A Preliminary Study in Using Virtual Reality to Train Dental Students

Vicki R. LeBlanc, Ph.D.; Alice Urbankova, M.L.L.Dr.; Farhad Hadavi, D.M.D., M.Sc.; Richard M. Lichtenthal, D.D.S.

Abstract: This study compared virtual reality simulator-enhanced training with laboratory-only practice on the development of dental technical skills. Sixty-eight students were randomly assigned to practice their skills in either a traditional preclinical dentistry laboratory or in combination with a virtual reality simulator. The results indicate that students who trained with the virtual reality simulator between six and ten hours improved significantly more than did the students in the control group from the first examination of the year to the final examination of the year. These results indicate that the use of virtual reality simulators holds promise for the training of future dentists. Additional research is necessary to determine the ideal implementation of virtual reality simulators into traditional dentistry curricula.

Dr. LeBlanc is Assistant Professor, University of Toronto, Faculty of Medicine; Dr. Urbankova is Assistant Clinical Professor, Columbia University School of Oral and Dental Surgery; Dr. Hadavi is Professor, Clinical Dentistry, Columbia University School of Oral and Dental Surgery; and Dr. Lichtenthal is Benfield Associate Professor and Chair of the Division of Operative Dentistry and Endodontics, Department of Restorative Dentistry, Columbia University School of Oral and Dental Surgery. Direct correspondence and requests for reprints to Dr. Vicki LeBlanc, University of Toronto Faculty of Medicine, Centre for Research in Education, 200 Elizabeth Street, 1 Eaton South 565, Toronto, ON M5G 2C4; 416-340-3054 phone; 416-340-3792 fax; vicki.leblanc@utoronto.ca.

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One of the most important skills for any dentist is the ability to prepare and restore damaged tissue resulting from carious lesions. The development of this skill requires mastery of two components: knowledge of the concepts of the procedure and the dexterity to perform it. Instruction regarding the concepts of cavity preparation and demonstrations of techniques can be offered by faculty in large group sessions. However, the performance component requires a situation in which students can repeatedly practice the application of the knowledge imparted by the instructor. In the past decades, educators have come to the realization that the clinical arena may not be an optimal environment for dental education. There are a number of reasons for this. Technical skills are increasingly complex due to advances in knowledge, materials, and technology. In parallel with the technological advances, financial restraints have increased the pressure for high patient turnover at dental school clinics, leaving less teaching time available to instructors and students. Finally, concerns over patient safety have led to a decrease in the acceptance of having students practice new skills on patients.[1,2]

The realization that the clinical setting is not an ideal environment for skills training, coupled with recent technological advances, is leading to an increased use of computer applications in health care education. Growth in computer-aided instruction has been fueled by increases in computer capacities, software applicability and accessibility, and decreased costs, as well as student demands for the most up-to-date training possible.[3,4] Computer-aided instruction can range from computer or web-based tutorials, discussion groups, and courses to more sophisticated virtual reality-based, computerized patient simulators and virtual reality-based simulations.[5] Simulators are useful learning tools because they allow for practice in controlled environments and are adaptable to flexible scheduling for students as well as instructors.[6] They offer an arena for students to test and observe the results of dental procedures without any patient morbidity.[7] They also facilitate repetition of the skill to be learned, offer controlled training variations, and provide opportunities to quantitatively assess student performance. Students can thus learn how to deal with the outcomes of their actions in safe environments.[8]

To date, most developments in virtual reality patient simulation have occurred in the field of surgery, where it is essential for surgeons to master complex procedures *prior* to performing them on patients.[6] However, dentistry has recently witnessed the introduction of simulated environments for the development of dental skills. Most dental schools have developed preclinical laboratories where students practice skills on typodont teeth with articulating mandibles in life-sized mannequin torsos. While such a method of practice does provide students with a means to practice the skills of preparing and restoring teeth, it has limits in the realism provided to the students and in the quantity and quality of feedback. The field of dentistry has also seen an increase in the use of computer-assisted simulation for the training and assessment of haptic (or tactile-based) skills, such as the ability to detect carious lesions.[9] Simulators are also used in preclinical training of dental students, as a tool to provide a smoother transition to clinic by broadening students' preclinical experiences.[5,10] Kaufmann proposes that natural progression of this technology will be for virtual reality simulators to be used for education, certification, and recertification in all health care fields.[1]

Dental operatory and virtual reality patient simulators (such as the DentSim developed by DenX) offer the promise of providing practice in a realistic environment filled with detailed, frequent, and objective feedback.[11] However, it is unknown if these characteristics will lead to better or accelerated development of skills. The purpose of this study was to evaluate the effect of training through virtual reality simulation on student performance during preclinical laboratory work, based on standard grading evaluation procedures at Columbia's School of Dental and Oral Surgery (SDOS). In this study, we investigated whether training with a computerized simulator was comparable to or better than traditional training in developing the skills necessary for performing operative dentistry procedures.

Methods

Sixty-eight students (forty-four males/twenty-four females) were enrolled in the second-year course of preclinical operative dentistry course at Columbia's SDOS. The study was introduced to the students during a large-group session, and all students initially volunteered to participate. Based on space limitations, simulator unit availability, and time restrictions, twenty of these students were randomly selected to engage in computerized simulation training (simulator group: twelve males/eight females) in addition to the standard 110 hours of traditional laboratory-based instruction in operative dentistry alongside the control students. One student (female) eventually dropped out of the study after the introductory session, but prior to any individualized training, due to a lack of interest in completing the computerized simulation training. Her results were not included in the data analysis. The remaining forty-eight students (control group: thirty-two males/sixteen females) continued to receive *only* the traditional laboratory-based instruction. In addition to the course time, all sixty-eight students were free to engage in extracurricular practice in the traditional preclinical laboratory on their own time. This research project received approval from Columbia University's Internal Review Board, and the students gave signed consent for their performance to be used as research data.

Simulator

The DentSim® computer-assisted simulator, manufactured by DenX Ltd. of Israel,[12] is a clinical simulator providing real-time tactile feedback with use of 3D graphics and real time image processing. The DentSim® unit combines a patient mannequin, the typodont with a set of teeth, and rotary dental instruments. In addition, it is equipped with infrared light emitting diodes and an overhead infrared camera feeding to two computers and a monitor to interpret the spatial orientation of the mannequin and to produce a three-dimensional image of the patient's mouth. The operator can view any cut made in a tooth from any angle on the monitor.

The software provides detailed feedback comparing the operator's performance with a preprogrammed acceptable "ideal" cavity preparation in its database at any point of the procedure. Feedback consists of detailed diagrams with quantitative analysis in various cross sections. Using the feedback during the procedure serves as a guidance tool, while using it strictly at the end simulates an examination. The entire procedure is saved and stored in individual student files that can be reviewed later in movie format with a final evaluation and a list of error messages, allowing students to actually watch how each mistake was made. Errors are also audio signaled in real time while students are working and can be viewed immediately. This allows students to know the results of their errors when they are made, rather than after the preparation has been completed (as in traditional preclinical instruction). They can thus develop the skill to make mid-course adjustments that increase both the quality of the final product and the efficiency of the skill development itself.[13] The virtual environment is enhanced with complete patient records including medical and dental history, X-rays, examination notes, diagnosis, and treatment plan.

The computerized simulation module at Columbia University's SDOS has been in use for three years. To date, students involved in training and participating in study have been first- and second-year students. There is no designated class time for computerized training in the students' class schedule due to an already densely filled curriculum. Students worked during their free time. Time spent in the simulation laboratory was monitored by upperclass student teaching assistants and a sign-up sheet.

Procedure

All sixty-eight students received the conventional instruction and training in operative dentistry. This consisted of in-class faculty lectures and demonstrations, as well as scheduled laboratory practice in the preparation and restoration of carious lesions. All students participated in the traditional education together, with the same faculty instructors. Seven faculty members provided instruction throughout the academic year to all sixty-eight students, and the instructor-student ratio in the class was, on average, 1:10. All students could also engage in individual practice outside of regular class hours, and this practice time was not monitored.

Students who were assigned to the simulator group received an additional six to ten hours of training on the computerized simulator in three blocks over a period of eight months. During Block 1 (December-April), students received one to two hours of training with the computerized simulator. This training consisted of a one-hour introduction and a hands-on demonstration on interacting with the simulator. During Block 2 (April-May), students in the simulator group received two to three hours of independent practice with the simulator. In Block 3 (May–July), the students in the simulator group received an additional three to five hours of training with the computerized simulator. Each student in this study group was required to perform two cavity preparations that were deemed acceptable based on the DentSim unit's computerized grading system in each two-hour session, for a total of four cavity preparations. Students who fulfilled this requirement in less than the allotted time were not required to stay for the remainder of the session. Instructors were not present to evaluate or aid the students during these final two training sessions, and an upper-class student teaching assistant was present to monitor attendance and provide assistance for any technical difficulties. Students in the simulator group were also free to engage in individual practice in the traditional operative dentistry laboratory, as were the control group students.

Measures

Performance on the practical exams in the preclinical course in Operative Dentistry was used as an assessment of the effects of the additional six to ten hours of training with the DentSim. The practical exams in the course take place in December, April, May, and July. During these exams that last five to eight hours each, students perform a variety of cavity preparations and restorations. Two instructors independently rate the quality of the cavity preparations and restorations on a scale of 0-100, in intervals of five points, with the lowest grade awarded being a 60 up to a high of 95. The average of the two ratings determines the score for a particular preparation or restoration, and the scores for each item are averaged to provide the student with an overall score on the practical component of the exam. Typically, students complete between three and six procedures for each exam, with a preparation and restoration of the same tooth counting as two procedures. All instructors grading student performance on the practical exams, including two investigators in this study, were blinded as to which students were in the study or the control groups.

As the year progressed, the procedures included in the practical exams increased in complexity and skill required to achieve a passing grade. For example, Exam 1 consisted of only class I and II amalgam cavity preparations. Exam 4 required competence in preparing and restoring class II, class IV, and a gold onlay with retentive boxes and bevels. In this manner, each exam was considered a cumulative test of skills, with the final examination being used as a capstone to evaluate competence in the entire year's worth of procedures.

Scores for the cavity preparations on each of the four practical exams in the operative dentistry course were compared between students in the simulator group and those in the control group. Scores on the exams were submitted to a 2 x 4 mixed-design analysis of variance, with group (simulator vs. control) as a between-subject variable and test (Test 1, Test 2, Test 3, and Test 4) as a repeated measure.

Results

Overall, the average scores on the exams increased throughout the year, $F(3, 177)=12.59$, $MSE=9.3$, $p<.01$. This result indicates that the students' ability to prepare cavities improved throughout the course. Students in the two groups did not differ on their overall performance scores during the year, $F(1, 59)=.352$, $MSE=23.12$, $p=.56$. However, we observed a significant group by test interaction, $F(3, 177)=4.15$, $p<.05$. On the early exams, the students in the control group obtained higher scores than did the students in the simulator group. However, by the final exam, the students in the simulator group showed a trend towards obtaining higher scores than did the students in the control group (78.4 vs. 76.6, $p=.07$). An independent t-test indicated that the exam scores of the students in the simulator group improved significantly more from the first to the fourth exam than did the exam scores of the students in the control group (improvement of 4.8 pts vs. 1.4 pts, $p=.01$). In a few short hours of training, the DentSim group improved significantly more than the control students. See Table 1 for the scores on each of the exams.

Discussion

The results of this study suggest that virtual reality simulation provides an effective training method for the development of operative dentistry skills in students. Students assigned to the simulator group demonstrated better improvements in exam scores throughout the year than did students in the control group. These findings are very positive, given that the individual practice time never exceeded eight hours throughout the academic year.

Our results are in line with other research on the effect of computer simulation in the training of dentistry skills. Buchanan has published some of the few studies investigating the effectiveness of computer simulation instruction. Her findings show that students learn procedures faster with computerized simulation training than students who train in traditional laboratories.[5] She hypothesized that the reason for this acceleration of learning is that the students are able to complete more preparations per hour (up to twice as many) than students in the traditional laboratory.

We believe that the advantage of computerized simulation training comes from a variety of factors. In traditional operative dentistry instruction, preclinical students practice on mannequins in large groups. There are limits in the objectivity and the frequency of the feedback provided by the instructors in traditional training. The laboratories are typically large ones, and the ratio of instructor to student is low. Thus, students often have to wait extended periods of time before receiving any feedback. Research has shown that, for the most effective instruction, some external feedback should be offered when students are practicing.[14]

While this study does provide evidence in support of technology in the training of dental students, further research needs to be conducted to determine the optimal coordination of the traditional didactic instruction with emerging technology-based instruction. First, it is unknown what is the optimal amount of training required on the computerized simulator to lead to improvements in the acquisition of skills. Anecdotal evidence from the University of Pennsylvania showed that postgraduate dentists required, on average, five hours of training on a computerized simulator before realizing significant benefit based on the computerized grading system. In this study, students just barely crossed the five-hour plateau. This finding suggests that more extensive training time would lead to more profound improvements in skill. Second, it is unknown when is the best time to schedule computerized simulation training during the acquisition phase of operative skills. It may be hypothesized that the earlier the training, the better, while others have argued that a tactile skill cannot be fully optimized without the didactic knowledge base in place.[15,16] We are currently investigating the benefits of computerized simulation training incorporated early versus later in the skills acquisition.

Table 1. Performance on practical exams

Exam	Exam 1	Exam 2	Exam 3	Exam 4
Simulator Group n=19	73.6 (.84)*	73.9 (.83)	76.9 (.80)	78.4 (.81)
Control Group n=48	75.3 (.57)	75.8 (.56)	76.7 (.54)	76.6 (.54)
Average	74.4 (.51)	74.9 (.50)	76.8 (.48)	77.5 (.49)

*Numbers in parentheses are standard errors of the mean.

We are aware of limitations in the design of the study, most notably that we were not able to control the amount of time students practiced the skill on their own time. Thus, we are not in a position to determine whether the increased performance of the simulator group results from training specifically with the virtual reality simulator or whether it simply results from them having more practice time overall than the students in the control group. Our belief is that the six to ten hours of actual individualized training was insignificant compared to the 110 hours of in-class laboratory time as well as any additional hours of self-practice. An informal survey of the students revealed that they spent, on average, approximately eighty-three hours practicing outside of class throughout the year. We believe those six to ten hours had a greater impact due to the individualized attention and evaluation each student in the DentSim group received, rather than due to significantly extra time spent on practice. We are currently designing studies investigating this question.

While this study indicates that students who trained on the computerized simulator showed improvements on exams of operative dentistry, we wish to stress that the training on the simulators was not a stand-alone activity. Rather, training with the simulator was placed within the context of initial class-based instruction so that the trainees would learn the relevant principles of the skills of operative dentistry. Research in skill acquisition has shown that *knowledge of performance* (error information related to the characteristics of the performance) and *knowledge of results* (comparison between actual outcome and desired outcome) are required for acquisition and improvement of motor skills.[15,16] Such knowledge can be acquired during class-based instruction where the students learn demonstration through lectures and, by asking questions, how to discriminate between the desired performances and outcomes and ones that contain errors. Thus, it is our belief that the coordination of training on simulators with class-based instruction is necessary to ensure that the skills perfected on the simulator are the correct ones.

Conclusion

This study is one of the first investigating the effects of computerized simulation on the development of operative dentistry skills. The results indicate that students in the DentSim simulator group improved their scores significantly more from the first to the fourth examination of the year than did students in a control group who did not receive augmented instruction by the simulator. The simulation group improved from a mean score of 73.6 percent on the first exam of the year to 78.4 percent on the fourth exam, which served as a cumulative capstone assessment of the students' operative skills. The control group (traditional training only) improved from 75.3 percent on the first exam to 76.6 percent on the fourth exam. However, while the use of simulators for the training of dental holds promise, their integration into the curriculum should not go unchecked. Rather, the implementation of simulators should be guided by theory and by relevant research regarding how individuals obtain and process information. For this last purpose, simulators can serve the additional function of aiding researchers in determining areas of clinical practice that need enhancement and of guiding faculty in modifying curricula.

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