Virtual Endodontics: Three-Dimensional Tooth Volume Representations and their Pulp Cavity Access

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The purpose of this study was the application of both digital three-dimensional image processing and virtual reality techniques in endodontics. Three-dimensional volume representations of 2 teeth from each tooth category, 16 teeth in total, have been reconstructed. All teeth were embedded in polyester resin, and serial cross-sections 0.75-mm thick were taken from each tooth by using a special microtome. Each section was studied under a stereoscopic microscope, and its microscopic image was directly digitized using a video-camera. The surfaces of hard dental tissues were segmented from each section. Semiautomatic alignment and frame interpolation were performed on the sequence of tooth sections by using appropriate digital image processing techniques. Three-dimensional volume representations from each tooth were achieved in this project to produce the final three-dimensional teeth models, on which virtual accesses of pulp cavities have been performed. Three-dimensional teeth volume representations and virtual tooth “drilling” could serve as perfect educational tools under certain circumstances.

There is a great variety of tooth malformations, or dental anomalies in general, in number, size, and form of teeth. Thus, the study of internal and external tooth morphology becomes of great interest, especially for an endodontist. Many different methods have been used for the study of the tooth morphology. These methods include casts preparation of the root canals with Wood’s metal (1), celluloid (2), polyester resin (3), decalcification of the teeth and dye injection (4), sectioning of extracted teeth (5), and roentgenographic studies (6). All these methods have unavoidable pitfalls, and many difficulties can be encountered during their application.

The method of three-dimensional surface representation was also used, combining histological evaluation with computer graphic technologies (7–9). The main advantage of this method was that one could study in detail the internal anatomy of the teeth from different view angles.

This paper presents a new method for the study of tooth morphology based on three-dimensional, computer-aided volume reconstruction. By using computer methods, three-dimensional volume representations of 2 teeth from each tooth category, 16 teeth in total, were made. On these volume reconstructions, virtual access of their pulp cavities was achieved.

MATERIALS AND METHODS

Two teeth from each tooth category were used in this study—16 teeth in total. All these teeth were put in 3% NaOCl solution after their extraction and were washed under running water and air-dried. They were then embedded in a two-phase polyester resin, and serial cross-sections were taken from each tooth by using a special microtome (Isomet, Buehler, Lake Bluff, IL). The thickness of each section was 0.75 mm. Each section was studied under a stereoscopic microscope (Stemy SV8, Zeiss, Germany), and its microscopic image was directly digitized by using a video-camera. The surfaces of hard dental tissues (enamel, cementum, dentine) were segmented from each section. Semiautomatic alignment and frame interpolation were performed on the sequence of each tooth sections by using appropriate digital image processing techniques. Three-dimensional volume representations were achieved to produce the final three-dimensional teeth models, on which virtual accesses of their pulp cavities were performed. The three-dimensional tooth models can be rotated in any direction in space.

Virtual dental bur simulators were created to achieve the pulp chamber virtual accesses. The user can produce a new, spherical, cylindrical, or cylinder-conical bur tool with determination of its shape parameters. Alternatively, one can select a virtual bur tool shape from the ones already available commercially. The shape and the size of the virtual burs were arranged according to the real commercial dental burs that are available from Maillefer (Dentsply-Maillefer, Ballaigues, Switzerland). The bur tool was then applied to the appropriate point of the three-dimensional tooth model by clicking on it with the mouse. Using this procedure, a hole having the shape of the bur tool was created in the three-dimensional tooth model and displayed on screen. The virtual tooth...
“drilling” is implemented as a series of successive morphological erosions of the three-dimensional tooth volume. The mouse position and move determines the drilling position and direction. The procedure is very fast and gives the visual impression of a real tooth drilling on screen. During the progress of the procedure of the virtual tooth drilling, a red sign appears and an acoustic signal sound at the time the bur reaches the pulp cavity.

If a user (i.e. an inexperienced student) makes an error (e.g. pulp cavity penetration), he can undo his last drilling steps and continue in the right direction. This is impossible when drilling on real teeth phantoms and has significant educational value. Furthermore, the user can undo part of his work and continue with a different drilling approach or can store a partial virtual drilling job and continue another time.

All the above procedures (surface extraction, alignment, interpolation, three-dimensional volume representation, and virtual tooth drilling) were performed by using EIKONA3D (Alpha Tec Ltd., Thessaloniki, Greece), a digital three-dimensional image processing package developed for Microsoft Windows (10). This software has a special module for virtual tooth drilling (11).

RESULTS

Three-dimensional volume reconstruction was achieved for each tooth from each tooth category. Some results are shown in Figs. 1–4. Figures 1–3 show the three-dimensional volume representation of three maxillary teeth either from a lingual view (Fig. 1A), palatal-incisal view (Fig. 2A), or distal angle (Fig. 3A). In Fig. 4, the three-dimensional volume reconstructions of a mandibular tooth from different view angles is shown.

After that, a suitable bur was created (Fig. 5) and a virtual access of the pulp cavity was achieved for each tooth. On these images (Figs. 1 to 4) one can observe in detail the entrances of the root canals of each tooth from different view points. This is a very helpful and interesting ability, especially for the study of the upper and lower molars. The computer software allows the user to select the bur he wishes to work with, either a spherical, cylindrical, or cylinder-conical shape. A drilling tool used for a pulp chamber accessing can be seen in Fig. 5. Also, the user can view and save the whole procedure during the virtual preparation through a frame gallery, on which the virtual access of the pulp cavity is depicted in detail (Fig. 6). Sample volumes of virtual teeth (original and drilled ones) can be found in reference number 11.

DISCUSSION

A number of articles have been published on the application of the virtual reality technology in orthodontics (12, 13), restorative dentistry (14), orthognathic surgery (15), and implantology (16, 17), with very encouraging results. This is the first effort to apply the virtual reality technology in endodontics.

One of the advantages of the method is that the external anatomy of the tooth can be observed from different view angles and...
each stage of accessing the pulp chamber can be followed. This makes the method a very interesting educational tool. It is quite remarkable that the computer program used in this study gives the opportunity to the user to see each step of the tooth drilling and accessing the pulp cavity. The few problems that have become obvious are focused mainly on the method used to take the tooth sections. Unavoidably, some sections are deformed or destroyed and that makes more difficult the achievement of the exact volume representation of the tooth. Nevertheless, the results are satisfactory.

The virtual technique that was developed may eventually become a valuable tool for students, undergraduate and postgraduate, as well as for clinicians who desire to study in detail the first step of an endodontic therapy. It is known that the right pulp cavity access of a tooth can contribute highly to a good endodontic therapy. Problems that have been established during virtual drilling had to do with the lack of certain real senses. During the virtual pulp cavity access, the characteristic sense of fall that you feel during the real pulp cavity accessing or the hemorrhage in case of a pulpitis are lost, which makes the whole session more difficult. Nevertheless, the red sign that appears and the acoustic signal that sounds when the virtual bur reaches the pulp cavity are helpful.

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