Haptic Virtual Reality for Skill Acquisition in Endodontics

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Abstract

Introduction: Haptic virtual reality (VR) has revolutionized the skill acquisition in dentistry. The strength of the haptic VR system is that it can automatically record the outcome and associated kinematic data on how each step of the task is performed, which are not available in the conventional skill training environments. The aim of this study was to assess skill acquisition in endodontics and to identify process and outcome variables for the quantification of proficiency. **Methods:** Twenty novices engaged in the experimental study that involved practicing the access opening task with the haptic VR system. Process (speed, force utilization, and bimanual coordination) and outcome variables were determined for assessing skill performance. These values were compared before and after training. **Results:** Significant improvements were observed through training in all variables. A unique force used pattern and bimanual coordination were observed in each step of the access opening in the posttraining session. The novices also performed the tasks considerably faster with greater outcome within the first two to three training sessions. **Conclusions:** The study objectively showed that the novices could learn to perform access opening tasks faster and with more consistency, better bimanual dexterity, and better force utilization. The variables examined showed great promise as objective indicators of proficiency and skill acquisition in haptic VR. *(J Endod 2010;36:53–55)*

Key Words

Access opening, endodontics, haptic, novices, skill acquisition, virtual reality

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Virtual reality (VR) is a computer graphic technique for realizing an experience by supplying variable three-dimensional images (1). In particular, the haptic interface is the cutting-edge technology. The word “haptic” means relating to or proceeding from the sense of touch (2). Haptic interface is a device that allows a user to interact with a computer by means of tactile feedback. This feedback is derived by using a manipulator to apply a degree of opposing force to the user along the x, y, and z axes. Haptic interfaces can be used to simulate operations and actions such as deformation and cutting. Three-dimensional haptic devices can be used for applications such as surgical simulation of complex procedures and training unskilled surgeons. Recently, the haptic VR simulators have been introduced into the dental curriculum as training devices for clinical skill acquisition in several tasks. The haptic VR dental simulators that have been developed are the Iowa Dental Surgical Simulator (College of Dentistry, University of Iowa, Iowa City, IA) for teaching the tactile skills in detection of dental caries (3) and PerioSim (Perio-Sim, University of Illinois at Chicago, College of Dentistry, Chicago, IL) for teaching the tactile skills in the detection of subgingival calculus and a variety of other subgingival topographies (4).

Our research group has previously developed a haptic VR system for tooth preparation and used the kinematics from the haptic VR to examine dental skill proficiency (5). However, our findings still have been limited for two major reasons. First, the assessment of bimanual coordination has been ignored, although dental tasks usually require movements of both arms (indirect vision) in a specific time-phasing relationship. Second, previous studies actually measured the differences between experts and novices in one time tooth preparation task. There are practically no data on differences of the kinematic patterns through training. Such data could provide a realistic profile of the novices’ movements while learning to use the haptic VR. Such data would be useful to develop real-time augmented feedback to trainees in future generations of VR systems.

Therefore, the aim of this study was to assess skill acquisition through a designed training protocol using not only common outcome variables but also bimanual coordination and force utilization. Our goal was to identify feasible variables for better quantifying the extent of proficiency and skill acquisition.

Material and Methods

Participants

Twenty volunteer fourth-year dental students (novices), 11 men and 9 women ages 20 to 23 years, were enrolled in this study. Novices had experience using dental handpieces in cavity preparation from the operative preclinical course but no prior experience performing endodontic access opening. All were right-handed. None of them had received any skill training using a haptic VR system. All participants had good computer skills as assessed by computer literacy self-assessment (6).

Task

Their task was to perform access opening on the upper right first molar with a haptic VR system (5). The task was designed to mimic real access opening and to require hand-eye coordination for quality performance (Fig. 1). The participants were required to use indirect vision during the procedure.

Experimental Protocol

The experimental protocol included one pretraining test, five training sessions, and one posttraining test. All participants were briefly instructed on the use of the system

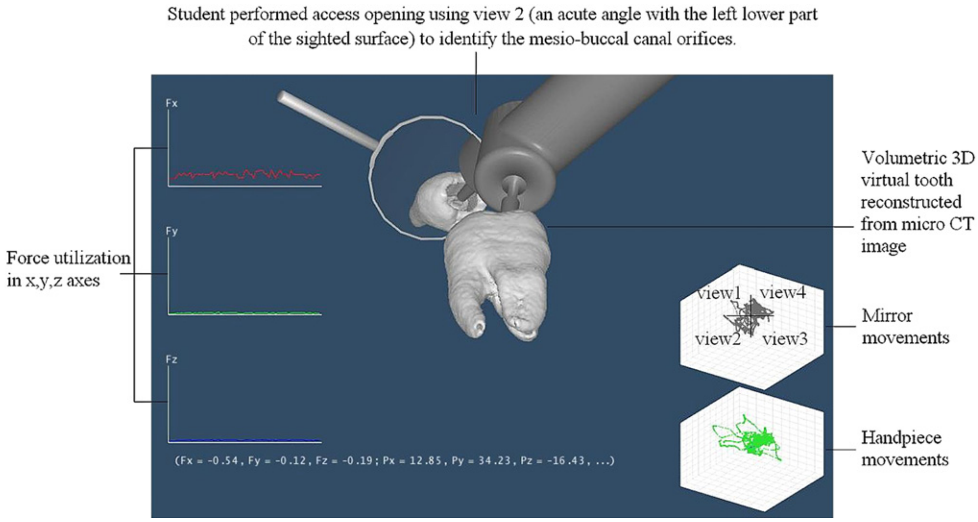

Figure 1. A student performed an access opening task with a haptic VR system.

and the requirements of access opening for 15 minutes. After the familiarization, the participant performed two trials of the task while data were not acquired. The third trial was used for data analysis for the pretraining session. Within 3 days after the pretraining test, the participant started the training sessions by practicing the access opening task five times. During practice, the participant received augmented feedback on movement pattern and performance score at the end of each trial. At the end of each session, the participant performed the task while data were acquired. Within 1 week after the training session, the posttraining session was conducted in the same manner as the pretraining session.

Measurements

Kinematics of the haptic device was collected by using the Application Programmer's Interface provided by PHANTOM Omni (SensAble Inc., Woburn, MA). A custom user's performance view program was written by our group to interface with the haptic. During data collection, the system recorded data associated with performance process in each step of the access opening including time to task completion (T) and force utilization (F) in the x, y, and z axes (x, mesiodistal direction; y, faciolingual direction; and z, long axis of the tooth) and the total traveling distance with respect to the handpiece (D) movements. To quantify the extent of bimanual dexterity, a coordination analysis was conducted to evaluate the direct relationship between the mirror positions (M) and the handpiece. Sightline angles were classified into four views. View one denoted an acute angle with the left upper part of the sighted surface. View two denoted an acute angle with the left lower part of the sighted surface. View three denoted an acute angle with the right lower part of the sighted surface. View four denoted an acute angle with the right upper part of the sighted surface.

The preparation outcome (O) scores were randomly graded by one expert in the field who did not participate in the data collection. Four-point scales were used: with four on the scale defined as "minimally extended cavity affording unimpeded access to/and visibility of the orifices of all canals presents"; three as "a coronal cavity permitting effective debridement of the canal system without prejudice to subsequent restoration; two as "incomplete removing of pulp chamber roof and/or inadequate retention form for the maintenance of an effective dressing"; and one as "unidentified canals and/or perforation."

The group mean values for the dependent variables of T, F-x-y-z, D, M, and O were compared between the pretraining and posttraining sessions with dependent t tests ($\alpha = 0.05$) using SPSS 12.0 (SPSS, Chicago, IL).

Results

The means and standard deviations of all the dependent variables for both testing sessions are summarized in Table 1 (T, O, D, and M analyses) and Figure 2 (F-x-y-z analyses). The results showed

TABLE 1. Mean and Standard Deviation Values for Time to Task Completion (T), Outcome Score (O), Total Traveling Distance of the Handpiece (D), and MODE Values for Mirror View (M) Analysis of Pretraining (PRE), 5 Training (T1-T5), and Posttraining (POST) Sessions 8.

	PRE	T1	T2	T3	T4	T5	POST
T (s)	362 ± 27	305 ± 22	245 ± 21	220 ± 23	185 ± 25	178 ± 24	158 ± 20
O (Score)	1.5 ± 0.6	2.2 ± 0.4	3.1 ± 0.5	3.3 ± 0.5	3.5 ± 0.5	3.5 ± 0.5	3.7 ± 0.5
D (mm) Step 1	45.35 ± 4.95	40.12 ± 2.38	39.18 ± 2.28	37.28 ± 1.27	28.18 ± 1.29	19.78 ± 2.21	16.67 ± 2.35
D (mm) Step 2	46.56 ± 3.67	39.59 ± 3.14	37.59 ± 2.24	32.57 ± 1.54	25.58 ± 1.64	18.56 ± 1.34	12.34 ± 1.78
D (mm) Step 3	41.59 ± 2.78	38.73 ± 2.47	34.76 ± 2.49	33.86 ± 2.48	27.36 ± 2.49	20.34 ± 2.45	11.45 ± 2.56
D (mm) Step 4	42.54 ± 4.34	34.21 ± 2.82	31.51 ± 3.01	29.21 ± 1.23	24.25 ± 1.83	19.45 ± 1.63	13.67 ± 1.98
M (view) Step 1	1	1	1	1	1	1	1
M (view) Step 2	1	2	2	2	2	2	2
M (view) Step 3	1	1	2	3	3	3	3
M (view) Step 4	1	1	2	3	3	4	4

$n = 20$. Step 1: cut into the palatal pulp horn. Step 2: extend the opening laterally to the mesiobuccal canal orifices. Step 3: extend the opening laterally to the distobuccal canal orifice. Step 4: extend the opening laterally to the palatal canal orifice.

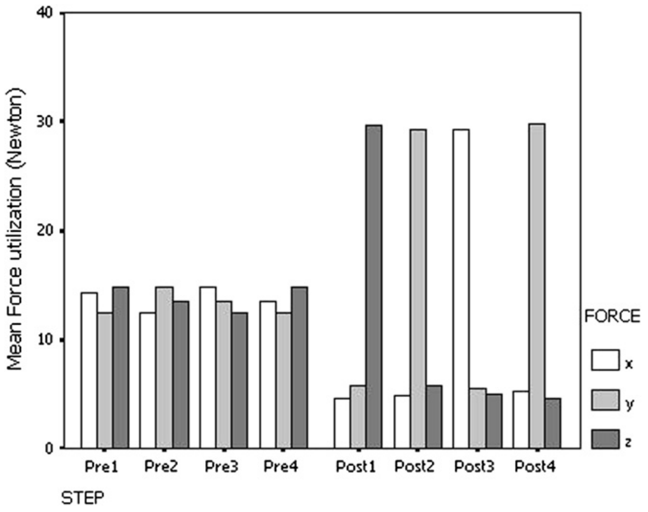

Figure 2. Force utilization in the x, y, and z axes for each step (1-4) of the pretraining and posttraining sessions.

a significant shorter T in the posttraining condition ($p \leq 0.05$). The learning curves with respect to T showed that they achieved the time reduction at the end of each training session. A significantly greater O value was observed in the posttraining condition ($p \leq 0.05$). The learning curves with respect to O showed that they achieved the outcome score increasing at the end of each training session. The participants showed significantly shorter D in the posttraining condition ($p \leq 0.05$). The learning curves with respect to D showed that they achieved the distance reductions at the end of each training session.

Unique force used patterns were observed in each step of the access opening in the posttraining session (Fig. 2). Almost all steps required pushing forces along one axis. Cutting into the palatal pulp horn required pushing forces mainly along the z axis (long axis of the tooth). Extending the opening laterally to the mesiobuccal canal orifice required pushing forces mainly along the y axis (faciolingual direction). Extending the opening to the distobuccal canal orifice required pushing forces mainly along the x axis (mesiodistal direction). Extending the opening to the palatal canal orifice required pushing forces mainly along the y axis (faciolingual direction). Participants did not show a unique force utilization pattern and significantly used less main pushing force in the pretraining session ($p < 0.05$).

Discussion

This study objectively showed the change in endodontic access opening for the novice users of the haptic VR before and after their engagement in a designed training protocol. As in a previous study (7), the novice users in this study showed a significant reduction in task completion time (T) after the training sessions. Remarkably, their learning curves for the time score showed that they achieved a drastic time reduction with only a few training sessions. Similar results were obtained for the total traveling distance of the handpiece (D). Specifically, the participants showed a significantly shorter distance for two of the three experimental tasks through training. In addition, rapid improvement of the outcome score was observed in the first two or three training sessions. Our results confirm that task completion time (T), traveling distance (D), and outcome score (O) can be used to represent improvements in the extent of proficiency and/or skill acquisition. Another explanation for these results is that the haptic VR system is designed specifically to mimic the same hand motions as those used during dental procedures. The novice participants in this study showed a unique pattern of the mirror views and force utilization in each step of the access opening at the posttraining session. This shows the sensitivity of our mirror vision and force utilization analysis for distinguishing between different procedure steps. Thus, mirror vision and force utilization analyses are important for distinguishing between procedure steps for quality training. Future studies should evaluate dental students with more realistic clinical settings (the ultimate goal of any training program) to gain further insight into the nature of transferability of the motor skill acquired from the haptic VR training system and to identify more applicable variables for patient care.

In conclusion, the identification of appropriate variables that can quantitatively show the extent of proficiency and/or skill acquisition is important for the development of objective scoring criteria that lead to the establishment of rational educational formats. In the current study, several variables were automatically collected through the real-time kinematics from the haptic VR Application Programming Interface, which emphasizes the importance of incorporating haptic VR systems into endodontic training programs. Moreover, such variables are needed to build algorithms for the new generation of improved surgical systems and/or training devices that may allow more effective training experience with real-time feedback of clinical performance. These variables should be composite and obtainable from direct data acquisition without any subjective judgment.

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