Impact of Computerized Dental Simulation Training on Preclinical Operative Dentistry Examination Scores

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Abstract: Simulation training may be useful in the preclinical operative dentistry curriculum; however, the optimal timing and duration of training have not been defined. This study compared eight hours of adjunctive computerized dental simulator (CDS) training at two different time points to traditional teaching alone. First-year dental students (n=75) were randomized to CDS training (n=39) or traditional preclinical dental training alone (n=36). Of thirty-nine students in the CDS group, twenty-six were trained before exam 1 (pre-exam group) and thirteen after exam 1 (post-exam group). The primary outcome was performance on three practical examinations. The secondary outcome was the influence of timing on exam performance. CDS-trained students performed significantly better than controls on exams 1 and 2 and were higher but not significantly so on exam 3. There were no differences between CDS groups. These results suggest that eight hours of CDS training administered early in the preclinical operative dentistry may improve student performance.

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In the pursuit of developing students' clinical competence, simulation technology has been utilized in some fields of medicine to compensate for a lack of faculty resources or to replace instructional tasks traditionally performed by instructors.[1] Cardiology, anesthesiology, laparoscopic surgery, orthopedics, and neurophysiology are among the broad spectrum of medical specialties in which simulation technology has been used. Simulations have also been used to aid in the placement of dental implants and other biomedical tools and devices.[2-7]

Despite these successes, questions remain surrounding the use of simulation technology in dentistry.[8] Early results suggest that computer simulation in dental education influences learning efficiency and manual dexterity skill development.[9-11] Buchanan[9] found that students who trained with a computerized simulator learned procedures faster than without it. In that study, students in the computerized simulator group completed twice as many cavity preparations as students trained by conventional methods. Similarly, a study by Jasinevicius et al.[10] found that significantly less faculty instruction time was needed for students who received computerized simulator instruction in order to achieve acceptable performance levels when compared to traditionally trained students. However, the optimal time for introducing computerized dental simulator (CDS) training into the curriculum remains uncertain.

It has been suggested that the timing of simulation training with highly structured immediate feedback is potentially significant. LeBlanc et al.[11] compared students who received CDS training in addition to conventional training at three different times during a preclinical operative dentistry course. In that study, improvements in examination scores were noted in the CDS group but only by the end of the course. However, CDS training was not administered until relatively late in the course, and the CDS sessions were relatively short in duration. Since higher scores were noted in the CDS group only towards the end of the semester, the current study considered whether earlier and more prolonged CDS training might have a greater impact on student performance. Therefore, the purpose of this study was to further explore the role of CDS in preclinical training and to evaluate the timing and duration of the simulation training on students' skill acquisition. Its hypotheses were that simulation training added to traditional instruction improves examination performance compared with traditional instruction alone in a preclinical operative dentistry course and that the timing and duration of CDS training are important.

Methods

One entire second-year dental school class (n=79) consented to participate in the study, which was approved by Columbia University's Institutional Review Board. Students were randomly assigned to two groups: a simulator group and a control group. The simulator group (n=39) was trained for eight hours on the CDS in addition to completing its regular course activities. The control group (n=40) was trained in the traditional preclinical dental laboratory only.

During one academic year (September to July), three practical exams were administered for the purpose of monitoring students' progress in the development of clinical competence. Simulator group and control group students' scores were compared at each testing period. In order to test the timing of the intervention, the simulator group was further divided into a pre-exam group and post-exam group (Figure 1). The pre-exam group (n=26) completed all CDS training prior to exam 1 in December. The post-exam group (n=13) started training after exam 1 and completed training prior to exam 2 in March.

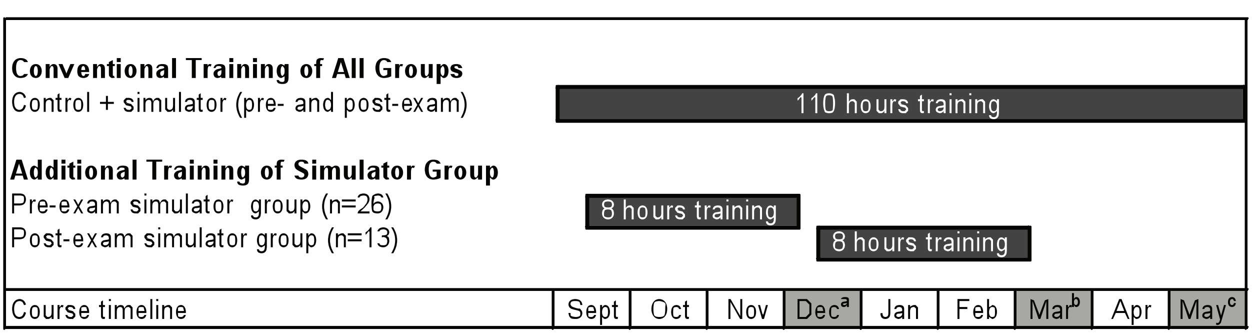
There was no additional access to the simulator beyond the eight hours of study instruction, and the control group students were not given access to the simulator equipment. All participants in both groups proceeded through the standard preclinical operative course with equal opportunity to practice their skills on their own in the traditional preclinical laboratory. All members of this class received standard training in the 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. Thus, the main difference between the simulator (pre- and post-exam) group and the control group was the additional eight-hour exposure to CDS training during the first months of the course.

Four students were excluded from this study because they did not complete all three practical exams. Of these, two students dropped the course because of medical reasons, one student transferred to another school, and one student missed the final examination because of family reasons. All four students who dropped were in the control group.

Experimental Materials

The simulator training sessions took place on a commercially available CDS, DentSim, made by Image Navigation (Jerusalem, Israel) (see Figure 2). As described elsewhere,[11-14] the CDS provides real-time feedback with the use of three-dimensional (3-D) graphics and image processing.

CDS users can utilize five training feedback features. First, an on-demand evaluation features detailed graphical analyses that compare students' work with ideal cavity preparation forms. The feedback may be viewed as cross-sections of the practice



[a-c]Practical examinations 1, 2, and 3 occurred in these months respectively.

Figure 1. Timeline of total training hours received by groups in preclinical operative dentistry course

Figure 2. How the computerized dental simulator (DentSim) combines a patient mannequin, rotary instruments, and a computer monitor with real-time feedback

tooth—enabling the student to assess the cavity depth and direction of the cavity walls—or by overlaying the student's result and the ideal preparation outline. The images are accompanied by a scale allowing recognition of differences at 200-micron resolution. Second, a student's work is stored on the hard drive and can be retrieved if desired in moving image format along with a final evaluation report and a list of error messages. This feature allows interested students to watch their own progress on a procedure and note what was done correctly and incorrectly. Third, errors are audio-signaled as they are made, in real-time, rather than after the preparation has been completed (as is the case in conventional instruction), and the error messages can be viewed immediately. This allows a student to make mid-course adjustments that potentially increase both the quality of the final product and the efficiency of the skill development itself. Fourth, students can use an "evaluation" feature at any time during the procedure. This allows them to receive immediate feedback on their work and to view a graphic analysis with comparison of their current work to the ideal model. The instant access to feedback with graphic comparison allows the learner to visualize and perform needed adjustments. Fifth, the virtual environment is enhanced with complete patient records, including a medical and dental history, X-rays, examination notes, diagnosis, and treatment plan. These provide a more realistic environment during the CDS practice sessions.

Taken together, these CDS features provide feedback that is standardized, consistent, immediate, and accessible at any time during a session.

Procedures and Measures

The additional training for the simulator (pre- and post-exam) group consisted of four two-hour sessions (Figure 1). The first session was a hands-on demonstration to familiarize students with the simulator itself, as well as the graphic analysis they would encounter as they worked through their procedures in the subsequent three sessions. In the subsequent sessions, participants' time was spent on independent practice that included unlimited access to detailed graphic feedback from the simulator. The students' assignment was to prepare ten cavity preparations: five Class I preparations on tooth #19 and five Class II preparations on tooth #18, with closest approximation to ideal model. An instructor was always available to provide technical assistance with the simulation unit, yet in no way did the instructor evaluate or aid the students' work. Therefore, the only feedback students received during the CDS training was from the computer software. The scoring feature of the CDS unit was disabled in order for students to focus on the quality of the cavity preparations.

The scores from three preclinical exams, which were conducted on conventional phantom heads, were used as dependent measures. The operative practical exams took place in December, March, and May. On each examination, which lasted five to eight hours, students prepared two or three cavity preparations and restorations on model teeth; they did not previously know the assignment. While each examination typically included cavity preparations and restorations, for the purposes of the present research, only the cavity preparation scores are included. Out of the seven possible instructors available for assessment, a combination of two instructors independently graded each student's preparation. These ratings were based on a scale of 60 to 100 in intervals of five points: the lowest grade awarded was a 60 and the highest was a 95. 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. Based on these scores it was concluded that each instructor, when paired with any other instructor, scored preparations in a systematic and reliable way. As a result, the scores for each tooth preparation and each evaluator were averaged into a total score for each of the three exams.

The procedures included in the practical examinations increased in skill complexity with each passing examination. For example, exam 1 consisted of only a Class I on tooth #12 and Class II on tooth #30 cavity preparations for amalgam. Exam 2 tested Class II cavity preparations for amalgam and restoration on teeth #4 and #5. Exam 3 required competence in preparing and restoring Class II cavities for amalgam on teeth #13 and #14 and a gold onlay on tooth #19 preparation, with retentive boxes and bevels. In this manner, each examination was considered to be a cumulative test of skills.

Statistical Methods

Performance on each of the three practical exams was compared between students in the pre-exam and post-exam simulator group and those in the control group using SPSS statistical software. Scores on the exams were submitted to a 2x3 mixed-design analysis of variance (ANOVA), with group (pre-exam and post-exam vs. control) as a between-subject variable and examination (exam 1, exam 2, and exam 3) as a repeated measure.

Results

A significant main effect was found for the examination scores of the participants who had CDS training in their preoperative dentistry experience versus those who did not, $F(1,74)=10.1$, $p=0.002$ (Figure 3). For each of the first two examinations, the combined CDS (pre-exam and post-exam) group students performed significantly better than the control group ($p=0.002$ and $p=0.003$, respectively). On the third examination, the CDS group had higher mean examination scores, but the difference was not statistically significant.

We also compared the individual CDS groups (those who had CDS training prior to exam 1 [pre-exam group] and those who had CDS training after exam 1 but before exam 2 [post-exam group]) with

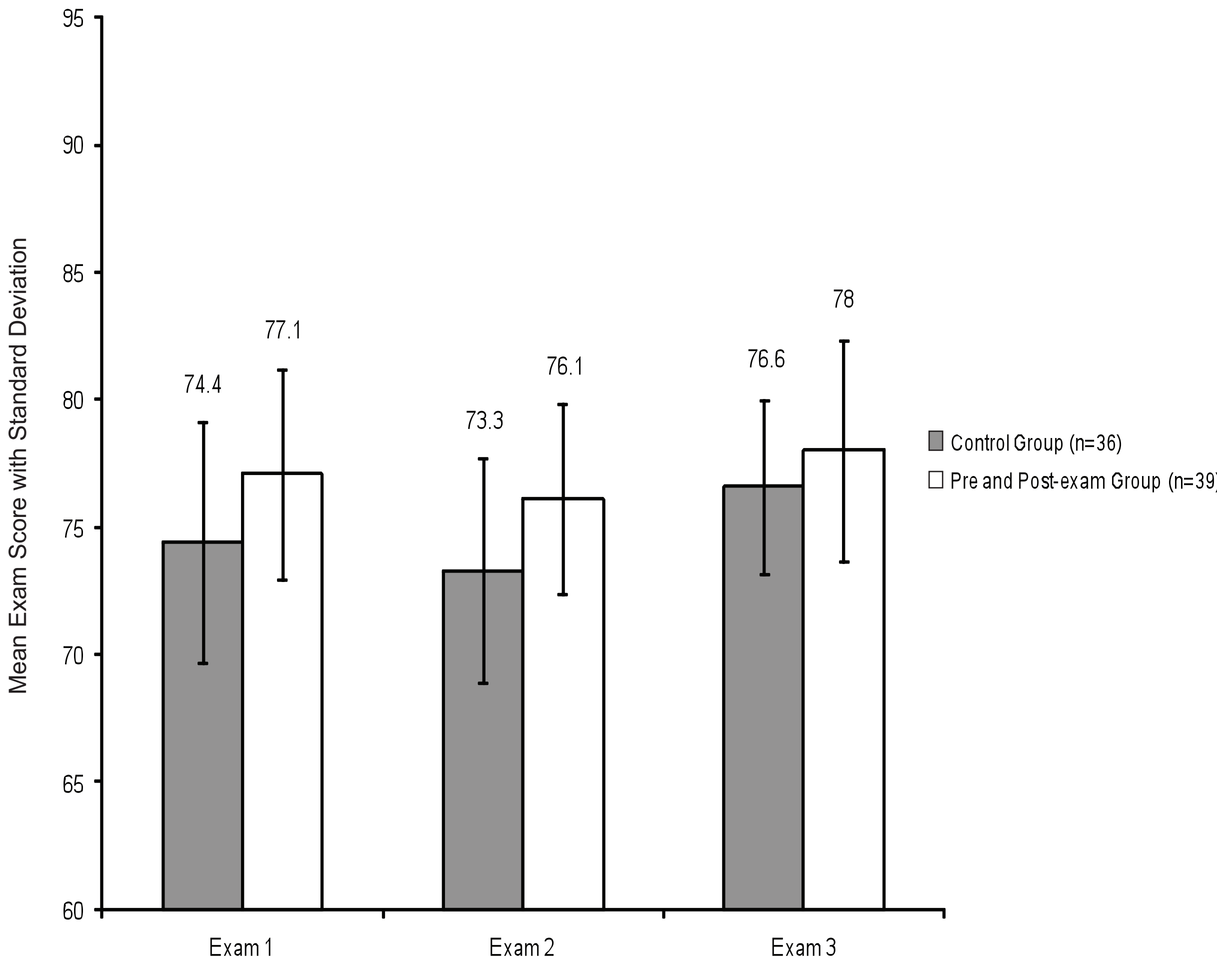


Figure 3. Performance on practical exams as indicated by experimental condition

Note: The CDS group (pre- and post-exam) performed significantly better on exam 1 and exam 2 (p=0.002 and p=0.003 respectively), but not on exam 3 (N.S.).

the control group. Mean pre-exam CDS group examination scores on exam 1 (78.0±4.0 SD) were higher than scores of the post-exam CDS group (75.3±3.7) and the control group (74.4±4.6). Subsequently on exam 2, the mean of the post-exam CDS group scores (76.2±3.7) were higher than those of the control group (73.3±3.8) and similar to the pre-exam CDS group (76.1±3.9). By exam 3, both CDS groups (pre-exam 78.2±4.4, and post-exam 77.4±4.6) had higher scores than the control group (76.6±3.4), but these individual group comparisons were not statistically significant after using a post hoc adjustment (Bonferonni).

Discussion

The results of the present study suggest that training with CDS in a preclinical operative dentistry course enhanced students' practical examination scores. Further, we observed that examination scores were influenced by CDS training regardless of whether training was implemented before or after the first practical examination. The CDS training appears to have put the students significantly ahead and potentially kept them at an advantage for the rest of the year (Figure 3), although by the end of the year there were no significant differences between the groups. This may be explained in part by the long time period between CDS training and exam 3. Nonetheless, the examination score differences we observed between the CDS and control groups appeared to have been influenced by the CDS training.

The unique finding of this study is that early training with CDS technology allowed students in the experimental group to perform better than students in the control group and hold this trend for the rest of the year. Previous work by LeBlanc et al.,[11] in which shorter periods of CDS training were dispersed mostly over the second half of the course, reported that students in the experimental group showed a trend towards obtaining higher examination scores than students in the control group. The trends in that study, however, were not statistically significant. The results from that study suggest that an earlier and more intense implementation of CDS training may be more effective in improving examination performance. In the present study, students received eight hours of CDS training at only one time point early in the course. It found that CDS training had a statistically significant effect on examination scores. Further, individual subgroup comparisons between pre-exam and post-exam groups were not statistically significant. Hence, it does not appear that the timing of the CDS training is crucial, at least with respect to these early time points in the course. Based on these findings, it would appear that there is an advantage to earlier and more intense CDS training.

Generally, the timing of directed, detailed, and guided feedback during the initial stages of preclinical operative training appears to be strategic.[11] It is at this stage of students' skill development when manual skills are practiced and the metacognitive perception cues are forming.[15] Metacognition in the learning environment refers to a level of thinking that involves active control over the procedure performance, including planning the way to approach a task, monitoring comprehension, and evaluating progress towards the task completion. It appears that when these skills are developed early, they promote good habits, result in better performance, and allow for more complex learning to take place. We have observed that as preclinical training progresses and students gain experience, they typically become more autonomous in their learning, and the need for feedback decreases. Hence, computer simulation with frequent feedback may play a meaningful role in student training. It remains to be seen whether continuous CDS training during the preclinical operative dentistry course might lead to still further improvements.

Throughout the education process, the transition from student to clinician is accelerated by frequent feedback from trained experts. At appropriate times, the feedback from such individuals helps students to progress beyond what they would be able to accomplish alone.[16] In the literature of learning and cognitive development, this process is oftentimes referenced as transitioning students through what Lev Vygotsky, an early Russian psychologist and educational theorist, describes as their zone of proximal development.[17]

In the preclinical operative dentistry lab, instructors typically provide this expert help in the transition process. The time available for each student is limited by the instructor to student ratios, time and budget constraints, and a dwindling pool of qualified educators. Despite these limitations, instructors remain the main source of feedback about students' performance. The data from the present study suggest that CDS training may be a useful supplement to human instruction, especially at times when faculty members are not available.

CDS devices are capable of providing students with instantaneous feedback through visual cues to teach proper eye/hand coordination, acceptable tooth preparation forms, and other necessary procedural skills such as understanding of self-assessment during the procedure. Additional advantages of computerized simulation in dentistry include 1) twenty-four-hour availability with step-by-step guidance and evaluation; 2) standardized educational experiences that can be used repeatedly with fidelity and reproducibility[3]; and 3) an individualized learning process that allows students to focus on areas that will enhance their level of competence most efficiently.[18,19] Such characteristics offer the opportunity to improve specific skills through guided self-learning.[12]

The present study has several limitations. First, although all students in both groups (CDS and control) received identical training in the operative dentistry course, it was not possible to arrange for the control group to have an additional eight-hour, non-simulator-based independent work experience. Accordingly, it cannot be ruled out that the extra eight hours of CDS training might account for the differences between group examination scores. Second, the present study did not track the exact amount of practice time students spent outside of the course hours. Thus, it cannot be ruled out that there may have been differences between groups in the amount of time spent on practice. Students typically spend large amounts of time outside of the scheduled laboratory sessions practicing preclinical operative dentistry procedures, and the eight hours' practice difference by itself is unlikely to have impacted examination scores. Third, it was also not possible to mask the students with regard to experimental and control group. Given the sometime competitive nature of professional students, knowing that their classmates were taking part in a simulation exercise may have biased time spent practicing skills. Nonetheless, the randomization process should have minimized that potential bias. Future study designs should take these potential sources of bias into account. Fourth, there are technical issues inherent in the CDS system that was used. Calibration of the units was done according to manufacturer guidelines prior to each training session. However, there were instances of false positive and false negative feedback messages that were reviewed by the faculty and were accepted or rejected on a case-by-case basis. Fifth, for technical reasons the typodont teeth used in the CDS unit are different from the teeth used in preclinical lab. The CDS typodont uses KaVo (www.kavousa.com) typodont teeth, while Columbia Dentoform (www.columbiadentoform.com) typodont teeth were used in the preclinical lab. The extent to which this factor influenced the study outcome cannot be determined; however, all examinations were scored on the same type of typodont tooth (Columbia Dentoform).

The type, frequency, and amount of feedback provided by the CDS unit allow students to instantly review their cavity preparation and compare it with an ideal model. The graphic comparison is presented in the form of overlaying outlines and cross sections in any direction (mesio-distal or bucco-lingual). Thus, students can see their mistakes in either color-coding or number measurements. Significant student errors are audio-signaled as they are made, in real-time, and the error messages may be viewed immediately under an "evaluation" feature at any time during the procedure. This allows a student to make mid-course adjustments. Making mistakes and correcting them immediately have the potential to increase learning efficiency and skill development. The immediate feedback, which is standardized, consistent, and immediate with visual graphic analysis, enhances students' understanding of needed adjustments. In the present study, better examination performance may be attributable to the type of training rather then simply the added amount of practice time. Additional studies in the area of dental simulation feedback are needed to more fully explore its impact on student development.

At present, virtual reality simulators should not be viewed as a substitute for human instruction; however, they do provide an additional layer of instructional quality and content to the preclinical educational experience. Thus, adding simulation technology to the curriculum in ways that complement faculty instruction—especially at the beginning of the preclinical experience—appears to be useful and worthwhile.

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