from various perspectives.27 It should be noted that a significant difference in the preparation time between DS and DSF only at Ex. 1 may suggest that our students needed more time to understand the error and the evaluation on the monitor at their first exposure to VRS in the absence of an instructor; therefore, instructor feedback may accelerate the learning speed of students at the early stage of training by VRS.

Time is an important factor affecting the performance of a dental practitioner. While a shorter
time spent for preparation may bear advantages such as less patient anxiety and an increased capacity of patients to be served in a clinic, a possible association between the time spent for a preparation and its quality should be considered. The psychomotor skills of the dentist play a vital role in this regard. Preparation times were shorter in group NDS than in group DSF and group DS since the students performed preparation without having to follow VRS instruction or error messages or stop cutting to check for the accuracy of their work. On the other hand, significantly inferior outcomes of the NDS group suggest that the shorter preparation times in these cases cannot be considered as an advantage. Scores for wall incline were higher in group DSF and DS than group NDS in the four experiments, suggesting it is a major advantage of VRS for students without clinical experience to be able to confirm the taper during the procedure. Using VRS, students can obtain a 3D understanding of standard images of the tooth during or after tooth preparation. Scores for occlusal reduction in group DSF and group DS were higher than those in group NDS. Furthermore, repeated training increased the scores of group DSF and group DS. However, repeated training did not increase the scores of group NDS. The amount of reduction in the occlusal site had a direct effect on clearance, and use of VRS provided a better sense of the amount of reduction required and prevented overreduction—thereby leading to development of better skills. While distinguishing between enamel and dentin during preparation of a tooth requires a certain clinical skill level, on the VRS monitor, dentin is colored yellow, and enamel is white. Thus, students can visually understand the
Iatrogenic damage to the adjacent, and possibly, intact tooth is of great importance in clinical practice today, as such damage, even superficially, may cause further complications. In this study, it seemed that it was difficult for novice students to understand the positions of the mesial and distal adjacent teeth and the bur by looking at the illustration on the monitor. The buccal margin location can be confirmed by visual observation, but the locations of the mesial and distal adjacent teeth and the lingual margin are difficult to observe even with a mirror and experience, and advanced skills are needed. The scores hardly differed between groups DSF and group DSF because the margin from any directions could be seen on the VRS monitor in real-time. This suggests that the use of the DentSim provided effective understanding of the margin location. The scores for inter-proximal clearance, retention, resistance, chamfer width, and wall smoothness did not differ significantly among anatomical shape of the structure and appropriate amount of reduction. Also, in evaluation mode, the difference between the standard preparation and students’ preparation was shown quantitatively, which guided the students.

The number of students who made undercut in Ex. 1 to Ex. 4 differed between group NDS and groups DS and DSF. A total of twenty-two sites are evaluated for undercut by the DentSim, and only a single undercut site is enough for the case to be judged as a Fail. Without the use of VRS, the students had difficulty performing the preparation even after four experiments, as reflected by the similar scores in group NDS for Ex. 1 to Ex. 4. It is worth mentioning that the evaluation system of VRS is an objective means of evaluating clinical skills, but the scoring system may be too strict for novice students. Selection of the doctrine or customizing the parameters for evaluation might be required.
Figure 7. Average scores for retention, occlusal reduction, and resistance in each experimental group

Note: Maximum points of retention and resistance were 10. Maximum points of occlusal reduction were 20. Data are represented as mean±SD.

Figure 8. Percentage of undercut case in each experimental group
the groups or experiments. It appears that, with regard to these items, the conventional training had been as effective as VRS.

Buchanan found that students who used feedback learning with VRS arrived at the same level of performance faster than students who learned using a conventional training program.20 Our study also indicated that, with repetition of training and evaluation by the DentSim VRS, students could efficiently acquire skills with a better overall performance outcome.

The effect of feedback contents provided by the instructor needs to be considered in further studies. In our study, the VRS messages were explained only to the students in the DSF group, but students usually receive technical advice during practice class. Further experiments and considerations are needed for the evaluation criteria and points reduction in the VRS. Especially, additional studies are needed to compare students’ performance using both faculty evaluation and DentSim evaluation. VRS may be an effective means not only for students, but also for practicing dentists. Wierinck et al. showed that the VRS was effective for training of dental specialists.30 Future tasks include a shift from conventional model training to computer-based learning using VRS. However, the cost of the system is another issue. The VRS is expensive, and purchasing several units for use by all the students may be beyond the financial ability of many dental institutions. Moreover, as indicated by Quinn et al., routine maintenance was needed for tuning and installation of the equipment.31

Based on the results, our study found that DentSim with access to its VRS evaluation was effective for PFM crown preparation training. The presence of the instructor did not result in significant difference when VRS was used for training, while it shortened the preparation time at early stages. Combination of conventional preparation training and the use of VRS can be a more effective training approach that produces a major improvement in clinical skills.

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