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The use of cone-beam computed tomography and virtual reality simulation for pre-surgical practice in endodontic microsurgery

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Abstract

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Aim To design and evaluate the impact of virtual reality (VR) pre-surgical practice on the performance of actual endodontic microsurgery.

Methodology The VR system operates on a laptop with a 1.6-GHz Intel processor and 2 GB of main memory. Volumetric cone-beam computed tomography (CBCT) data were acquired from a fresh cadaveric porcine mandible prior to endodontic microsurgery. Ten inexperienced endodontic trainees were randomized as to whether they performed endodontic microsurgery with or without virtual pre-surgical practice. The VR simulator has microinstruments to perform surgical procedures under magnification. After the initial endodontic microsurgery, all participants served as their own controls by performing another procedure with or without virtual pre-surgical practice. All procedures were videotaped and assessed by two independent observers using an endodontic competency rating scale (from 6 to 30).

Results A significant difference was observed between the scores for endodontic microsurgery on molar teeth completed with virtual pre-surgical practice and those completed without virtual presurgical practice, median 24.5 (range = 17–28) versus median 18.75 (range = 14–26.5), $P = 0.041$. A significant difference was observed between the scores for osteotomy on a molar tooth completed with virtual pre-surgical practice and those completed without virtual pre-surgical practice, median 4.5 (range = 3.5–4.5) versus median 3 (range = 2–4), $P = 0.042$.

Conclusions Pre-surgical practice in a virtual environment using the 3D computerized model generated from the original CBCT image data improved endodontic microsurgery performance.

Keywords: cone-beam computed tomography, endodontics, microsurgery, virtual reality.

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Introduction

The benefits of three-dimensional cone-beam computed tomography (CBCT) imaging are already well established in dentistry. The greatest advantages of this technology have been in providing additional information for diagnosis and enabling more predictable management of complex endodontic problems compared with using intraoral radiographs alone (D'Addazio *et al.* 2011, Faitaroni *et al.* 2011). Virtual simulation is attractive in the field of surgery because it avoids the use of patients for skill development and ensures that trainees have some practice before treating patients (Sutherland *et al.* 2006). The applications of CBCT enhanced by computer-assisted surgery encompass a wide range in oral and maxillofacial operations including computer-assisted planning in

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dental implantology, surgical guiding drill aided by the patient model generated from the original image data and intraoperative instrument navigation using image data of the patient, which corresponds to the actual position of the instrument (Bell 2010).

In cases of endodontic failure following primary root canal treatment and nonsurgical retreatment, clinicians frequently face the dilemma of whether to undertake endodontic surgery of a questionable tooth or to extract and replace it with a dental implant (Zitzmann *et al.* 2009). With the advent of modern endodontic surgical concepts and practice, those teeth can be preserved utilizing endodontic microsurgery that combines the magnification and illumination provided by the microscope with the proper use of microinstruments (Kim & Kratchman 2006). However, endodontic surgery is perceived as difficult because the surgeon must often approximate the location of anatomical structures as well as locate, clean and fill all the complex canal apical ramifications.

Surgery is a skill-driven discipline. Other high-stake professions with comparable cognitive and psychomotor skill requirements often use warm-up exercises for achieving better proficiency. However, surgical warm-up would not be possible on the actual patient, but the increased availability of CBCT and virtual environments (Suebnukarn *et al.* 2009) makes this a realistic opportunity in endodontic microsurgery. This study aims to determine whether pre-surgical practice in a virtual environment using the 3D computerized model generated from the original CBCT image data improves the performance of actual endodontic microsurgery. All surgical procedures and CBCT imaging were performed in fresh cadaveric porcine mandibles.

Materials and methods

Virtual reality simulation

The virtual reality (VR) operates on a laptop with 1.6-GHz Intel processor and 2 GB of main memory. Two Omni haptic devices (SensAble Inc., Woburn, MA, USA) were used, which allowed six degrees of freedom for positional sensing and generated three degrees of freedom for force feedback with a maximum of 3.3 *N*. Volumetric anatomical data were acquired from a fresh cadaveric porcine mandible prior to the endodontic microsurgery. The data were obtained from an i-CAT CBCT (Imaging Sciences International, Hatfield, PA, USA) scan of the whole mandible.

During the pre-processing step, volumetric anatomical data (voxel density values) were loaded into PolyVox's Block Volume called an occupancy map/3D grid array, and the tool models were volumetrically sampled (Fig. 1). In each interactive haptic time step, each volume sample point in the tool was checked for intersection with the tooth volume. A surgical tool had six degrees of freedom and moved relative to the position and orientation of a haptic stylus. To simulate bone and tooth cutting and provide force feedback to the operator's hand, the number of volumetric sample points of the tool model immersed into bone or tooth voxels was detected (Fig. 2). The immersed sample points indicated the depth penetrated (Tsai *et al.* 2007). The force feedback whilst cutting the tooth varied depending on the density values of various tissues. The operator thus received different force feedback when cutting through compact bone, cancellous bone, enamel, dentine and pulp.

Participants and study design

Ten junior endodontic postgraduate trainees with limited surgical experience (performed one to two endodontic microsurgical procedures in patients) were recruited. Informed consent was provided upon recruitment to the study. A randomized crossover design was used (Fig. 3). All participants attended a virtual preoperative surgical training seminar. The participants received a verbal explanation and demonstration about the use of the system from the investigators and familiarized themselves with the system interface for

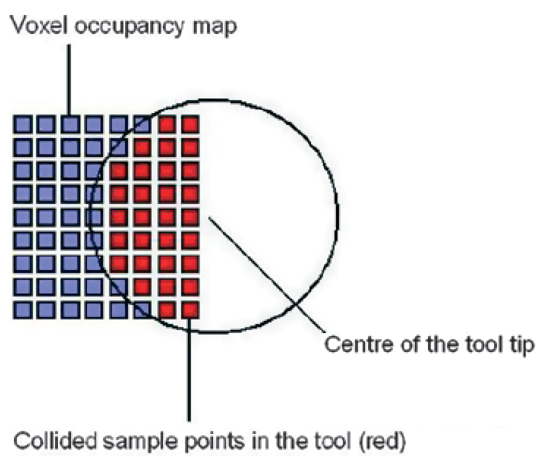

Figure 1 Volumetric sample points of a tool collide with a tooth model represented by an occupancy map.

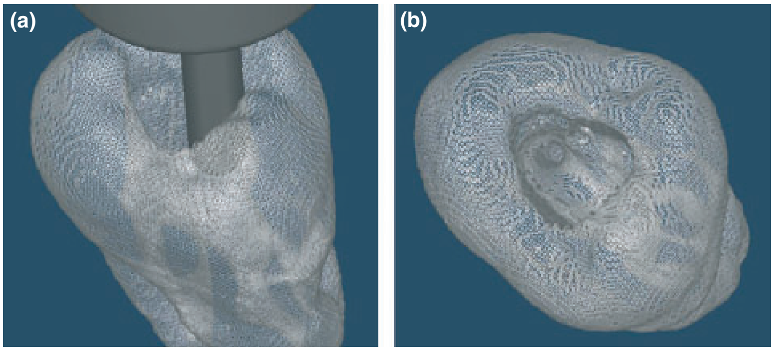

Figure 2 Tooth cutting (a) and the result from haptic rendering (b) shown in the wireframe representation.

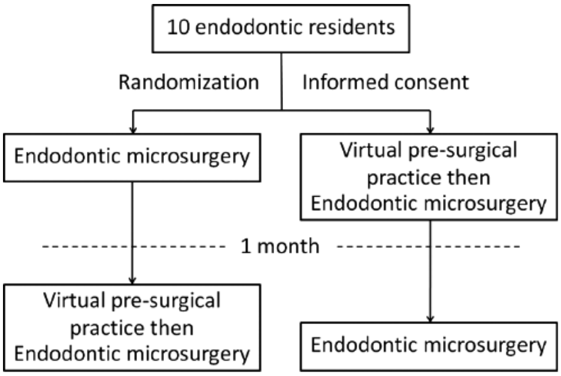

Figure 3 Study design.

30 min. During this familiarization period, the participants were allowed to ask questions and receive further explanation and suggestions from the investigators. After completion of the preliminary training, half of these participants (n = 5) performed virtual pre-surgical practice using the haptic devices and 3D computerized model generated from the CBCT image data of a fresh cadaveric porcine mandible before their first endodontic microsurgery on the mesiobuccal root of mandibular premolar and molar teeth, followed by a second endodontic microsurgery with no virtual pre-surgical practice. The other five participants performed their first endodontic microsurgery without virtual pre-surgical practice, followed by a second endodontic microsurgery with virtual pre-surgical practice. In this way, each participant served as their own individual control. Participants were randomized using the closed envelope technique; that is, participants were given random allocations within closed opaque envelopes as to whether they performed their first endodontic microsurgery with or without virtual pre-surgical practice (washout period = 1 month).

Virtual pre-surgical practice

The VR simulator has microinstruments to perform three procedure steps (osteotomy, root end resection and root end preparation) using up to 26 × magnification (Fig. 4a–d).

This virtual pre-surgical practice was conducted before the actual microsurgical procedure and lasted approximately 15 min.

Endodontic microsurgery on fresh cadaveric porcine

The surgery performed by the participants on the mesiobuccal root of a mandibular premolar and molar of fresh cadaveric porcine was conducted using endodontic microsurgery instruments and an operating microscope (OPMI Pico; Carl Zeiss, Jena, Germany). The case was classified as class A representing the absence of a periapical lesion, no mobility and normal pocket depth (Kim & Kratchman 2006). The procedure itself was video-recorded and blindly assessed by two experienced endodontists using an endodontic surgical competency rating scale modified from an objective structured assessment of technical skills (OSATS). The OSATS formally assesses discrete segments of surgical tasks using bench model simulations and demonstrates high reliability and construct validity, suggesting it can measure effectively the technical ability of trainees using bench model simulations. This consists of six items (Table 1) that are scored on a 5-point Likert scale, with one indicating poor performance and five representing excellent performance (Reznick *et al.* 1997).

Data analysis

Data were analysed using SPSS version 16.0 (Chicago, IL, USA). The primary outcome measure was the

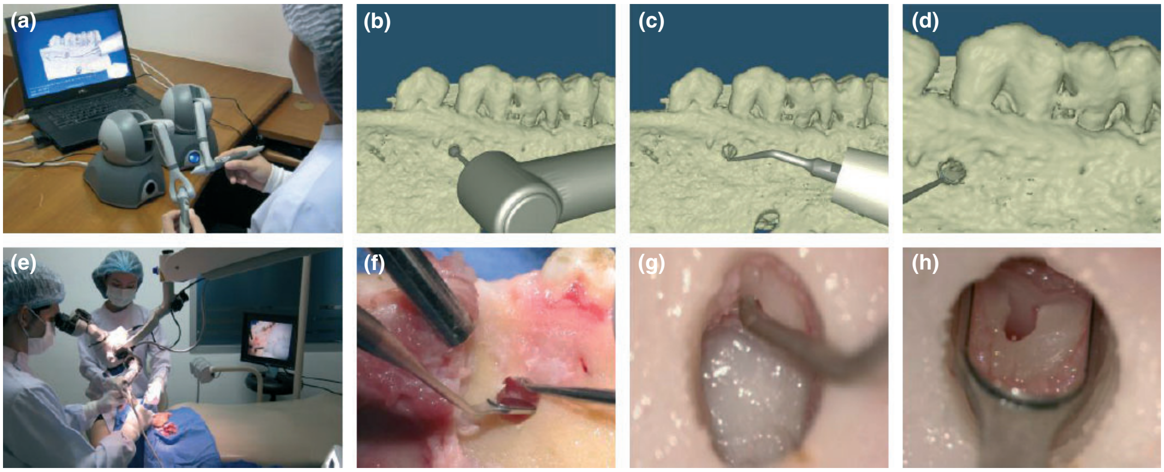

Figure 4 Virtual pre-surgical practice using haptic devices and 3D computerized model generated from the CBCT image data of a fresh cadaveric porcine (a–d) and actual endodontic microsurgery (e–h).

Table 1 Endodontic microsurgery performance scores with and without prior virtual pre-surgical practice

	Premolar			Molar		
	No pre-surgical practice	Pre-surgical practice		No pre-surgical practice	Pre-surgical practice	
Assessment items	Median (Range)	Median (Range)	*P*	Median (Range)	Median (Range)	*P*
Soft tissue handle	4.25 (3–4.5)	4 (2–4.5)	0.46	4.25 (3–4.5)	4 (2–4.5)	0.46
Osteotomy	3 (2–4)	4.25 (3–4.5)	0.061	3 (2–4)	4.5 (3.5–4.5)	0.042
Root end resection	3 (1.5–4.5)	4 (2–4.5)	0.36	3 (2.5–4.5)	4.25 (2–5)	0.242
Root end preparation	3 (2.5–4.5)	3.5 (3–5)	0.419	3 (2.5–4)	4.25 (3.5–4.5)	0.056
Root end filling	3 (2–4)	3.5 (3–5)	0.421	3 (2.5–4.5)	3.5 (3–5)	0.419
Flow of operation	2.75 (1.5–5)	4 (2.5–4.5)	0.268	2.75 (1.5–5)	4 (2.5–4.5)	0.268
Total score	19 (12.5–26.5)	23.25 (15.5–28)	0.059	18.75 (14–26.5)	24.5 (17–28)	0.041

quality of performance, assessed using the endodontic surgical competency rating scale. Cronbach's alpha test statistic was used to ensure reliability of the video-based assessment scores between the two expert endodontists. The nonparametric Wilcoxon's significance test was used to analyse any differences in the performance of endodontic microsurgery conducted with prior virtual pre-surgical practice and endodontic microsurgery conducted without virtual pre-surgical practice. A value of $P < 0.05$ was considered statistically significant.

Results

Ten participants (six women and four men) aged between 25 and 30 years were recruited. The reliability of the video-based assessment was excellent with an alpha value of 0.91. Using an endodontic surgical competency rating scale modified from the OSATS, a significant difference was observed between the scores for endodontic microsurgery on molar teeth completed with virtual pre-surgical practice and those completed without virtual pre-surgical practice, median 24.5 (range = 17–28) versus median 18.75 (range = 14–26.5), $P = 0.041$ (Table 1). The breakdown of the differences observed between the two groups on premolar and molar teeth for each assessment item can be seen in Table 1. A significant difference was observed between the scores for osteotomy on the molar tooth completed with virtual pre-surgical practice and those completed without virtual pre-surgical practice, median 4.5 (range = 3.5–4.5) versus median 3 (range = 2–4), $P = 0.042$.

Discussion

One of the most important developments in endodontic surgery has been the advent of the microscope, microinstruments and endodontic microsurgery. Accordingly, developing the necessary technical expertise for endodontic microsurgery is an essential component of training. Although endodontic microsurgery can provide distinct advantages for the patient (Setzer *et al.* 2010), one concern has been whether endodontic microsurgical techniques should be learned solely in the clinic. It is unfortunate that, unlike medical surgery, attempts have not been made in providing several types of simulations for pre-surgical training and rehearsal (Crochet *et al.* 2011).

The present study was conceived as a pilot trial to examine the potential value of a VR simulation in improving endodontic residents with surgical proficiency. Clearly, pre-surgical practice in a virtual environment using the 3D computerized model generated from the original CBCT image data improved the actual endodontic microsurgery performance, especially in the molar area of fresh cadaveric pigs. A previous study of laparoscopy has shown that VR warm-up improved performance in this procedure (Calatayud *et al.* 2010).

The advent of CBCT has made it possible to visualize the relationship of anatomical structures in three-dimensions. The decision to order a CBCT scan must be based on the patient's history and clinical examination and justified on an individual basis by demonstrating that the benefits to the patient outweigh the potential risks of exposure to X-rays (American Association of Endodontists, American Academy of Oral and Maxillofacial Radiology 2011). In this study, cadaveric porcine teeth with no apical lesions were used for the endodontic microsurgery. This made it difficult for the participants to locate the root and the root canals. At this point, CBCT and VR technology provided multimodality images and VR instruments in guiding pre-surgical practice. Although simulation-based training may require an initial investment in terms of software, costs must be balanced against that of traditional training. With this in mind, VR trainers are becoming an attractive option as they require little running cost, once bought are always available for use and allow for repeatable skills training. A limitation of this study was the small sample size. However, a significant difference was demonstrated between virtual pre-surgical practice and no virtual pre-surgical practice. These results are also limited by specificity to porcine teeth with no apical lesion. The extent to which this finding can be generalized to other cases and procedures is unknown. From a patient safety perspective, by improving performance in the clinic, further studies should look at the potential pre-surgical practice to improve patient outcome.

Conclusion

Under the condition of this trial, pre-surgical practice in a virtual environment using the 3D computerized model generated from the original CBCT image data improved the actual endodontic microsurgery performance. This may lead to an increased uptake of such training by embedding pre-surgical practice into the day-to-day working environment of an endodontic microsurgery unit, thus potentially leading to greatly improved safety and quality of care for patients.

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