A Complex Haptic Exercise to Predict Preclinical Operative Dentistry Performance: A Retrospective Study

Alice Urbankova, D.D.S.; Miroslav Eber, C.Sc., FCMA; Steven P. Engebretson, D.M.D., M.S., M.S.

Abstract: A reliable test of manual dexterity could potentially have utility in dental education. Recently, haptic technologies have emerged that may offer a means of testing manual dexterity in the preclinical setting. The purpose of this study was to determine whether performance on a complex haptic simulator exercise was associated with preclinical operative dentistry practical examination scores or the Perceptual Ability Test (PAT) scores of the Dental Admission Test. All thirty-nine first-year dental students enrolled in the Operative Dentistry preclinical course at the Stony Brook University School of Dental Medicine completed a haptic exercise consisting of a single manual dexterity test (D-circle), repeated eight times in succession during a single session at midterm. A score reflecting accuracy and time to completion of each trial was calculated automatically and resulted in a success or failure for each trial. Preclinical operative dentistry practical examinations consisting of plastic tooth preparations given at three time points during the course were scored by four calibrated and masked course faculty members. Examination scores were compared with students' performance on the haptic test using linear regression. Number of failures during a single session on a complex haptic exercise was found to be a significant predictor of examination performance in the preclinical setting. These results suggest a role for haptics in identifying students with potential learning challenges in the preclinical stages of dental education. Identification of students with manual dexterity problems at an early stage may allow for early intervention to prevent failure.

Dr. Urbankova is Assistant Professor, Department of General Dentistry, School of Dental Medicine, Stony Brook University; Dr. Eber is Professor, Department of Dentistry, University of Palacky, Olomouc, Czech Republic; and Dr. Engebretson is Associate Professor, Ashman Department of Periodontology and Implant Dentistry, College of Dentistry, New York University. Direct correspondence and requests for reprints to Dr. Steven Engebretson, Ashman Department of Periodontology and Implant Dentistry, College of Dentistry, New York University, 345 East 24th Street, 3W, New York, NY 10010; 212-998-9640 phone; spe2002@nyu.edu.

Keywords: haptics, virtual reality, simulation, operative dentistry, psychomotor performance, dental education, computer-assisted instruction

Submitted for publication 12/21/11; accepted 1/1/13

Predictors of success in dental education continue to be of great interest to educators. While dental school admissions criteria are largely successful in determining the best candidates for the didactic portions of dental education,[1] there is considerable variability in students' manual dexterity skills. In many dental school curricula, the first assessment of psychomotor skill development potential may not occur until many weeks have passed in the preclinical operative dentistry course. Only then can faculty members provide the necessary remedial steps to improve student success in the course. Ideally, recognition of low performance would occur at an earlier stage, before course practical examinations. Early remediation may foster a more positive learning environment and improve student course performance, a foundation for clinical patient care. Hence, an accurate and validated manual dexterity test to identify dental student psychomotor ability and manual dexterity learning potential would be of considerable use to dental educators. A pre-admissions assessment might be of even greater significance in this regard.

The Perceptual Ability Test (PAT) of the Dental Admission Test has been found to be a valid cognitive determinant for spatial ability of dental school applicants;[2-5] however, a validated psychomotor test does not currently exist.[1] Earlier methods for assessment of psychomotor skills, the chalk carving test,[6] waxing tests,[7,8] or tweezer tests were ceased for various reasons, including the difficulty and costliness of administering them as well as questionable validity.[9] Computer-assisted simulation training has been shown to be useful in the preclinical operative dentistry curriculum,[10-14] both as a means of improving preclinical examination performance and as a potential diagnostic to predict learning potential.[15]

Emerging haptic technologies have the potential to improve the simulation experience. Haptics rely on computer-assisted force feedback to produce

a tactile sensation for the user and have gained favor among some educators.[5] Haptics have been evaluated for their ability to distinguish between expert and novice performance.[5,16] Researchers have found that haptics can reliably simulate tooth surface or structure.[17] They have also found that novice students can learn dental surgical procedure (such as endodontic access opening) solely in a virtual reality (VR) environment and that a similar learning outcome can be achieved whether the student learns in a conventional or VR environment.[18] Overall, faculty perceptions regarding haptic simulators have been positive when studied in the preclinical setting.[5,19]

Previously, we demonstrated the potential for a haptic device to be used as a testing platform to predict preclinical performance in a small dental student cohort.[15] In that study, a range of haptic exercises were tested for their association with student performance on traditional preclinical operative dentistry examinations and the PAT. It was determined that the more complex and difficult haptic exercises had the most association with student results on preclinical performance. Hence, a new exercise named the "D-circle" emerged that introduced an additional increment of complexity. The D-circle object resembles a torus, with a bend along the midline. The student's task is to "remove" the D-circle structure with accuracy within a given time and without penetrating the walls beyond an allowable extent.

Additionally, based on our previous study, we determined a need to evaluate the influence of repetition of an exercise on the results of the predictive test (whether students were learning the exercise while they were completing it). Hence, the purpose of this study was twofold: first, to determine whether performance on a new complex haptic simulator exercise allowing for multiple repetitions was associated with standard practical preclinical examinations in operative dentistry; and second, to test whether performance on the complex haptic test was associated with PAT scores.

Materials and Methods

The simulator used in this study was the Individual Dental Education Assistant (IDEA) simulator (IDEA, Inc., Las Vegas, NV, USA). This commercially available computer-assisted simulator uses a contemporary gaming approach in conjunction with high-precision haptics interfaces. The system as previously described[15] consists of a handheld stylus haptic device (Sensable Technologies, Inc., Woburn, MA, USA) that simulates a dental handpiece with force feedback and simulation software that may be installed on standard computers. The student operator holds the haptic stylus device while observing the simulation on the conventional two-dimensional computer display (Figure 1). The system is multi-client with a central server controlled by an administrator. Tasks can be assigned for each trainee, determining their number and level of difficulty. For each task, the simulator measures and records task time, percentage of desired material removed, and

Figure 1. Haptic exercise set-up

deviation from the assigned drilling task, reflecting level of accuracy. Manual dexterity in this module is defined as a user's ability to perform activities that require hand-eye coordination.

The virtual reality test environment consists of a surface featuring different paths coated in material that needs to be removed by the user. The paths can be of different shapes, e.g., straight line, circle, D-shaped circle. In this study, we used the D-shaped circle exercise that has the added complexity of a vertical component (Figure 2). There are two main parameters the user is required to consider to reach high scores, accuracy, and pace. At the beginning of the test, the user receives a certain quantity of accuracy in the accuracy bar and a limited amount of time to finish the level. During the carving activity, the accuracy bar is reduced whenever the carving deviates from the predefined path. The accuracy bar decreases more rapidly as the deviation from the predefined path increases. If the accuracy bar is depleted, the test ends with failure. To motivate the user to carve as quickly as possible, a score bonus proportional to the time remaining is added to the final score. If the user is carving too deeply, touching the nonremovable material or applying excessive force on the handpiece, a warning sound prompts the user to adjust appropriately, before the level ends with failure. The test is time limited. The computer software evaluates the following: carving distance from the path, time elapsed since beginning the test, carving depth, removed area percentage, haptic force (pressure used on the handpiece), and handpiece position. The data are exported into a report providing the level of accuracy at the end of the test and the time remaining on completion of the test.

All thirty-nine first-year dental students enrolled in the Operative Dentistry I preclinical course of the Stony Brook University School of Dental Medicine participated in this study. This protocol was deemed exempt from review by the Committees on Research Involving Human Subjects at Stony Brook University. Nonetheless, all participants were informed of the nature of the study, and all gave written informed consent and were provided the ability to opt out without academic consequence.

The first practical preclinical operative exam (Exam 1) took place two months after the beginning of the course (Figure 3) and tested students' performance on mesio-occlusal (MO) Class II cavity preparation of a left mandibular first molar typodont tooth. The second practical preclinical operative exam (Exam 2) took place five months after the course began and tested a Class II MO cavity preparation of a right mandibular first molar typodont tooth and a Class II MO restoration on a mandibular left first molar. The third and final practical examination (Exam 3) took place at the end of the eight-month course and tested a Class II MO cavity preparation on a maxillary first premolar, an amalgam restoration mesio-occluso-distal (MOD) of a left maxillary

Figure 2. The D-circle exercise

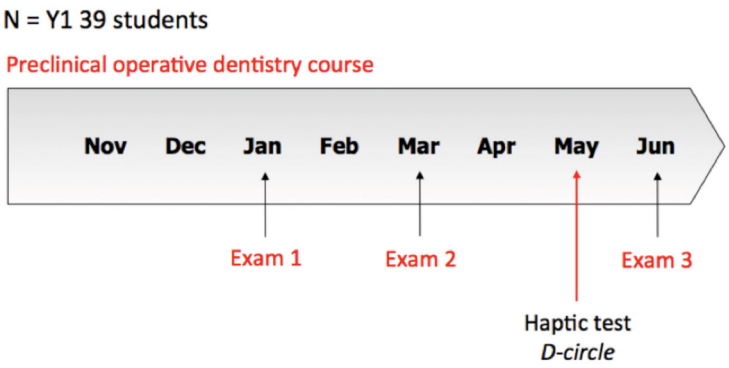

Figure 3. Timeline of study events

first molar typodont tooth, and a composite Class III disto-lingual (DL) preparation and restoration of a maxillary lateral incisor. The specific assignment for each examination was not known to the students prior to the tests. The examination scores were determined by four clinical faculty members who were calibrated and masked with respect to student identity and haptic scores as previously described.[15]

The haptic test consisted of a complex manual dexterity exercise D-circle, using the haptic simulator's manual dexterity module. Students were instructed to complete the exercise eight times in succession during a single fifteen-minute session, administered at a time point between Exam 2 and Exam 3 (Figure 3). Scores were thus generated for each of eight trials for every student participant by the module software (IDEA) and consisted of accuracy and time to completion as previously described.[15] If the exercise was not completed in the allotted time or the stylus was moved out of bounds, the trial was counted as a failure. Hence, each student could score between zero and eight failures. In addition, PAT scores were obtained from the admissions records for each student.

The number of haptic failures among the eight exercises was tabulated and resulted in about one-fourth of the students with no success or only one success among the eight trials. Exam scores were recorded as continuous variables and were normally distributed (Shapiro-Francia test for normality). The PAT score is a continuous variable. Simple linear regression models using Exam 1, 2, or 3 failure as dependent variables and Number of Haptic Failures (NHF) as the independent variable were used to determine whether associations were observed. We tested the hypothesis that the haptic test outcome is predictive of exam performance or PAT score. Data were analyzed using commercially available statistical software (STATA SE, Version 12.1, StataCorp., LLC, College Station, TX, USA).

Results

All thirty-nine students completed the fifteen-minute exercise that consisted of eight consecutive trials at the haptic exercise D-circle (Figure 2). Over the eight trials, mean accuracy scores (ranging from a low of 1 to a high of 20) on the haptic increased in a linear fashion until about the fifth repetition, after which no further gains were observed for most participants (Figure 4). Most students failed the first three attempts on the haptic test, but by the fourth attempt, the majority had experienced at least one success. Inversely, as accuracy increased over the eight trials on the haptic, the number of students failing each exercise decreased until about the fourth repetition; thereafter, failures appeared to remain stable.

Overall, eight students failed all attempts at the haptic exercise, and three students were successful only once. Only two students had no failures over eight attempts (Figure 5). Accuracy was a measure of the student's ability to remove the designated material without going out of bounds during the D-circle exercise. An accuracy score was generated only when a successful trial at the haptic has occurred. Figure 6 shows the accuracy over eight consecutive attempts by those who were successful at least twice.

Regression models with Exam 1, 2, or 3 as the dependent variables and number of failures on the

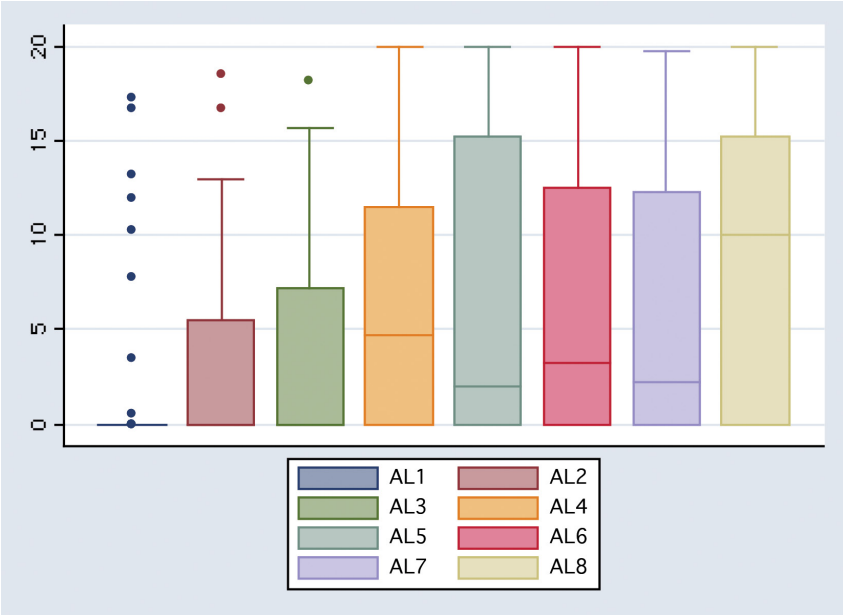

Figure 4. Box and whisker plot showing group mean accuracy over eight consecutive manual dexterity exercises of thirty-nine preclinical operative dentistry students

Note: Mean accuracy scores on the haptic increased in a linear fashion until about the fifth repetition, after which no further gains were observed for most participants.

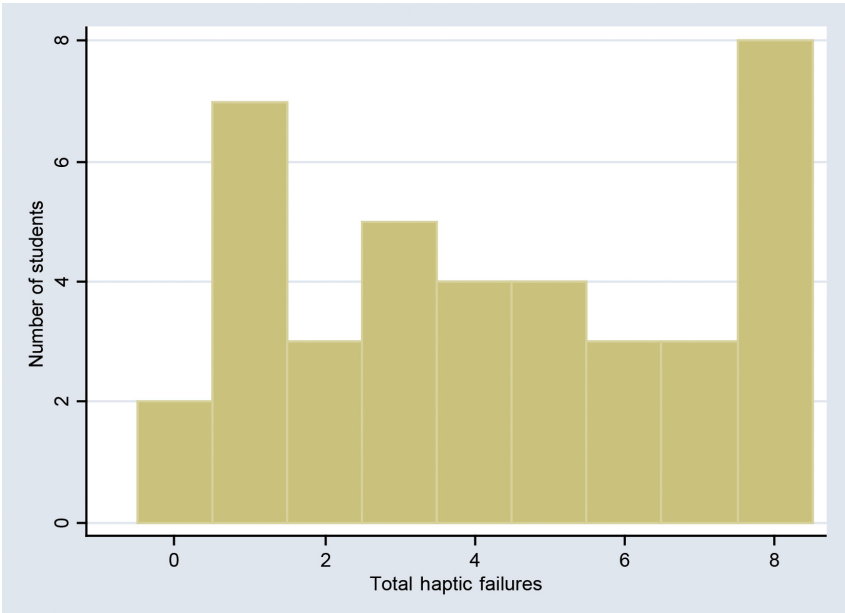

Figure 5. Total number of failures at D-circle haptic exercise over eight consecutive attempts by thirty-nine students

Note: Two students were successful on all eight attempts, while eight students failed all attempts. The median number of failures per student was four.

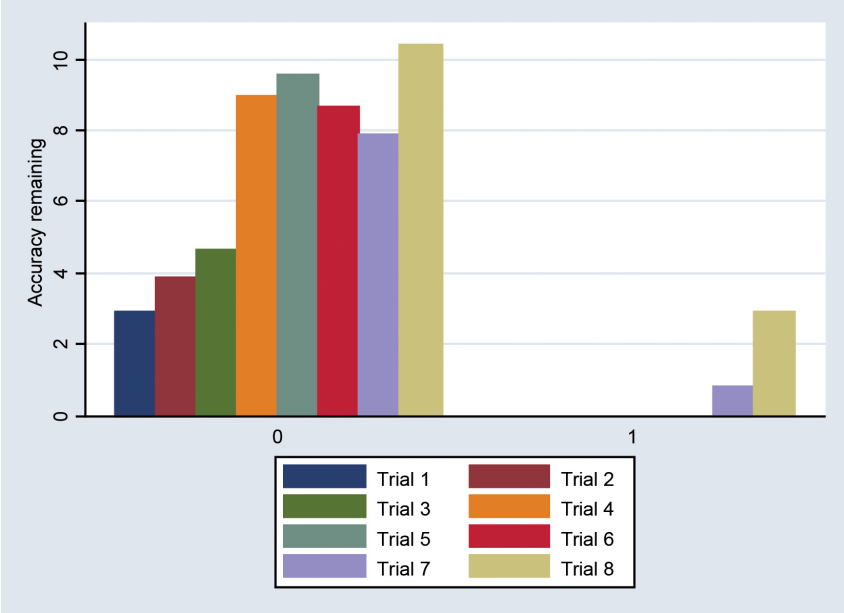

Figure 6. Students' ability to remove designated material without going out of bounds during D-circle exercise (known as "accuracy remaining")

Note: Accuracy only remains after a successful trial at the haptic. Chart demonstrates the increase in mean accuracy over eight consecutive attempts by students who were successful at least twice, while group without success appears to have made no or little progress over eight trials. Of thirty-nine students, eight were not successful over eight attempts, while three had only one success over eight attempts. Twenty-eight students were successful at least twice over eight attempts (0=successful at least twice, 1=failed all or all but one attempt).

haptic test as an independent variable were statistically significant for Exam 1 (p=0.025, R-squared=0.13) and Exam 2 (p=0.03, R-squared=0.12), but not Exam 3 (p=0.08, R-squared=0.08). NHF was not a significant predictor of PAT score (p=0.19, R-squared=0.02) (Table 1).

Discussion

Haptic technologies have recently emerged that may provide an environment in which to test manual skills needed to perform operative dentistry procedures. One use for this new technology has been as a pretest or diagnostic to help identify individuals for whom operative dentistry procedures are likely to pose a greater challenge. In our previous study,[15] we tested three simple manual dexterity exercises (line, circle, and mirror line) on one of the newer commercially available haptic devices. The results of that study led us to conclude that the more complex exercises were the most strongly associated with early preclinical operative dentistry performance and that repetition of the exercises revealed that learning of the test was also a factor that needed to be evaluated. Additionally, we found that no single haptic test was predictive of both Exam 1 and PAT scores.

Hoping to improve the predictive ability of preclinical performance using haptic exercises, for this study we selected a new exercise of higher complexity, the D-circle exercise, and tested a new cohort of dental students. Further, we allowed the students to repeat the same exercise eight times in succession, counting the number of successes among the eight trials for each student. The results of this new more complex test, eight repetitions of D-circle exercise, reported here revealed a consistent and strong association with early practical examinations Exam 1 and Exam 2 but not with Exam 3. We also evaluated the association between performance on the haptic test and the PAT test, collected during students' admission to dental school, and found no significant association. Taken together, these results suggest for the first time that a single haptic simulator manual dexterity test is a strong predictor of student performance on the early preclinical operative dentistry practical

Table 1. Simple linear regression models with Exam 1, Exam 2, and Exam 3 as dependent variables and Number of Haptic Failures (NHF) as independent variable

Exam 1 Score		Exam 2 Score		Exam 3 Score	
NHF	-4.456	NHF	-3.507	NHF	-3.135
(2.33)*		(2.27)*		(1.77)	
_cons	82.953	_cons	86.725	_cons	87.171
	(32.91)**		(42.61)**		(37.29)**
R2	0.13	R2	0.12	R2	0.08
N	39	N	39	N	39

*p<0.05; **p<0.01

examinations. These data expand on and confirm the results of our first haptic study and provide direction for prospective studies to determine risk for poor performance in the preclinical curriculum.

Historically, the assessment of psychomotor skill in the United States consisted of a chalk carving test that was replaced by the PAT portion of the Dental Admission Test in 1972.[20] The lack of a standard manual dexterity evaluation prior to dental school admission has led investigators to seek alternative means through a variety of creative tests. The Learn-A-Prep (LAP) exercise has been used in many dental school curricula to familiarize handpiece-naïve students with use of high-speed rotary instruments. A recent study by Boushell et al.[21] found that students who were unable to maintain acceptable preparation depth during the LAP exercise were less likely to be successful on early but not later practical examinations.

Our data tend to support the findings of Boushell et al.[21] in that the majority of our students were eventually able to achieve clinically acceptable performance by the end of the course. Also consistent with the Boushell et al. study is that we found an association between experimental test performance (haptic manual dexterity exercises) and early practical examination performance. We found that students who were not successful on the haptic exercise had lower performance on all three preclinical examinations although the association with Exam 3 was not statistically significant. One explanation for the lack of correlation between the haptic exercise results and student performance on later preclinical operative examinations may be due to the effects of rigorous practice and additional assistance in the form of remediation and tutoring in the latter half of the course. As mentioned in Gansky et al.'s study,[22] preclinical operative dentistry courses are designed to pass students (eventually) or to allow remediation until passing work has been demonstrated. Additionally, we tested students during the operative dentistry course, after Exam 1 and Exam 2. We cannot rule out that participation in the operative dentistry skill exercises during the course may have influenced performance on the haptic. Future studies should test handpiece-naïve students before the course begins to address this potential limitation in our study.

The use of traditional manual dexterity tests or LAP methods in our preclinical curricula can be time-consuming for both students and faculty members.[10,21,22] Haptic exercises, on the other hand, seem to provide a relatively easy and safe environment for the testing and learning of operative dentistry skills with reduced need for one-on-one faculty instruction and the elimination of disposables.

The results of this cross-sectional study conducted on a single dental school cohort in the United States suggest that a complex haptic exercise was strongly associated with early student preclinical performance in a preclinical operative dentistry course. Multiple attempts at the D-circle exercise during a single fifteen-minute session revealed learning of the test by most but not all students. Students who were not successful at the haptic exercise had significantly lower examination scores early in the course, but not later. Students' PAT scores were not associated with examination success and were not associated with performance on the haptic test in regression models. These results suggest a potential future role for haptic devices in dental education and a direction for further use of haptics in dental school preclinical teaching. Future studies should be aimed at evaluating haptic exercises for their utility in the admissions process.

Conclusion

A complex haptic exercise during a single session was strongly associated with low student performance in the preclinical setting and appears to have the potential for diagnostic use in the dental curriculum. Early identification of students who are challenged by preclinical operative dentistry tasks may benefit from early intervention in the form of more focused instruction, which in turn may lead to a more favorable educational experience. Based on these results, prospective studies in larger dental school cohorts are warranted in order to validate these findings. Further refinements and successful validation of such haptic tests may lead to improvements in the ability to discriminate among applicants in an increasingly competitive dental school admissions environment.

Acknowledgments

The authors acknowledge the participation of the Stony Brook University School of Dental Medicine Class of 2012 for their enthusiastic participation in this study. Grateful thanks to Ofir Baruch of IDEA Inc. for his expert technical assistance and Drs. Ann Nasti, Ying Gu, and Jeff Seiver for their expert scoring of the examinations. This study was made possible by an unrestricted grant from the Office of the Dean, School of Dental Medicine, Stony Brook University.

REFERENCES

1. 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.
2. Boozer CH, Lee MM, Rayson J, Weinberg R. Prediction of academic success: a study with dental students using noncognitive and cognitive variables. J Am Coll Dent 1984;51(3):14-21.
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. Staat RH, Yancey JM. The admission index in the dental school admissions process. J Dent Educ 1982;46(8):500-3.
5. Gal GB, Weiss EI, Gafni N, Ziv A. Preliminary assessment of faculty and student perception of a haptic virtual reality simulator for training dental manual dexterity. J Dent Educ 2011;75(4):496-504.
6. Oudshoorn WC. The utility of Canadian DAT perceptual ability and carving dexterity scores as predictors of psychomotor performance in first-year operative dentistry. J Dent Educ 2003;67(11):1201-8.
7. Smithers S, Catano VM, Cunningham DP. What predicts performance in Canadian dental schools? J Dent Educ 2004;68(6):598-613.
8. Walcott AM, Knight GW, Charlick RE. Waxing tests as predictors of students' performance in preclinical dentistry. J Dent Educ 1986;50(12):716-21.
9. Dworkin SF. Further correlational and factor analyses of the DAT as a predictor of performance: conclusions and summary. J Dent Educ 1970;34(4):358-64.
10. Urbankova A, Engebretson SP. Computer-assisted dental simulation as a predictor of preclinical operative dentistry performance. J Dent Educ 2011;75(9):1249-55.
11. 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.
12. Buchanan JA. Experience with virtual reality-based technology in teaching restorative dental procedures. J Dent Educ 2004;68(12):1258-65.
13. Urbankova A. Impact of computerized dental simulation training on preclinical operative dentistry examination scores. J Dent Educ 2010;74(4):402-9.
14. 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.
15. Urbankova A, Engebretson SP. The use of haptics to predict preclinical operative dentistry performance and perceptual ability. J Dent Educ 2011;75(12):1548-57.
16. Rhienmora P, Haddawy P, Suebnukarn S, Dailey MN. Intelligent dental training simulator with objective skill assessment and feedback. Artif Intell Med 2011;52(2):115-21.
17. Rhienmora P, Haddawy P, Khanal P, Suebnukarn S, Dailey MN. A virtual reality simulator for teaching and evaluating dental procedures. Methods Inf Med 2010;49(4):396-405.
18. Suebnukarn S, Hataidechadusadee R, Suwannasri N, Suprasert N, Rhienmora P, Haddawy P. Access cavity preparation training using haptic virtual reality and microcomputed tomography tooth models. Int Endod J 2011;44(11):983-9.
19. Steinberg AD, Bashook PG, Drummond J, Ashrafi S, Zefran M. Assessment of faculty perception of content validity of PerioSim, a haptic-3D virtual reality dental training simulator. J Dent Educ 2007;71(12):1574-82.
20. Graham JW. Substitution of perceptual-motor ability test for chalk carving in a dental admission testing program. J Dent Educ 1972;36(11):9-14.
21. Boushell LW, Walter R, Phillips C. Learn-A-Prep II as a predictor of psychomotor performance in a restorative dentistry course. J Dent Educ 2011;75(10):1362-9.
22. 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.