Computer-Assisted Dental Simulation as a Predictor of Preclinical Operative Dentistry Performance

Alice Urbankova, D.D.S.; Steven P. Engebretson, D.M.D., M.S., M.S.

Abstract: We tested whether a computerized dental simulator (CDS) pre-test could predict preclinical operative dentistry examination scores. Thirty-eight first-year students completed cavity preparations during a single four-hour CDS pre-test prior to the operative dentistry course and during subsequent practical examinations. Masked, calibrated faculty members scored the preparations in both settings. Pass rates for the CDS pre-test, Exam 1, and Exam 2 were 50 percent, 66 percent, and 86 percent, respectively. Students who passed the CDS pre-test were more likely to pass Exam 1 (95 percent vs. 37 percent, p=0.0004) but not Exam 2 (89 percent vs. 83 percent, p=0.66) and had better mean scores on Exam 1 (73.4 vs. 68.3, p<0.0001), but not Exam 2 (76.2 vs. 74.7, p=0.35). As a diagnostic, success on the CDS pre-test predicted success on Exam 1 with 72 percent sensitivity and 92 percent specificity (positive predictive value 95 percent, negative predictive value 63 percent). As a diagnostic for Exam 2 performance, the CDS pre-test was a weaker predictor and not statistically significant. These findings suggest that a pre-course CDS test may help to identify students in need of early instructional intervention. Future studies are warranted to further define and implement the use of simulation technology in the assessment of students' psychomotor learning potential.

Dr. Urbankova is Assistant Professor, Department of General Dentistry, School of Dental Medicine, Stony Brook University; Dr. Engebretson is Associate Professor, Department of Periodontology and Implant Dentistry, School of Dental Medicine, Stony Brook University. Direct correspondence and requests for reprints to Dr. Alice Urbankova, Department of General Dentistry, School of Dental Medicine, Stony Brook University, 133 Westchester Hall, Stony Brook, NY 11794-8706; 631-632-8937; alice.urbankova@stonybrook.edu.

Keywords: psychomotor skills, dental education, dental students, computer-assisted instruction, operative dentistry, manual dexterity

Submitted for publication 9/25/10; accepted 1/31/11

Quality control and quality assurance measures in the dental school curriculum are aimed at maintaining a high standard among those entering the dental profession in the United States and throughout the world. Predictors of success in dental school continue to be of great interest to dental educators.[1-4] Manual dexterity is an important aspect of clinical dentistry, but despite many attempts to date, there are no standardized means of determining manual dexterity potential of dental school candidates.[5-9] An accurate and validated manual dexterity test would be of potentially great importance to dental educators.

There is considerable variation in the speed and degree to which students acquire the necessary manual dexterity to perform standard clinical procedures in a consistent and clinically acceptable manner. The first opportunity to assess students' manual dexterity generally occurs during the first preclinical courses of the dental curriculum. Once there, students who are manually challenged may not be objectively identified until the first practical examination. Also, the first practical examination may not occur until two or three months into the course. Students with less manual dexterity require disproportionately more faculty assistance and guidance and more resources, such as plastic teeth, burs, rubber dam, amalgam, and costly composite materials. Students with less manual dexterity generally are less successful on practical examinations, require more extracurricular practice time, and are more likely to require remediation, which is labor-intensive and not always successful.[10-13] An appropriate early manual dexterity assessment might aid educators in allocating resources in the curriculum early and implementing preventive remedial mechanisms to direct resources to those students in need.

Previously, we evaluated whether computerized dental simulator (CDS) training could play a useful role in the preclinical operative dentistry course.[14,15]

We found that as few as eight hours of CDS training in the beginning of the preclinical operative dentistry course could increase practical examination scores.[14] We also found that students who were exposed to CDS training learned procedures faster and required less faculty interaction than students who did not train on the CDS.[16] Additionally, we observed that students who had difficulties on the CDS had difficulties later in the course. As a result of those observations, it became apparent that the CDS might have potential as a screening tool to detect students who might have more difficulty in the course.

The use of simulation technology to predict student performance is not new. Imber et al.[17] used a CDS pre-test on handpiece-naïve students prior to enrollment in the operative dentistry preclinical course and found an association between CDS performance and preclinical operative dentistry scores. Similarly, Gray at al. compared student performance on a CDS pre-test with portions of the Dental Admission Test (DAT), predental grade point averages, and preclinical practical course scores and found associations with the academic average and total science but only one component of preclinical lab student performance.[18] However, in both of these studies the researchers used the simulator-computed grade as the primary assessment outcome of the CDS pre-test. The simulator grading feature may not provide optimal evaluation of tooth preparation because of technical limitations as previously elaborated by Quinn et al.[19] Therefore, comparisons between simulator-generated scores and actual clinical instructor assessments of student tooth preparations may have limited utility.

Evaluation of tooth preparations by clinical instructors may provide a more meaningful outcome assessment of the effects of simulator training on student preclinical performance. We reasoned that using the same evaluation criteria in both a simulator pre-test and operative course examination setting may provide a more valid comparison. Therefore, we hypothesized that a CDS pre-test can predict preclinical operative examination scores. The purpose of this study was to further explore the role of CDS in preclinical training and to evaluate its ability to predict students' scores in preclinical operative dentistry.

Methods

One entire first-year dental school class of seventy-five consented to be potential participants in this study, which was deemed exempt by Columbia University's Institutional Review Board. Due to time limitations in the curriculum and number of simulators available, only thirty-eight of the seventy-five students were randomly selected to participate. The remaining thirty-seven students were not pre-tested and continued their education within the standard first-year curriculum without further involvement in this study.

The simulator assessment was performed on a commercially available computerized dental simulator (CDS) made by DentSim (Jerusalem, Israel; Figure 1). This patient simulator has a fully manageable torso, an adjustable head, and an advanced articulator that imitates real head movements, removable jaws, and replaceable plastic teeth manufactured by KaVo (www.kavo.com/). This simulator is designed to aid in training of procedures involving plastic tooth structure removal. The computer software provides real-time feedback of critical errors made during work (e.g., pulp exposure) with the use of three-dimensional graphics and image processing and detailed analyses of user performance during or at the end of the procedure. The instant access to feedback with graphic analyses allows the learner to visualize and perform needed adjustments.

Prior to the preclinical operative dentistry course and before the students' first experience with a dental handpiece, each of the thirty-eight selected students participated in one four-hour CDS session (CDS pre-test). The goal of that CDS pre-test was to complete at least two cavity preparations for amalgam on tooth #19 occlusal and submit the last two completed preparations for evaluation. After completing the CDS session, there was no additional access provided to the CDS simulator. The CDS session consisted of a thirty-minute introduction to the simulator, use of the dental handpiece, and the computer software with feedback function. Then, a ten-minute step-by-step tutorial and video demonstration of the occlusal cavity preparation of tooth #19 was provided by the simulator. The remaining time was spent by the student to complete at least two occlusal cavity preparations for amalgam on tooth #19. No other procedures or tooth types were permitted during the CDS session. The goal during the four-hour period was to achieve the closest approximation of a completed cavity preparation to ideal model. Students were instructed to use the assistance of computer feedback function for guidance to achieve the ideal cavity preparation outcome. The CDS scoring feature, which automatically calculates the student grade in real time, was disabled from

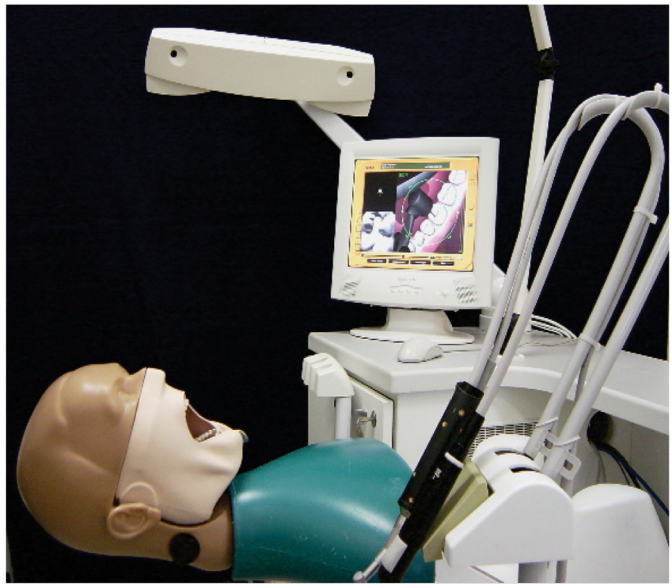

Figure 1. Computerized dental simulator used in study

viewing in order for students to focus on the cavity preparation quality rather than a performance score. Faculty assistance was limited to technical support with the simulator. Most students completed three to four cavity preparations; four students completed five cavity preparations, and two completed only two cavity preparations. The last two cavity preparations completed during the CDS session were submitted for evaluation.

Three months later, students began the standard preclinical operative dentistry course, which consisted of 110 hours of in-class laboratory-based instruction and sixty-five hours of lectures. The instructor-student ratio was, on average, 1:10. All students had equal access to the preclinical laboratory to practice their skills on their own outside of the scheduled course time. The practical preclinical operative dentistry Exams 1 and 2 on cavity preparations were administered in this setting in the months of April and June, approximately seven to ten months after the CDS pre-test (Figure 2). Each exam lasted five hours. Students did not previously know the assignment of the exam. On Exam 1, students were assigned to complete two cavity preparations for amalgam (#30 MO and #29 O) and, on Exam 2, one cavity preparation (#4 O) and one amalgam restoration (#30 MO).

The scores from the CDS pre-test (two preparations) and two preclinical course practical examinations Exam 1 and Exam 2 were the outcome measures. All tooth preparations or restorations of the CDS pre-test, Exam 1, and Exam 2 were evaluated by two masked instructors independently using a scale of 60 to 100. Scores between each of the two raters for any given examination were assessed for reliability, and all resulting correlation coefficients were between .69 and .90. The final scores for each examination consisted of the average of two evaluators' scoring of the tooth preparations or restorations.

Means and standard deviations were calculated for CDS pre-test and practical examination scores (Exam 1 and Exam 2). CDS and exam scoring resulted in a numerical score as well as a dichotomous pass/fail distinction. Proportions of students who passed each exam were calculated. Two-sided t-tests were used to compare exam score means by CDS pre-test passing group. Fischer exact test was used to compare proportions of students passing each exam by CDS pre-test passing group. Odds ratios and 95 percent confidence intervals were calculated for Passing Exam 1 or Passing Exam 2 (dependent variable) according to CDS pre-test Passing status (independent variable). Sensitivity and specificity of the CDS pre-test to predict Exam 1 and 2 success

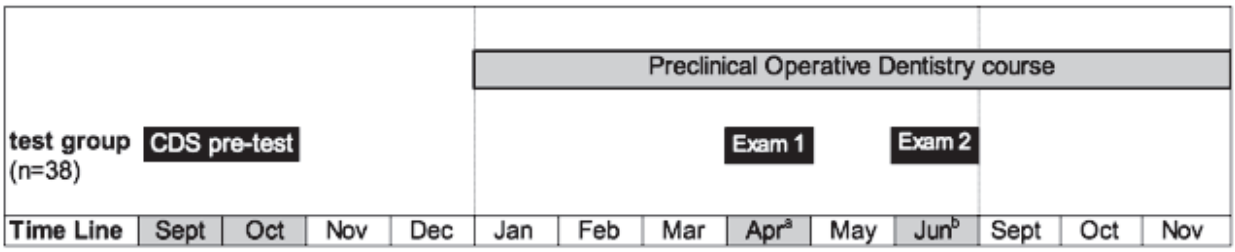

Figure 2. Schedule for CDS pre-test and preclinical operative dentistry course exams

were calculated. All analyses were performed using Stata/SE version 8.2 for Macintosh (StataCorp., College Station, Texas, USA) statistical software.

Results

Of the thirty-eight students in this study, nineteen (50 percent) passed the CDS test, and nineteen failed. The mean score on the CDS test was 69.9 (SD 6.4) ranging from 60 to 83.75. The mean score on Exam 1 was 70.8 (SD 4.0), ranging from 62.5 to 80. The students who passed the CDS test had significantly higher average Exam 1 scores (73.4 vs. 68.3, two-sided Students t $p<0.0001$). The mean Exam 2 scores were also higher for students who passed the CDS test, 76.3 vs. 74.7, but this difference was not statistically significant ($p=0.35$). Twenty-five of thirty-eight students (66 percent) subsequently passed Exam 1. Of the nineteen students who passed the CDS test, eighteen (94.7 percent) passed Exam 1, and one (5.2 percent) failed. Of the nineteen who failed, seven (36.8 percent) passed Exam 1, and twelve (63.2 percent) failed. Students who were successful on the CDS pre-test were 30.9 times more likely (95 percent CI 3.1-1389.5) to have also passed Exam 1 (two-sided Fisher's exact $p=0.0002$; Table 1). As a diagnostic, success on the CDS test predicted success on Exam 1 with 72 percent sensitivity and 92 percent specificity (positive predictive value 95 percent, negative predictive value 63 percent). As a diagnostic for Exam 2 performance, the CDS test was a weaker predictor. Odds for success on Exam 2 were 1.7 (CI 0.17–22.6 [exact], $p=0.66$) and not statistically significant. Since participants were randomly selected from the class to participate, we compared Exam 1 and Exam 2 scores of the participants and nonparticipants and observed no statistically significant differences between scores (not shown).

Table 1. Odds for success on Exam 1: 30.9 if passed CDS

	Pass CDS	Fail CDS	Total
Pass Exam 1	18	7	25
Fail Exam 1	1	12	13
Total	19	19	38
Odds ratio	30.9 [95% C.I.; 3.1–1389.5]		
Sensitivity		Pr (+|D)	72.00%
Specificity		Pr (-|~D)	92.31%
Positive predictive value		Pr (D|+)	94.74%
Negative predictive value		Pr (~D|-)	63.16%
Correctly classified			78.95%

Note: Out of nineteen students who passed the CDS test, eighteen also passed Exam 1, and one failed. Out of nineteen who failed the CDS test, only seven passed Exam 1, and twelve failed.

Discussion

The results of our study suggest that performance on a CDS pre-test was a strong predictor of early preclinical exam performance in a preclinical operative dentistry course. The CDS pre-test was administered to handpiece-naïve students three months before the course began, and the primary outcome assessments (Exams 1 and 2) were done seven and ten months later, respectively. We found a strong association between the CDS pre-test outcome and individual scores on Exam 1 but not on Exam

2. These findings are consistent with and expand upon previous work that demonstrated an association between performance on a CDS device and scores on subsequent student performance in preclinical dentistry. An accurate diagnostic pre-test may have significant implications for teaching preclinical operative dentistry and suggests a strategy for early detection of students who are challenged by manual dexterity tasks. An appropriate early manual dexterity assessment might aid educators in allocating resources in the curriculum early and using preventive remedial mechanisms to direct resources to those students in need. Based on these results, larger validation studies are warranted to determine whether predicting student performance using a CDS pre-test is generalizable to other dental school cohorts.

The results of this study support those found by Imber et al., in which performance results of twenty-six students on a CDS pre-test were associated with their high or low performance in a preclinical manikin course.[17] We found a highly significant association between the level of student performance on the CDS pre-test and the preclinical operative dentistry Exam 1. However, our study differs in several important aspects. First, in the Imber et al. study, CDS software computed grades for six teeth, and the researchers did not report the amount of time spent with the CDS, while in our study the CDS pre-test scores of last two teeth resulted from a single four-hour CDS session and scores were calculated by masked examiners. It would be important to know the amount of time spent with the CDS if it were to become a practical means of pre-testing students. Second, the primary outcomes were different. The Imber et al. study compared the CDS pre-test scores with students' preclinical operative dentistry final comprehensive grades, which consisted of the average of ten practical examinations that included cavity preparations and restorations, while in our study the practical examination scores were the sole outcomes. Measuring the association between the CDS pre-test and the individual examination scores may provide some insight into whether the predictive ability of the test is based on some innate individual learning capability or the CDS is predicting individuals who take longer to learn or need more practice. Further studies are needed to explore these issues.

Another study by Gray et al. compared a one-time, fifty-five-minute CDS pre-test with later performance on preclinical lab scores.[18] Gray et al. found an association among a software-computed CDS scores, certain measures of academic performance, and performance in early preclinical technique course Lab 1, but not later preclinical technique course Lab 2. Our study is consistent with these results in that early and not late preclinical performance was associated with CDS performance. These findings may be explained partly by the fact that our Exam 2 was administered ten months after the CDS pre-test.

Other aspects of our study protocol may account for the strong association between CDS pre-test scores and Exam 1 and the lack of association with Exam 2. First, the Exam 2 score consisted of a combination of both tooth preparation and amalgam restoration scores. We have observed that restoration scores on practical examinations are in general higher and subject to less variation than preparation scores. Second, on Exam 2 the use of indirect vision was required while on the CDS pre-test and Exam 1 direct vision was used. Indirect vision may require different skills. These aspects of Exam 2 were different from the CDS pre-test and Exam 1 and, together with the time interval following the CDS pre-test, may in part explain why associations were not observed between the CDS pre-test and Exam 2. Further, factors such as student motivation to improve their performance after lower performance on Exam 1 and student differences in extracurricular practice time, none of which we could measure, should be considered. Students after low performance on the first practical preclinical examination are usually motivated to improve their scores on the second practical examination, and they do so by increased practice time or even tutoring sessions.

Two aspects of validity also warrant discussion. First, the preparation type (Class I amalgam, Class II or V amalgam) and tooth selection (i.e., mandibular or maxillary, molar or premolar) on each practical exam is chosen by the instructor and is not known to the students prior to the exam. Therefore, students needed to prepare and practice any possible tooth and preparation type. The CDS pre-test tooth type was Class I #19 O, while Exam 1 was Class II #30 MO and Class I #29 O—different tooth and preparation types. We cannot rule out that the ability of the CDS pre-test was specific to the tooth or preparation type that was tested. In general, Class II amalgam preparations are more complex and are frequently used as a general measure to assess student ability. Further study may be needed to determine how the pre-test predicts performance on the different tooth and preparation types. Secondly, we could not determine whether students who were in the CDS pre-test exercise performed differently during the operative

course than students who were not chosen to be in the study. It is conceivable that students in the study were motivated differently and that the associations we observed may have been influenced by exposure to the CDS pre-test. However, we did not observe differences between participants' and nonparticipants' exam scores (data not shown), suggesting no obvious behavioral differences between the groups.

In the studies by Imber et al.[17] and Gray et al.,[18] the researchers used the computer simulator software to evaluate students' tooth preparations and to generate SIM scores, which were then submitted as pre-test scores. In our study, the scoring feature of the CDS unit was disabled from student viewing and not used as the CDS pre-test score. This was done in order for students to focus on the quality of the cavity preparations and make use of the CDS feedback to perform optimal cavity preparations. A key advantage of the CDS, after all, is the immediate feedback the unit provides without needing clinical instructors to be present.

In our study, CDS tooth preparations were scored by trained and calibrated operative dentistry instructors. This approach may offer several advantages over software-generated scores. First, depending on student hand positioning, handpiece movement, or camera obstruction, the computed score may not always be consistent with the actual result. Second, a student who is able to view the final SIM score may be driven to perform the task in such way that a high SIM score is generated on subsequent attempts regardless of the quality of the result. In pilot trials, we have in fact observed this behavior, which in part led to our decision to remove the SIM score feature from the study. Third, evaluations by course instructors represent a more real-world situation because the same instructors evaluated students' work in the pre-test and in the preclinical examinations. Clearly, there is a need to standardize research protocols across institutions in order to validate these questions as well as address the relatively small sample size of all these studies.

Conclusions

These results suggest that performance on a single four-hour CDS pre-test session was a strong predictor of early but not later preclinical exam performance in a preclinical operative dentistry course. Implementation of a CDS pre-test has potentially practical implications since early knowledge of student ability may allow for intervention in order to improve outcomes. Early detection of students in need may allow for implementation of preventive remedial mechanisms to improve the learning experience. Based on these results, larger validation studies are warranted to determine whether predicting student performance using a CDS pre-test is generalizable to other dental school cohorts. Also, intervention studies may use a CDS pre-test to identify those students most likely to benefit from additional assistance.

Acknowledgments

We gratefully acknowledge the support for this study from the Department of Restorative Dentistry, Division of Operative Dentistry, College of Dental Medicine, Columbia University.

REFERENCES

1. Tennant M, Kruger E. Early intervention surveillance strategies (EISS) in dental student clinical performance: a mathematical approach. J Dent Educ 2005;69(12):1353–8.
2. Knight GW, Guenzel PJ, Feil P. Using questions to facilitate motor skill acquisition. J Dent Educ 1997;61(1):56–65.
3. Sandow PL, Jones AC, Peek CW, Courts FJ, Watson RE. Correlation of admission criteria with dental school performance and attrition. J Dent Educ 2002;66(3):385–92.
4. Boreham NC, Russell C, Wastell DG. Can past academic criteria predict students at risk of future failure? Med Educ 1988;22(2):94–8.
5. Ranney RR, Wilson MB, Bennett RB. Evaluation of applicants to predoctoral dental education programs: review of the literature. J Dent Educ 2005;69(10):1095–106.
6. de Andres AG, Sanchez E, Hidalgo JJ, Diaz MJ. Appraisal of psychomotor skills of dental students at University Complutense of Madrid. Eur J Dent Educ 2004;8(1):24–30.
7. Walcott AM, Knight GW, Charlick RE. Waxing tests as predictors of students' performance in preclinical dentistry. J Dent Educ 1986;50(12):716–21.
8. Lundergan WP, Lyon L. Research on hand dexterity and the practice of dentistry: reality and myth. J Am Coll Dent 2007;74(3):15–6.
9. Gansky SA, Pritchard H, Kahl E, Mendoza D, Bird W, Miller AJ, Graham D. Reliability and validity of a manual dexterity test to predict preclinical grades. J Dent Educ 2004;68(9):985–94.
10. Guenzel PJ, Knight GW. Long-term outcomes for remedial students. J Prosthet Dent 1992;67(6):865–9.
11. Knight GW, Walcott AM, Guenzel PJ. A paradigm for teaching a remedial preclinical course. J Dent Educ 1988;52(10):558–61.
12. Branson BG, Toevs SE. An assessment of issues related to clinical skill remediation in dental hygiene education. J Dent Hyg 1999;73(4):200–4.

13. Edwards WS, Smith CD, Garman TA, Morse PK, Zwemer JD. In-course remedial system. J Am Coll Dent 1984;51(1):46–8.
14. Urbankova A. Impact of computerized dental simulation training on preclinical operative dentistry examination scores. J Dent Educ 2010;74(4):402–9.
15. LeBlanc VR, Urbankova A, Hadavi F, Lichtenthal RM. A preliminary study in using virtual reality to train dental students. J Dent Educ 2004;68(3):378–83.
16. Jasinevicius TR, Landers M, Nelson S, Urbankova A. An evaluation of two dental simulation systems: virtual reality versus contemporary non-computer-assisted. J Dent Educ 2004;68(11):1151–62.
17. Imber S, Shapira G, Gordon M, Judes H, Metzger Z. A virtual reality dental simulator predicts performance in an operative dentistry manikin course. Eur J Dent Educ 2003;7(4):160–3.
18. Gray SA, Deem LP, Sisson JA, Hammrich PL. The predictive utility of computer-simulated exercises for preclinical technique performance. J Dent Educ 2003;67(11):1229–33.
19. Quinn F, Keogh P, McDonald A, Hussey D. A study comparing the effectiveness of conventional training and virtual reality simulation in the skills acquisition of junior dental students. Eur J Dent Educ 2003;7(4):164–9.