

Title	The usefulness of a haptic virtual reality simulator with repetitive training to teach caries removal and periodontal pocket probing skills
Author(s)	Yamaguchi, Satoshi; Yoshida, Yoshinori; Noborio, Hiroshi et al.
Citation	Dental Materials Journal. 2013, 32(5), p. 847-852
Version Type	VoR
URL	<a href="https://hdl.handle.net/11094/93089">https://hdl.handle.net/11094/93089</a>
rights	Copyright 2013 The Japanese Society for Dental Materials and Devices
Note	

***Osaka University Knowledge Archive : OUKA***

<https://ir.library.osaka-u.ac.jp/>

Osaka University

## The usefulness of a haptic virtual reality simulator with repetitive training to teach caries removal and periodontal pocket probing skills

Satoshi YAMAGUCHI<sup>1</sup>, Yoshinori YOSHIDA<sup>1</sup>, Hiroshi NOBORIO<sup>2</sup>, Shinya MURAKAMI<sup>3</sup> and Satoshi IMAZATO<sup>1</sup>

<sup>1</sup>Department of Biomaterials Science, Osaka University Graduate School of Dentistry, 1-8 Yamadaoka, Suita, Osaka 565-0871, Japan

<sup>2</sup>Department of Computer Science, Osaka Electro-Communication University, 1130-70 Kiyotaki, Shijonawate, Osaka 575-0063, Japan

<sup>3</sup>Department of Periodontology, Osaka University Graduate School of Dentistry, 1-8 Yamadaoka, Suita, Osaka 565-0871, Japan

Corresponding author, Satoshi YAMAGUCHI; E-mail: yamagu@dent.osaka-u.ac.jp

Our aim was to evaluate haptic virtual reality (VR) simulation with repetitive training as a tool in teaching caries removal (CR) and periodontal pocket probing (PPP) skills. For the CR simulation, multilayered virtual models composed of tooth substance, caries, and pulp were developed. Seven students completed three training sessions each, which were scored based on the volume of the cut region, the number of instances of handpiece overload, and total cutting time. For the PPP task, we developed a virtual periodontal disease model and 26 students received training in measuring pocket depth. Pocket probing force was measured and proficiency was evaluated. In the CR task, scores for the second and third training sessions were significantly higher than for the first training session. We likewise obtained effective repetitive training results for the PPP task. Our simulator was effective at teaching hand skills for both tasks within short-term evaluation.

**Keywords:** Haptic virtual reality, Haptic device, Repetitive training, Caries removal skills, Periodontal pocket probing skills

### INTRODUCTION

Virtual reality (VR) simulation is an effective tool in skill acquisition because it allows repetitive training with standardized scoring in clinical situations. The effectiveness of VR training has attracted attention in aerospace and medical engineering fields<sup>1–11</sup>, and VR already has practical use in flight and surgical simulators.

Traditionally, dental hand skills have been taught using mannequin-based tooth and jaw models<sup>12,13</sup>. The use of extracted teeth for dental training is increasingly difficult because of personal information protection and disease control requirements. Most educational institutions have adopted the use of mannequins for standard training, such as cavity and dental impression preparation.

Current dental mannequins have teeth made of simple plastic, which inadequately replicates the anatomical and mechanical properties of enamel, dentin, and pulp. In addition, repetitive training exercises require the use of many disposable artificial teeth on mannequin. In response to these shortcomings, the dental field has turned its attention to VR simulation<sup>14,15</sup>.

Tactile sensations are especially important to dentists because clinical dental procedures require exquisite skill working with a narrow and dark view. Several studies have been published since early 2000 on the use of VR coupled with haptic devices that are able to impart a sense of force feedback to the operator<sup>16–18</sup>.

The targeted skills of haptic VR simulation training are caries removal, cavity preparation,

periodontal pocket probing, and calculus removal. The development of a haptic VR simulator to teach cutting techniques for caries removal and cavity preparation is essential. Thomas *et al.* have developed a haptic VR training simulator to teach hand skills for caries detection<sup>19</sup>. Simodont® is another haptic VR simulator that has been commercially available to teach cutting skills in recent years. However, available systems have been limited to caries removal and cavity preparation simulation. The lack of versatility for other hand skill training applications is a disadvantage. Suebnukarn *et al.* have compared pre- and post-training results for mannequin-based *versus* VR-based training, using their own haptic VR simulator. They assessed VR training in the hand skills of access opening<sup>20</sup> and access cavity preparation<sup>21</sup> in endodontics, and of crown preparation<sup>22</sup> by both experts and novices in prosthodontics. Steinberg *et al.* have developed PerioSim and also assessed them for faculty perception of content validity of that<sup>23</sup>. However, these studies did not mention the efficacy of repetitive training. Thus, our aim was to evaluate the usefulness of our haptic VR simulator<sup>24</sup> with repetitive training in teaching caries removal and periodontal pocket probing skills.

### MATERIALS AND METHODS

#### *Caries removal task*

First, we developed a virtual molar model with the material properties of enamel that included a pulp cavity and a carious lesion on the occlusal fossa (Fig. 1). We used a viscoelastic Voigt model that could represent a material having both elasticity and viscosity. By following an experience of dentists, the spring and

Color figures can be viewed in the online issue, which is available at J-STAGE.

Received Jun 27, 2013; Accepted Jul 30, 2013

doi:10.4012/dmj.2013-174 JOI JST.JSTAGE/dmj/2013-174

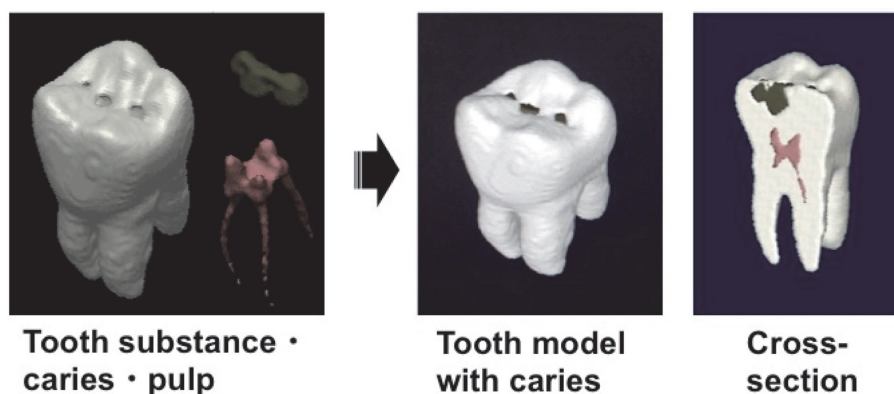


Fig. 1 Computational model for the caries removal task.  
Left: tooth substance, caries, and pulp. Right: combined multilayered model and cross section.

damper coefficients for elasticity and viscosity of the carious lesion were empirically set at 0.25 N/mm and 1.0 N·s/mm, respectively, which is softer<sup>25)</sup> than the region of the dental hard tissue. The carious lesion was also colored black to clarify the boundary between tooth substance and caries for the operator.

Seven dental students (fourth year students in Osaka University School of Dentistry) with no experience of either cavity preparation or caries removal were randomly selected to perform haptic VR training three times using the virtual tooth model (Fig. 2). The parameters for evaluation were the volume of the section removed from the carious region,  $V$ ; the number of instances of handpiece overload,  $N$ ; and the total cutting time,  $T$ . To evaluate the training results, we defined the score  $S$  based on these parameters as follows:

$$S = V + N + T \quad (1)$$

where the value of  $V$  was calculated using the volume of the actual cut section  $V_{actual}$  and an pre cut section  $V_{pre}$  in the caries region as follows:

$$V = \frac{V_{actual}}{V_{pre}} \times 50 \quad (2)$$

Here, the value of  $V_{actual}$  was calculated by subtracting the volume of caries at the end time from the one at the start time.

The overload number  $N$  was calculated as follows:

$$N = \frac{N_{thresh} - N_{actual}}{N_{thresh}} \times 25 \quad (3)$$

where the  $N_{thresh}$  and  $N_{actual}$  are the threshold of the overloaded number and the actual number of the overload 3 N, respectively. In this study, the value of  $N_{thresh}$  was set as 1. If the  $N$  was less than 0, it was set as 0.

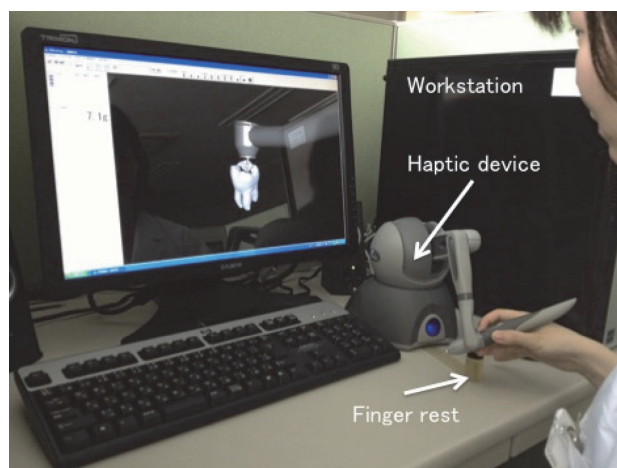


Fig. 2 Scene of running the caries removal task.

Finally, the cutting time  $T$  was calculated as follows:

$$T = \frac{(T_{thresh} - T_{actual})}{(T_{thresh} - T_{ideal})} \times 25 \quad (4)$$

where,  $T_{actual}$  was calculated by subtracting the start time from the end time. The  $T_{thresh}$  and  $T_{ideal}$  are the threshold of the cutting time and the ideal cutting time, assigned a value of 600 and 300 s, respectively, with experience of an expert dentist. If the  $T$  was over 25, it was set as 25. In this study, each weight of three parameters ( $V:N:T=50:25:25$ ) was empirically determined.

#### Periodontal pocket probing task

We scanned the gingiva and dentition in the region of the maxillary right first molar of a jaw model (D51FE-500A-QF, NISSIN, Kyoto, Japan) using a

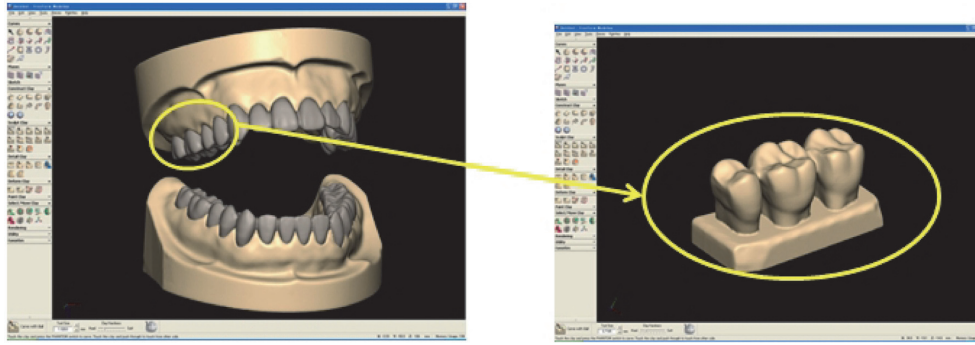


Fig. 3 Computational model for the periodontal pocket probing task.  
Yellow circle: periodontal disease modeled by CAD software (flipped vertically).

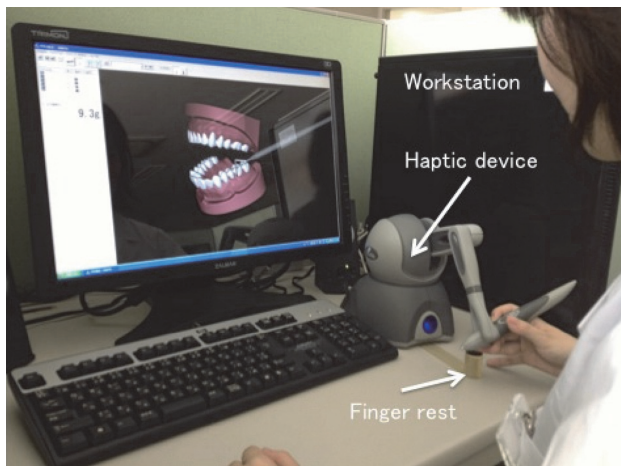


Fig. 4 Scene of running the periodontal pocket probing task.

three-dimensional scanner (Rexscan DS2, Solutionix, Seoul, Korea), which resulted in a three-dimensional digitized model. Based on this model, models of the gingiva and dentition were designed using CAD software (FreeFormModeling, SensAble Technologies, Wilmington, MA, USA) and were converted into STL data format. STL data from the maxillary right second premolar, first molar, and second molar were converted to octree data format<sup>24</sup>. Finally, a periodontal pocket model was developed for the proximal surface and cervical areas using CAD software (Fig. 3).

Twenty-six dental students (fourth year students in Osaka University School of Dentistry) with no prior experience in periodontal pocket probing were randomly selected to train using the haptic VR simulator. Students performed depth measurement training for 3-mm periodontal pockets in the central buccal region (Fig. 4). In pre-training, students performed five measurements of pocket depth, and probing forces were recorded

Table 1 Scores for the periodontal pocket probing task

Probing force $p$ (N)	Score
$0.20 < p \leq 0.30$	5
$0.30 < p \leq 0.40$	4
$0.40 < p \leq 0.50$	3
$0.50 < p \leq 0.60$	2
$0.60 < p$	1

without being displayed. The haptic device automatically saved the probing force as digital data. In the first step of training students practiced inserting the dental probe to the bottom of the periodontal pockets for five minutes. In the second step of training five measurements of periodontal pocket depth were made with no display of reaction force. After three repetitions of steps one and two, skill acquisition was evaluated by comparison of pre and post training results.

#### Statistical analysis

In the caries removal simulation, the mean±standard deviation of scoring results for first, second, and third training sessions were evaluated for significant difference using the two-way ANOVA followed by the Tukey-Kramer test, with  $p < 0.05$  and  $p < 0.01$  considered significant (SPSS Statistics 18, IBM-SPSS, Chicago, IL, USA).

In the periodontal pocket probing simulation, the mean probing force for five pocket depth measurements was calculated for each student, and the mean±standard deviation was calculated for all students as a group. These results were translated to a score from 1–5 as shown in Table 1. Scores were evaluated using the two-way ANOVA followed by the Tukey-Kramer test, with  $p < 0.05$  and  $p < 0.01$  considered significant.

## RESULTS

### Caries removal task

The scoring results of the first, second, and third training sessions for caries removal are shown in Fig. 5. The mean score after the first training session was 95.3. The mean score after the second training session was 98.9, significantly higher than the first training result. The

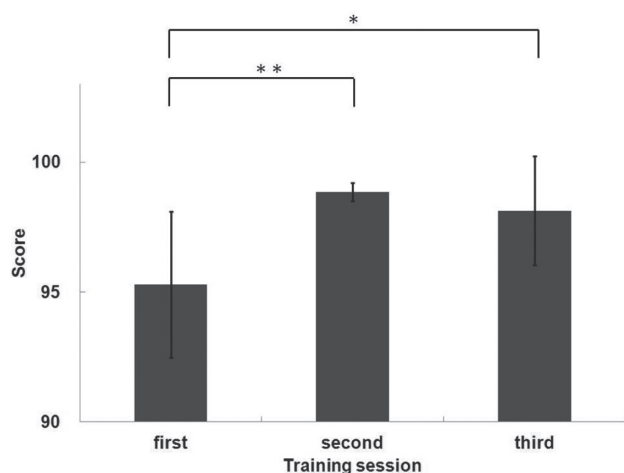


Fig. 5 Training results for the caries removal task. Mean scores of seven students are shown for the first, second, and third training sessions. The vertical bars indicate standard deviations. \* $p < 0.05$ , \*\* $p < 0.01$  Tukey-Kramer test.

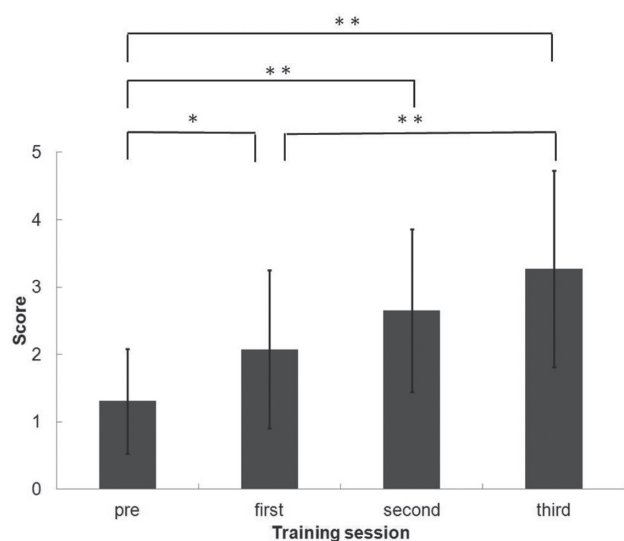


Fig. 6 Training results for the periodontal pocket probing task. Mean scores of 26 students are shown for pre-training and for first, second, and third training sessions. \* $p < 0.05$ , \*\* $p < 0.01$  Tukey-Kramer test.

mean score after the third training session was 98.1, also significantly higher than the first training result. However, there was no significant difference between the second and third session results.

### Periodontal pocket probing task

The results of mean probing force measurements during pre-training and for first, second, and third training sessions are shown in Fig. 6. The mean scores from the training sessions were significantly higher than the mean pre-training score. The mean score for first, second, and third training sessions was 2.1, 2.7, and 3.3, respectively. The mean was higher with increasing number of training sessions.

## DISCUSSION

Conventional haptic VR training simulators have been limited to teaching a single task: caries removal, cavity preparation<sup>26,27</sup>, or periodontal pocket probing<sup>23</sup>. Multiple training functions have not been available within a single simulator. One of the reasons for this limitation is the difficulty of modeling force, given the different requirements for operations such as cutting and probing. For example, in the case of a cutting simulation using a rapidly rotating diamond point, the model should take into account the force generated in the direction of rotation. However, such considerations are not necessary for simulated periodontal pocket probing. In this study, it was not necessary for all functions to be implemented in the haptic VR simulator. By creating a function to indirectly send information via parameters set using a human interface, for example “Available” or “Unavailable” for the cutting instruments, we developed a scalable system without the need for re-implementation when adding new tasks. As a result, we successfully used a single VR simulator for multiple training tasks without the requirements of complex force modeling found in conventional simulators.

Our results suggest that our haptic VR training simulator was an efficient tool to teach hand skills of caries removal. One reason for the success of this training may be the use of an adjustable virtual model that allowed us to accurately reproduce hardness differences between carious lesions and healthy tooth substance, as well as cutting sensations that replicated a clinical situation. The actual hardness of carious lesions is case-dependent and acquiring caries removal skills is not easy. Our haptic VR training simulator is adaptable to different learning levels by adjustment of the scoring parameters  $N_{thresh}$ ,  $T_{thresh}$ , and  $T_{ideal}$ . Despite the simulator's adjustability, the mean score in the first training session was over 95. However, the scoring criterion for cut volume measured only the volume of the cut region, and not the operator's cutting precision within the carious lesion. Because the fundamental goal of caries treatment is complete removal of the lesion without damage to healthy tissues, scores for excessive and insufficient cutting should be included in future training. Additionally, the current caries removal task



does not completely reproduce the clinical situation of using an electrical engine and hand instruments. In an effort to provide more realism we are developing additional tools with reproduction of accurate cutting properties and differences in cutting sensations.

Our VR training simulator was also efficient as a tool to teach periodontal pocket probing skills. In this task, the operator could easily feel the probing force generated by contact with the bottom of the periodontal pockets. Efficient and substantive training could be performed with real-time display of probing forces. Moreover, individual scores increased with each training session. Periodontal pocket probing is a difficult skill to acquire because dentists must measure pocket depth accurately without seeing the bottom of the pocket. If excessive probing force is applied damage to tissues and bleeding may result. Conversely, insufficient probing force results in inaccurate measurements because the tip of probe will not reach the bottom of the pocket. In mannequin-based training, learning to apply correct probing force is especially difficult because the bottom of periodontal pockets is not clearly reproduced. The ideal clinical probing force is 0.25 N<sup>28)</sup>. In this experiment, a score of 5 indicated correct probing force. The percentage of students demonstrating correct probing force in the first, second, and third training sessions was 0%, 3.8%, and 26.9%, respectively. These results suggest that repetitive training using a haptic VR training simulator is especially effective in teaching hand skills such as periodontal pocket probing, in which the sense of force is important. Thus, our haptic VR training simulator combined with a computerized tooth model displaying accurate tooth structure and material properties has the potential for expanded use in dental hand skills training. Finger actions of the operator in the VR situation are adjustable by calibrating the initial position, orientation, and scale of VR models in comparison with the actual situation. In addition, VR training involving the tissues surrounding the teeth will become available as models of soft tissue are developed. Furthermore, face models<sup>29)</sup> and stereoscopic viewing features are expected, which will improve realism and offer more practical uses.

## CONCLUSIONS

We evaluated the efficacy of our haptic VR simulator with repetitive training for caries removal and periodontal pocket probing tasks. Our simulator was effective at teaching hand skills for both tasks within short-term evaluation.

## ACKNOWLEDGMENTS

This study was supported by the Good Practice Project 2007 of the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT) and by Grants-in-Aid for Scientific Research No. 22360109 and 24592955 from the Japan Society for the Promotion of Science.

## REFERENCES

- 1) Chaudhry A, Sutton C, Wood J, Stone R, McCloy R. Learning rate for laparoscopic surgical skills on MIST VR, a virtual reality simulator: quality of human-computer interface. *Ann R Coll Surg Engl* 1999; 81: 281-286.
- 2) Colt HG, Crawford SW, Galbraith O 3rd. Virtual reality bronchoscopy simulation: a revolution in procedural training. *Chest* 2001; 120: 1333-1339.
- 3) Henn JS, Lemole GM Jr, Ferreira MA, Gonzalez LF, Schornak M, Preul MC, Spetzler R. Interactive stereoscopic virtual reality: a new tool for neurosurgical education. Technical note. *J Neurosurg* 2002; 96: 144-149.
- 4) Jordan JA, Gallagher AG, McGuigan J, McGlade K, McClure N. A comparison between randomly alternating imaging, normal laparoscopic imaging, and virtual reality training in laparoscopic psychomotor skill acquisition. *Am J Surg* 2000; 180: 208-211.
- 5) Ost D, DeRosiers A, Britt EJ, Fein AM, Lesser ML, Mehta AC. Assessment of a bronchoscopy simulator. *Am J Respir Crit Care Med* 2001; 164: 2248-2255.
- 6) Rycroft M, Houston A, Barker A, Dahlstron E, Lewis N, Maris N, Nelles D, Bagaoutdinov R, Bodrikov G, Borodin Y, Cheburkov M, Ivanov D, Karpunin P, Katargin R, Kiselyev A, Kotlayarevsky T, Schetinnikov A, Tylerov F. Training astronauts using three-dimensional visualisations of the International Space Station. *Acta Astronaut* 1999; 44: 303-306.
- 7) Salas E, Bowers CA, Rhodenizer L. It is not how much you have but how you use it: toward a rational use of simulation to support aviation training. *Int J Aviat Psychol* 1998; 8: 197-208.
- 8) Taffinder N, Sutton C, Fishwick RJ, McManus IC, Darzi A. Validation of virtual reality to teach and assess psychomotor skills in laparoscopic surgery: results from randomised controlled studies using the MIST VR laparoscopic simulator. *Stud Health Technol Inform* 1998; 50: 124-130.
- 9) Taylor JL, O'Hara R, Mumenthaler MS, Yesavage JA. Relationship of CogScreen-AE to flight simulator performance and pilot age. *Aviat Space Environ Med* 2000; 71: 373-380.
- 10) Tsai MD, Hsieh MS, Jou SB. Virtual reality orthopedic surgery simulator. *Comput Biol Med* 2001; 31: 333-351.
- 11) Tugby ML. Virtual reality flexible sigmoidoscopy simulator training: impact on resident performance. *J Am Board Fam Pract* 1998; 11: 426-433.
- 12) Green TG, Klausner LH. Clinic simulation and preclinical performance. *J Dent Educ* 1984; 48: 665-668.
- 13) Suvinen TI, Messer LB, Franco E. Clinical simulation in teaching preclinical dentistry. *Eur J Dent Educ* 1998; 2: 25-32.
- 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: 1151-1162.
- 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: 378-383.
- 16) Clancy JM, Lindquist TJ, Palik JF, Johnson LA. A comparison of student performance in a simulation clinic and a traditional laboratory environment: three-year results. *J Dent Educ* 2002; 66: 1331-1337.
- 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: 160-163.
- 18) Quinn F, Keogh P, McDonald A, Hussey D. A pilot 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: 13-19.
- 19) Thomas G, Johnson L, Dow S, Stanford C. The design and

- testing of a force feedback dental simulator. *Comput Methods Programs Biomed* 2001; 64: 53-64.
- 20) Suebnukarn S, Haddawy P, Rhienmora P, Gajananan K. Haptic virtual reality for skill acquisition in endodontics. *J Endod* 2010; 36: 53-55.
- 21) 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: 983-989.
- 22) Suebnukarn S, Phatthanasathiankul N, Sombatweroje S, Rhienmora P, Haddawy P. Process and outcome measures of expert/novice performance on a haptic virtual reality system. *J Dent* 2009; 37: 658-665.
- 23) 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: 1574-1582.
- 24) Yoshida Y, Yamaguchi S, Kawamoto Y, Noborio H, Murakami S, Sohmura T. Development of a multi-layered virtual tooth model for the haptic dental training system. *Dent Mater J* 2011; 30: 1-6.
- 25) Santis R, Ambrosio L, Nicolais L. Mechanical properties of tooth structures. *Integrated Biomaterials Science* 2002; 589-599.
- 26) Yau HT, Hsu CY. Development of a dental training system based on point-based models. *Computer-Aided Design and Applications* 2006; 3: 779-787.
- 27) Kim L, Park SH. Haptic interaction and volume modeling techniques for realistic dental simulation. *Visual Comput* 2006; 22: 90-98.
- 28) Lang NP, Nyman S, Senn C, Joss A. Bleeding on probing as it relates to probing pressure and gingival health. *J Clin Periodontol* 1991; 18: 257-261.
- 29) Yamaguchi S, Yamada Y, Yoshida Y, Noborio H, Imazato S. Development of three-dimensional patient face model that enables real-time collision detection and cutting operation for a dental simulator. *Dent Mater J* 2012; 31: 1047-1053.