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Original Article

Prediction of dental students' pre-clinical crown preparation performances by a virtual reality haptic-based dental simulator

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Abstract *Background/purpose:* Manual dexterity training is essential for dental students. The implementation of virtual reality haptic-based dental simulator Simodont (Nissin Inc., Nieuw-Vennep, Netherlands) can provide the real-time feedback in pre-clinical learning. The aim of this study was hypothesized that Simodont may act as a valuable assessment tool in predicting the performance of pre-clinical crown preparation.
Materials and methods: This retrospective cohort study was to analyze total 84 dental students' performance among manual dexterity exercises on Simodont, crown preparation on Simodont, and crown preparation test on phantom head. Spearman's correlation coefficient (r) was used to examine the relationships of performances among three groups. Subgroup analysis with dichotomous performance (low/high) and sex difference were further analyzed by chi-square test.
Results: Positive correlation was found between crown preparation test in phantom head and manual dexterity exercises on Simodont ($r = 0.390$, $P < 0.001$) and crown preparation on Simodont ($r = 0.326$, $P < 0.01$), respectively. Odds ratio analysis showed that students who scored highly with manual dexterity exercises on Simodont were 5.6 times more likely to be high performance in conventional crown preparation test in phantom heads ($P < 0.001$). Moreover, male students were shown to have stronger correlation between the performances on Simodont and phantom head test ($P < 0.001$). However, there were no significant correlations among three different test groups were found in female students.
Conclusion: Taken together, our data revealed the potential of Simodont in the prediction of dental students' subsequent crown preparation test in conventional phantom head.

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Introduction

The development of manual dexterity is a fundamental prerequisite for dental students to acquire clinical skills which require precise manipulation and force control. Dental students must begin to refine their fine psychomotor skills from the early years through a structured and progressive training approach to ensure accuracy and stability in future clinical procedures.[1] When they enter to the senior years, trainings become more specialized such as cavity preparation, open chamber, and crown preparation. Crown preparation is a core skill in fixed prosthodontics which integrate biomechanics, esthetics, and clinical techniques. Therefore, dental students need to have intricate hand movements, spatial awareness, and controlled application of force.[2] Simulation with phantom head is the current method to help dental students internalize their fundamental procedures. However, this simulation system cannot reflect the real-world clinical scenarios, particularly in the complex cases.[3] Consequently, dental students may struggle to transition from the pre-clinical training to clinical practice due to the lack of confidence and well preparation, especial in high-precision tasks such as crown preparation.[4,5]

Recently, many dental schools have implemented digital simulators not only to improve students' learning outcomes but also to facilitate the more objective assessments.[6–9] Virtual reality (VR) haptic-based dental simulators act as a good tool to deliver high-quality education, reduce educational disparities, and enhance environmental sustainablity.[9,10] With three-dimensional visualization, auditory cues, and haptic feedback, VR haptic-based dental simulator can mimic a realistic and immersive learning experience. Therefore, dental students can unlimited practice various procedures with real-time feedback to improve their learning efficiency and skill performance.[11,12] Moreover, VR haptic-based dental simulator can integrate with clinical real patients' cases for pre-treatment simulation.[13] This not only provide patient-centered care but also boost dental students' confidences.[14,15]

VR haptic-based dental simulator may also act a good tool for competency assessment. Researches have shown that manual dexterity training with VR haptic-based dental simulator could effectively distinguish learners' various preclinical skill levels and identify students who need the additional supports[16,17] and predict the hand skill proficiency.[17–21] Furthermore, sufficient manual dexterity training with VR haptic-based dental simulators have shown to enhance and also predict students' performances in operative dentistry.[19,20] However, little is known about the standardized method to determine the manual dexterity potential of dental student in more complicate cases such as crown preparation. In this study, VR haptic-based dental simulator Simodont (Nissin Inc., Nieuw-Vennep, Netherlands) was hypothesized as a valuable assessment and training tool in predicting the performance of crown preparation test on conventional phantom head. The retrospective cohort design was conducted to analyze dental students' performances among manual dexterity exercises on Simodont, crown preparation on Simodont, and crown preparation test on phantom head.

Materials and methods

Data sources and assessment

Study protocol and informed consent were approved by the Institutional Review Board of Chung Shan Medical University Hospital (Reference number: CS2-23090). This longitudinal study utilized Simodont to explore the relationship between dental students' performance at different learning stages in School of Dentistry, Chung Shan Medical University, Taichung, Taiwan. The participants included 84 fourth-year dental students (42 men and 42 women). Students' scores of manual dexterity exercises on Simodont, crown preparation on Simodont, and crown preparation test on phantom head were obtained. In addition, student's name was replaced by code number to enhance the confidentiality.

Manual dexterity exercises on Simodont was assigned in the second grade. This task involved the use of a dental hand piece to remove a target 'red zone' with cross- and circle shape in the middle of each block. It addition, dental students should try to minimize the removal of leeway zones (the 'safe' outer areas of the block) as much as possible (Fig. 1A). Real-time feedback on performance was presented on a computer monitor attached to the device throughout the task. All students were free to prepare within 20 min. Only the best performance of each participant was selected for the data analysis.

Crown preparation on Simodont was assigned in the fourth grade during the laboratory of fixed prosthodontics. The task "Target in Tooth model" is the new version for crown preparation on tooth #46 (Fig. 1B). The IdealPrep (red) represents the ideal tooth preparation. The OverPrepSub (green) represents the tolerance of acceptable tooth removal beyond IdealPrep. The OverPrepSub is fixed with a width of 0.4 mm. All students were free to learn up to 60 min within 3 weeks. Only the best performance of each participant was used for the data analysis.

Fourth year dental students have to attend an introductory lecture and pre-clinical skills laboratory on conventional phantom head for the discipline of fixed prosthodontics. The course was held every Thursday and lasted 4 h during 18 weeks' period per semester. After two semesters learning, tooth #46 crown preparation on conventional phantom head was the final exanimation for the test score of laboratory of fixed prosthodontics (Fig. 1C). Scoring criteria were based on the evaluation of occlusal surface form, margin design, surface smoothness, taper angle, and total cut volume. In addition, models were anonymized and assessed by a single evaluator. The test score from each student was used for the data analysis.

Statistical analysis

Spearman's rank correlation coefficient (rs) was used to examine the relationships among the raw data of manual dexterity exercises on Simodont group, crown preparation on Simodont group, and crown preparation test on phantom head group. Then, the ranking of students' scores was further divided into dichotomous groups (high and low

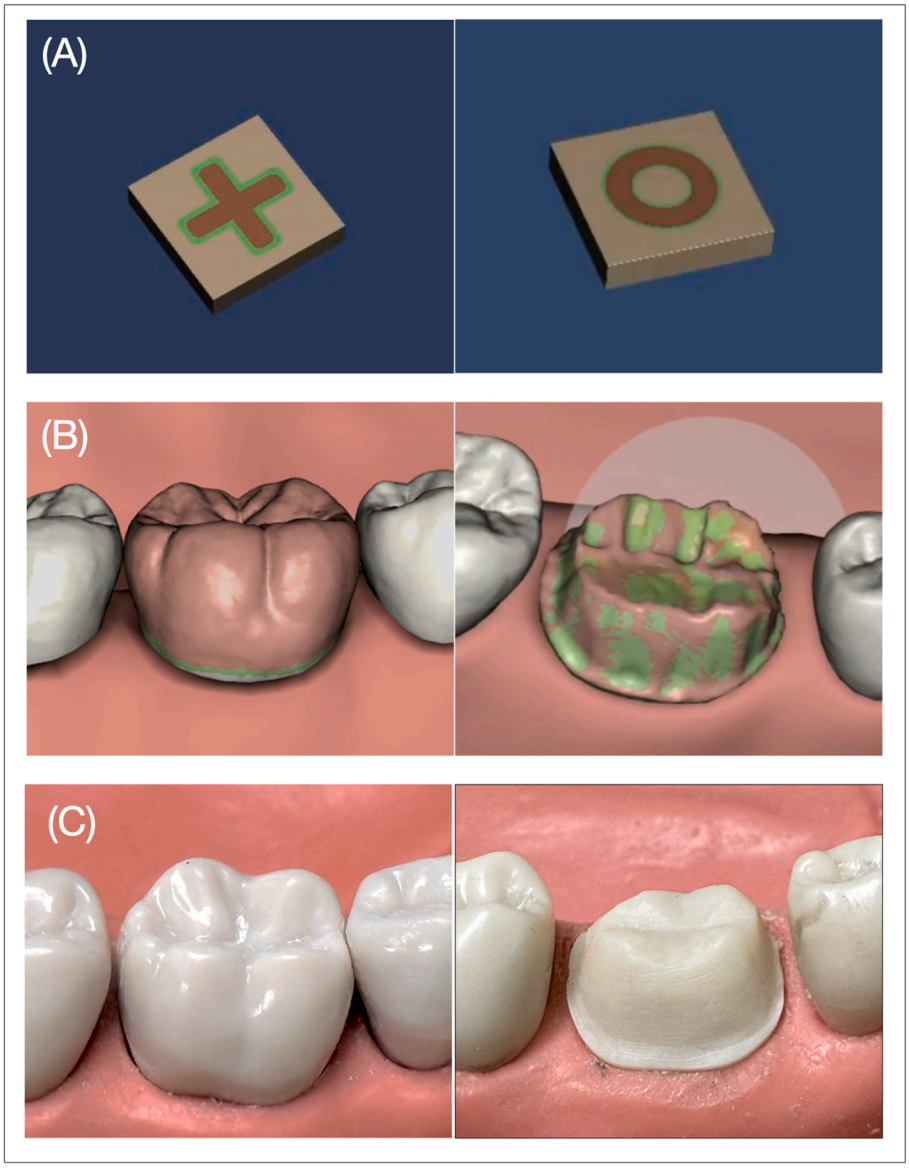

Figure 1 The images of (A) manual dexterity exercises on Simodont, (B) target in tooth model on Simodont, and (C) crown preparation test on conventional phantom head.

performers) for chi-square analysis. In addition, the expected frequency in each category must be greater than one and at least 80 % of the expected frequencies need to be equal or greater than five to ensure the validity of analysis. Furthermore, high performers were captured from two different Simodont tasks to evaluate their odds ratio (OR) and the 95 % confidence interval (CI) for predicting the higher performance in crown preparation test on phantom head. The level of significance was set at $P < 0.05$. All statistical analyses were conducted using SPSS software (Version 14.0, SPSS Inc., Chicago, IL, USA).

Results

As shown in Table 1, Spearman's rank correlation analysis revealed a significant positive correlation between manual dexterity exercises on Simodont and crown preparation on Simodont (rs (82) = 0.358, $P < 0.01$). Additionally, there was a stronger significant positive correlation between manual dexterity exercises on Simodont and crown preparation test on phantom head (rs (82) = 0.390, $P < 0.001$). Similarly, a significant positive correlation was found between crown preparation on Simodont and crown preparation test on phantom head (rs (82) = 0.326, $P < 0.01$).

The results of dichotomous performances between crown preparation test on phantom head versus manual dexterity exercises on Simodont and crown preparation on Simodont, respectively, were illustrated in Table 2. Chi-square test demonstrated a significant association between manual dexterity exercises on Simodont and crown preparation test on phantom head ($\chi^2(1) = 13.770$, $P < 0.001$). OR analysis further revealed that participants who with good test score in manual dexterity exercises on

Table 1 The results of Spearman's rank correlation analysis among three groups.

		1	2	3
1	Manual dexterity exercises on Simodont	—		
2	Crown preparation on Simodont	0.358**	—	
3	Crown preparation test on phantom head	0.390***	0.326**	—

**$P < 0.01$. ***$P < 0.001$.

Simodont were 5.6 times more likely to perform well in crown preparation test on phantom head compared to those with lower performance (95 % CI: 2.187—14.220). In Table 2, a statistically significant association between crown preparation on Simodont and crown preparation test on phantom head ($\chi^2(1) = 8.052$, $P = 0.005$). Moreover, those who with good test score in crown preparation on Simodont were 3.6 times more likely to outstand in crown preparation test on phantom head (95 % CI: 1.464—8.854).

Stratified analysis by sex was shown in Table 3. Spearman's rank correlation analysis showed that male students exhibited higher positive correlations among the three different test groups. Manual dexterity exercises on Simodont (rs (40) = 0.546, $P < 0.001$) and crown preparation on Simodont (rs (40) = 0.440, $P < 0.01$) were found to positive correlations with crown preparation test on phantom head, respectively. However, no significant correlations among three different test groups were found in female students.

As shown in Table 4, chi-square and OR analyses also revealed similar pattern. Male students who got the higher test scores in manual dexterity exercises on Simodont were 13.3 times more likely to perform well in crown preparation test on phantom head (95 % CI: 3.012—58.720, $P < 0.001$). In addition, male students with good test scores in crown preparation on Simodont were 6.3 times more likely to perform well in crown preparation test on phantom head (95 % CI: 1.638—23.843, $P = 0.005$). However, there were no significant correlations in female students between crown preparation test on phantom head and manual dexterity exercises on Simodont (OR: 2.5, 95 % CI: 0.710—8.803) or crown preparation on Simodont (OR: 2.6, 95 % CI: 0.754—9.134).

Discussion

This study was aimed to evaluate the predictive ability of students' performance on VR haptic-based dental simulator Simodont for crown preparation test on conventional phantom head. The results indicated that students' manual dexterity exercises and crown preparation performances on Simodont have the positive relationship with their crown preparation test on phantom head. Our findings suggest that Simodont could assist instructors or curriculum designers to identify students' pre-clinical operative potential and further create a customized guidance. However, Al-Saud et al.[22] found a negative correlation between manual dexterity performance and subsequent pre-clinical typodont crown test. Recently, a study also reported the ineffective prediction of preparation quality score on conventional simulator by using VR haptic-based dental simulator dexterity exercises.[21] The discrepancy of above observations is not quite clear. The possible reasons may be the different type of VR haptic-based dental simulator used, task designs, and outcome measurements. Therefore, cohort design with relatively large sample size is required for the further studies.

In addition to manual dexterity exercises on Simodont, we first conducted the objective assessment based on "Target in Tooth model" installed in Simodont. The advantages of this version can provide the formative assessment approach that allow users to attempt this task multiple times and receive immediate feedback during crown preparation. In this study, our results also indicated a positive relation to predict the performance of crown preparation test on phantom head. However, crown preparation on Simodont was found to have lower Spearman's rank correlation coefficient as compared with manual dexterity exercises on Simodont. The reasons might be partly explained as followings. The scoring system of Simodont for evaluating crown preparation is not entirely consistent with the assessment standards used on conventional phantom head such as the objectives, preparation steps, contour shape, and tooth reduction thicknesses. In

Table 2 Chi-square test and odds ratios for the dichotomous performances between crown preparation test on phantom head versus manual dexterity exercises on Simodont or crown preparation on Simodont

			χ^2	df	P	OR	95 % CI
Manual dexterity exercises on Simodont	VS	Crown preparation test on phantom head	13.770	1	<0.001***	5.6	2.187—14.220
Crown preparation on Simodont	VS	Crown preparation test on phantom head	8.052	1	0.005**	3.6	1.464—8.854

VS: versus.
**$P < 0.01$.
***$P < 0.001$.
χ^2 = Chi-square value.
df = Degree of freedom.
OR = Odds ratio.
CI = Confidence interval.

Table 3 The results of Spearman's rank correlation analysis among three groups stratified by sex.

	Male students	1	2	3
1	Manual dexterity exercises on Simodont	–		
2	Crown preparation on Simodont	0.502**	–	
3	Crown preparation test on phantom head	0.546***	0.440**	–
	Female students	**1**	**2**	**3**
1	Manual dexterity exercises on Simodont	–		
2	Crown preparation on Simodont	0.300	–	
3	Crown preparation test on phantom head	0.182	0.214	–

**$P < 0.01$. ***$P < 0.001$.

Table 4 Chi-square test and odds ratios for the dichotomous performances stratified by sex between crown preparation test on phantom head versus manual dexterity exercises on Simodont or crown preparation on Simodont

			χ^2	df	P	OR	95 % CI
Male students							
Manual dexterity exercises on Simodont	VS	Crown preparation test on phantom head	13.463	1	<0.001***	13.3	3.012–58.720
Crown preparation on Simodont	VS	Crown preparation test on phantom head	7.714	1	0.005**	6.3	1.638–23.843
Female students							
Manual dexterity exercises on Simodont	VS	Crown preparation test on phantom head	2.074	1	0.150	2.5	0.710–8.803
Crown preparation on Simodont	VS	Crown preparation test on phantom head	2.346	1	0.126	2.6	0.754–9.134

VS: versus.
**$P < 0.01$.
***$P < 0.001$.
χ^2 = Chi-Square value.
df = Degree of freedom.
OR = Odds ratio.
CI = Confidence interval.

addition, Hattori et al.[23] have reported that the unique characteristics of VR haptic-based dental simulator, such as the simulated cutting sensation and the simulated three-dimensional images created by stereo viewers, could affect operators' performance and evaluators' rating on assessment of crown preparation. Thus, it still needs further researches.

To the best of our knowledge, sex different was first taken consideration in the prediction of dental students' performances in pre-clinical crown preparation with VR haptic-based dental simulator. Correlation analysis demonstrated that male students had the significantly higher correlation than female students. These differences may indicate male groups have an advantage in the VR haptic-based dental simulator setting. This phenomenon might be due to the gamification of learning with Simodont. In general, men generally have the better spatial reasoning abilities. A previous study has shown that male students outperformed in VR situation with video game experience.[23,24] However, further comprehensive studies focus on sex difference are required.

This study has several limitations. First, this longitudinal study was conducted in one dental school. Multiple institutions as well as the different geography locations are required in the future. Second, prediction of dental students' performances in clinical crown preparation by VR haptic-based simulator will be more clinical relevance. Third, due to the lack of students' initial abilities or past academic performance in the baseline, further researches with pre-test or admission scores are required. Finally, additional qualitative research with questionnaire may gain the deep meaning such as learning motivation, practice time, psychological stress, and perceived usefulness.

Within the limitation of the present study, our study demonstrated that Simodont may serve as a predictor of dental students' performances on pre-clinical crown preparation. Male dental students revealed a significantly higher predictive rate than female students. Sex difference was noted in the prediction by Simodont on conventional crown preparation test. To bridge this gap, educators should implement personalized support, adaptive training, and instruction adjustments to ensure both female and male

students with optimal learning outcomes. Further large-scale and well-designed studies are urgently warranted.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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