

Virtual Endodontics: Three-Dimensional teeth volume representations and their pulp cavity access

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ABSTRACT

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 two teeth from each tooth category, sixteen teeth in total, have been reconstructed. All these teeth were embedded in polyester resin and serial cross sections 0.75mm 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, using appropriate digital image processing techniques. Three-dimensional volume representations from each tooth were achieved in this project in order to produce the final 3D teeth models, on which virtual accesses of pulp cavities have been performed. 3D 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 of dental anomalies in general, in number, size and form of the teeth. Under this perspective, the study of internal and external tooth morphology, becomes of great interest, especially for an endodontist. Many different methods have been used until today for the study of the tooth morphology. These methods include casts preparation of the root canals with Wood's metal (1), celluloid (2) or 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 graphics technologies (7, 8, 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 the tooth morphology, based on three-dimensional computer-aided volume reconstruction. By using computer methods, we succeeded to present three-dimensional volume representations of two teeth from each tooth category, 16 teeth in total. 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, sixteen teeth in total. All these teeth were put in 3% NaOCl solution after their extraction and were washed under running water and were 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 Ltd., Lake Bluff, Illinois, U.S.A.). 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 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 in this project in order to produce the final three-dimensional teeth models, on which virtual accesses of their pulp cavities have been performed. The three-dimensional tooth models can be rotated in any direction in the space.

Virtual dental bur simulators were created, in order 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 by Maillefer (Dentsply-Maillefer, Ballaigues, Switzerland). The bur tool was then applied on 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 on 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.

In case a user (i.e. an inexperienced student) makes an error (e.g. pulp cavity penetration), he can undo his last “drilling” steps and continue to the right direction. This is impossible when “drilling” is followed 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, surfaces 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

Through our developed programme, three-dimensional volume reconstruction was achieved for each tooth from each tooth category. All these results are shown on Fig. 1a-11a. Regarding Fig. 1a to 6a, images show the three-dimensional volume representation of six teeth of maxilla, either from lingual view (Fig. 1a), palatal-incisal view (Fig. 2a), distal angle (Fig. 3a, 5a, 6a) and mesial view (Fig. 4a). Continuing, on Fig. 7a to 11a, the three-dimensional volume reconstructions of five mandibular teeth from different view angles is shown.

After that, a suitable bur was created (Fig. 13) and a virtual access of the pulp cavity was achieved for each tooth volume (Fig. 1b-11b). On these images 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 (Fig. 5-6 [b, c, d], 10-11 [b, c, d]). The computer software gives the ability to the user to select the bur tool 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 on Fig. 13. More than that, 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 12). Sample volumes of virtual teeth (original and “drilled” ones) can be found in (11).

DISCUSSION

A number of articles have been published on application of the virtual reality technology in orthodontics (12, 13), restorative dentistry (14), orthognathic surgery (15), 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 as well as that 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 programme used in this study gives the opportunity to the user to see each step of the tooth “drilling” and accessing its pulp cavity. The few problems that have become obvious are focused mainly on the method used in order 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 could be 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 haemorrhage in case of a pulpitis are loosen, and that 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 very helpful.

Furthermore, if an inexperienced user makes an error during the procedure of the virtual tooth “drilling”, he can undo his last “drilling” steps and continue to the right direction. This is impossible during the real teeth preparation for endodontic therapy and has significant educational value.

In conclusion, this new method has been proved to be very interesting as an application of the new computer technologies in dentistry and composes the first attempt to use virtual reality in endodontics. It seems to be a very promising tool in the future.

Acknowledgements

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Legends

FIG. 1 (a.) Three-dimensional volume representation of a central maxillary incisor. Lingual view. **(b.)** Virtual access of the pulp cavity of the same tooth.

FIG. 2 (a.) Three-dimensional volume representation of a maxillary canine. Palatal-incisal view. **(b.)** Virtual access of the pulp cavity of the same tooth.

FIG. 3 (a.) Three-dimensional volume representation of a maxillary first premolar. Distal-incisal view. **(b.)** Virtual access of the pulp cavity of the same tooth. The two root canals' entrances are seen.

FIG. 4 (a.) Three-dimensional volume representation of a maxillary second premolar. Mesial view. **(b.)** Virtual access of the pulp cavity of the same tooth.

FIG. 5 (a.) Three-dimensional volume representation of a maxillary first molar. Distal-buccal view of the tooth. Virtual access of the pulp cavity. The entrances of the mesial-buccal **(b.)**, the distal-buccal **(c.)** and the palatal **(d.)** root canals.

FIG. 6 (a.) Three-dimensional volume representation of a maxillary second molar. **(b.)** Virtual access of the pulp cavity. The entrances of the mesial and distal-buccal **(c.)** and the palatal **(d.)** root canals are seen.

FIG. 7 (a.) Three-dimensional volume representation of a mandibular central incisor. **(b.)** Virtual access of the pulp cavity of the same tooth.

FIG. 8 (a.) Three-dimensional volume representation of a mandibular canine. **(b.)** Virtual access of the pulp cavity of the same tooth.

FIG. 9 (a.) Three-dimensional volume representation of a mandibular first premolar. Mesial view of the tooth. **(b.)** Virtual access of the pulp cavity.

FIG. 10 (a.) Three-dimensional volume representation of a mandibular first molar. **(b.)** Virtual access of the pulp cavity. View of the distal **(c.)** and the mesial **(d.)** root canals' entrances.

FIG. 11 (a.) Three-dimensional volume representation of a mandibular second molar. **(b.)** Virtual access of the pulp cavity. View of the mesial **(c.)** and the distal **(d.)** root canals' entrances.

FIG. 12 Frame gallery of the virtual access of the pulp cavity of the tooth shown on Fig. 1.

FIG. 13 View of the computer screen, where one can see a tooth section, the result of the virtual access of a pulp cavity, as well as the possibilities that are available in this program for a spherical, cylindrical or conical tooth bur, in order to achieve a virtual access of the pulp cavity.

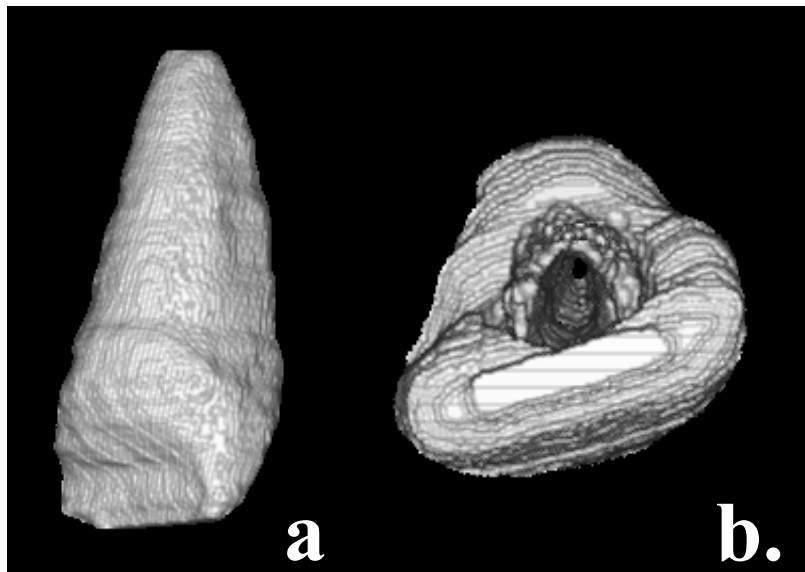


FIGURE 1

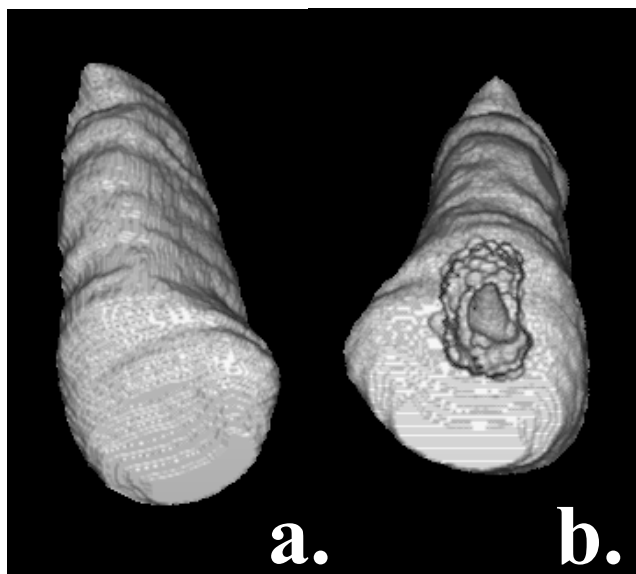


FIGURE 2

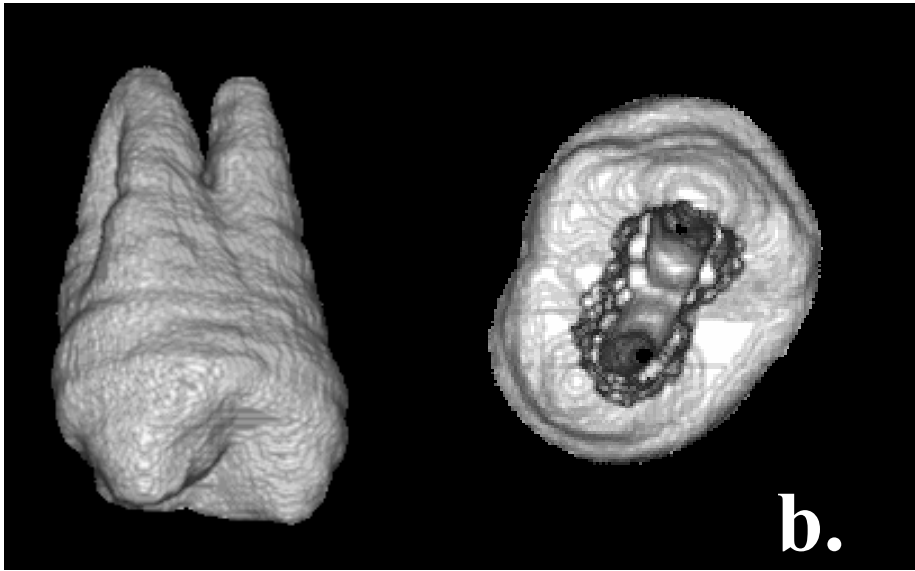


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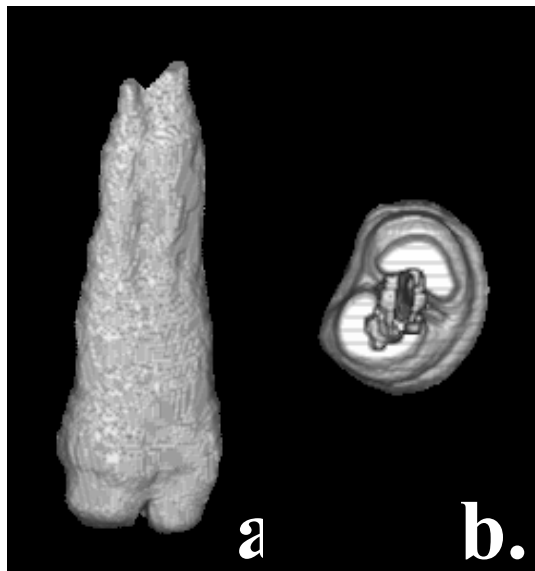


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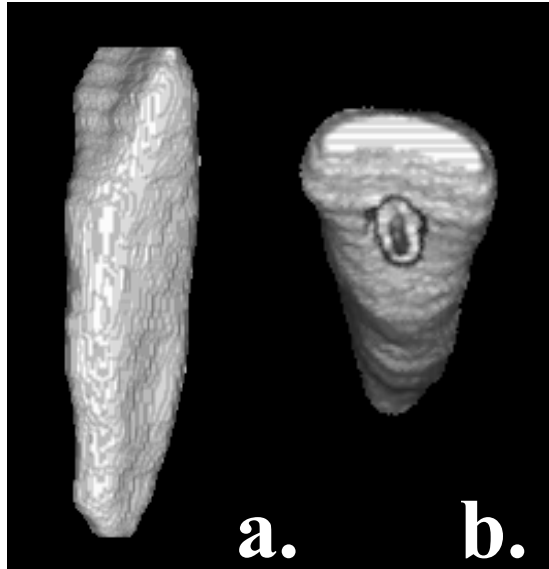


FIGURE 7

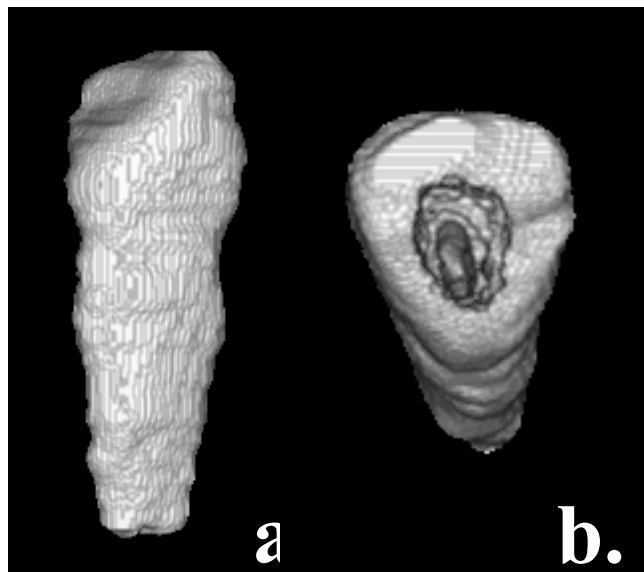


FIGURE 8

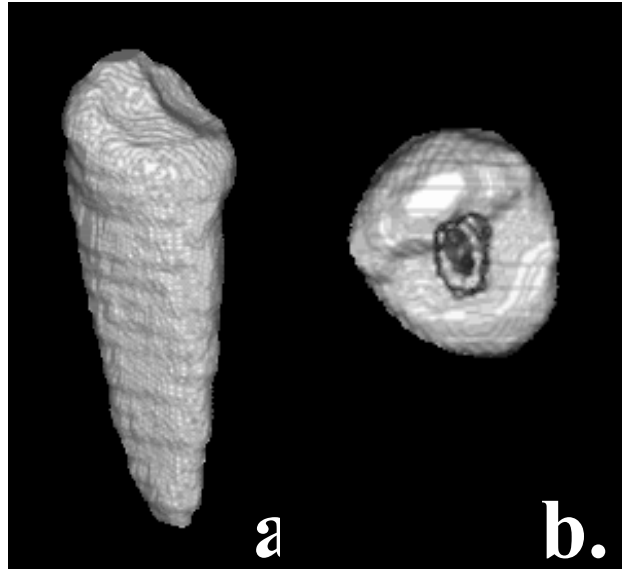


FIGURE 9

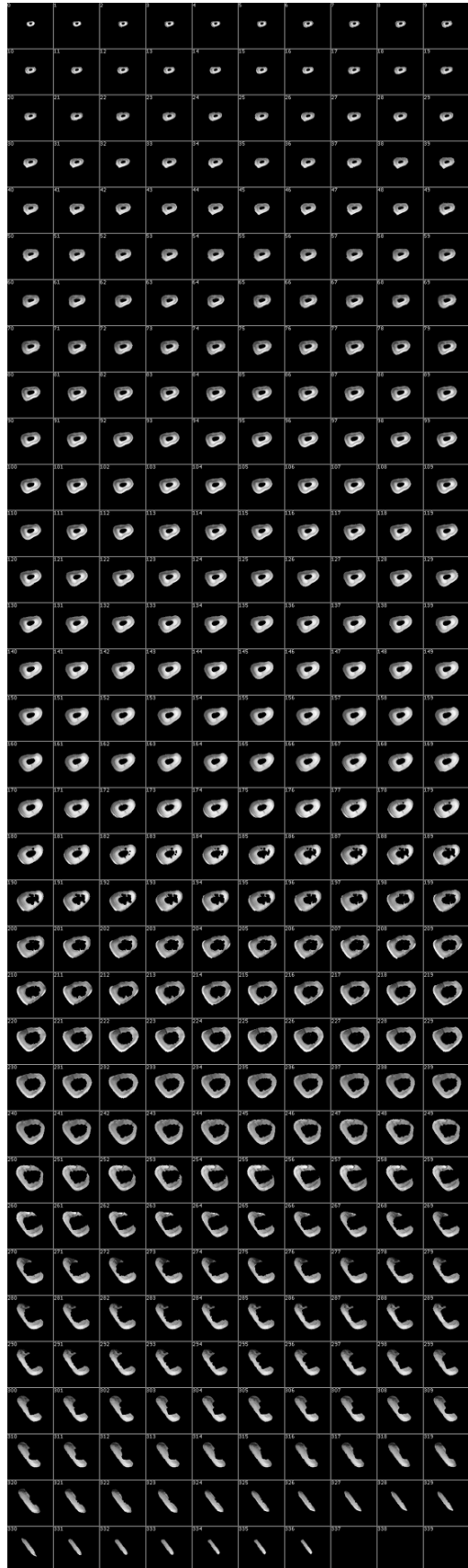


FIGURE 12

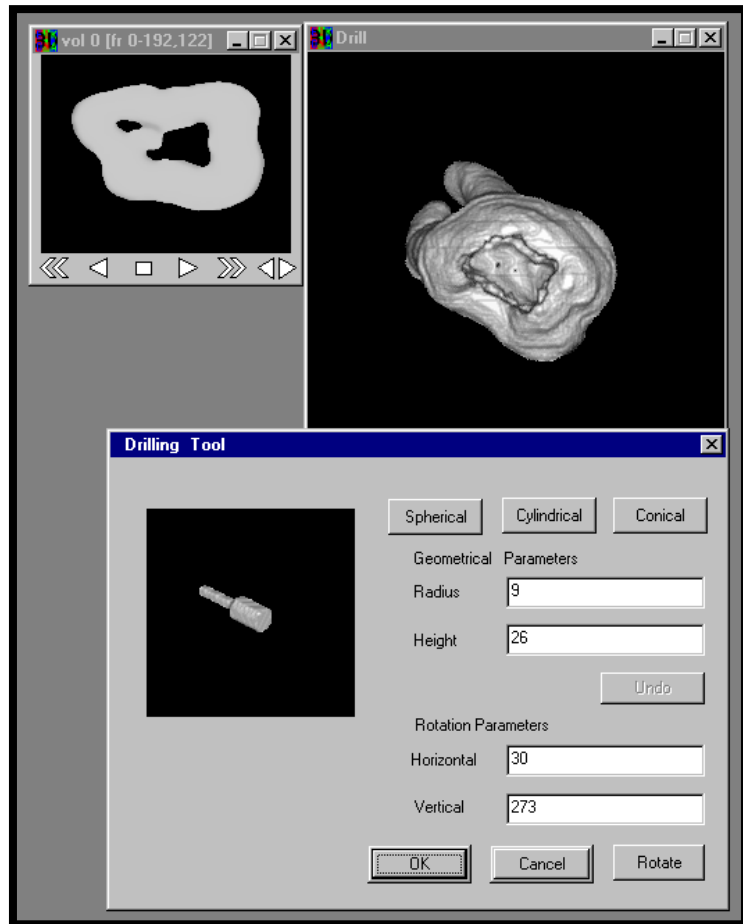


FIGURE 13

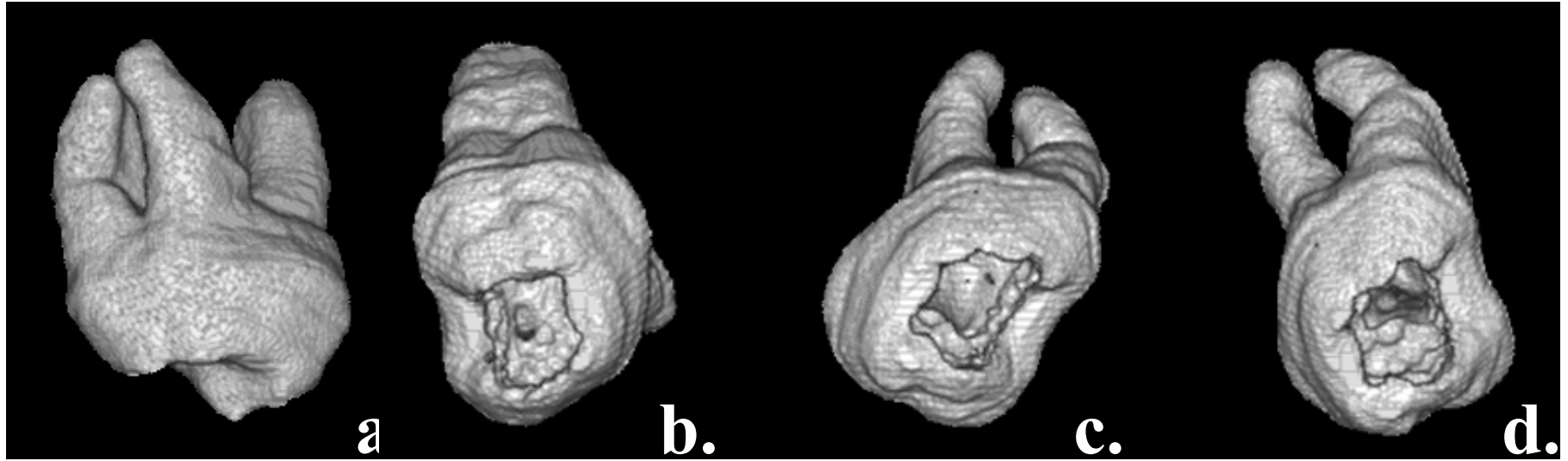


FIGURE 5

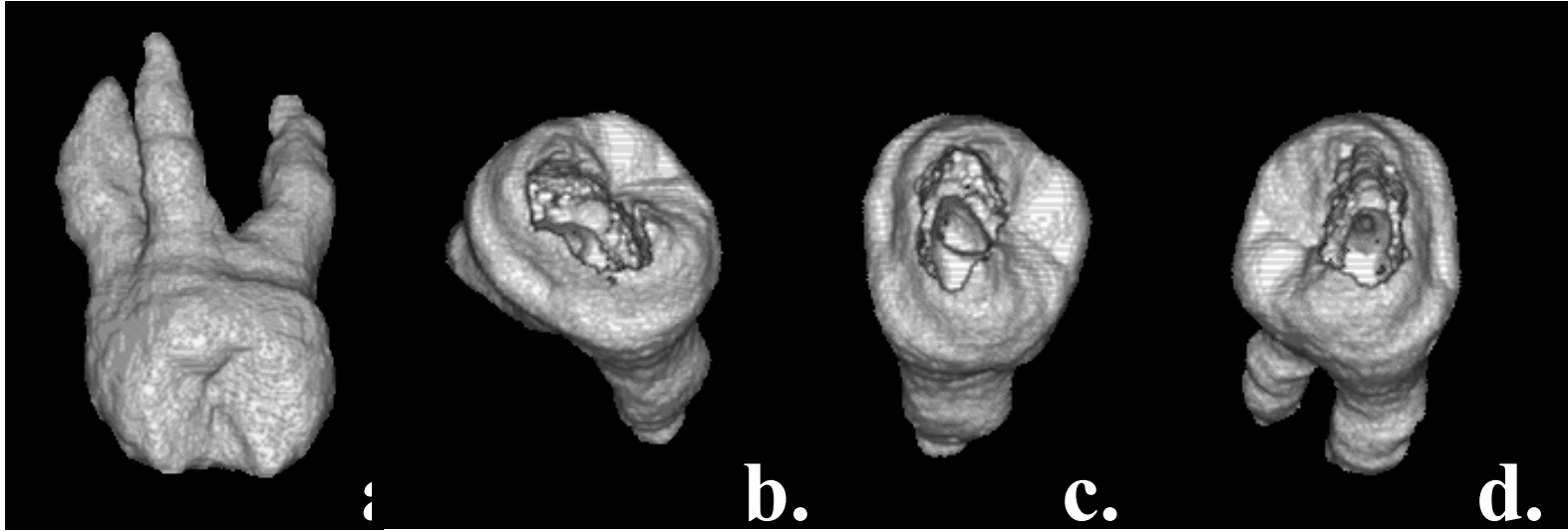


FIGURE 6

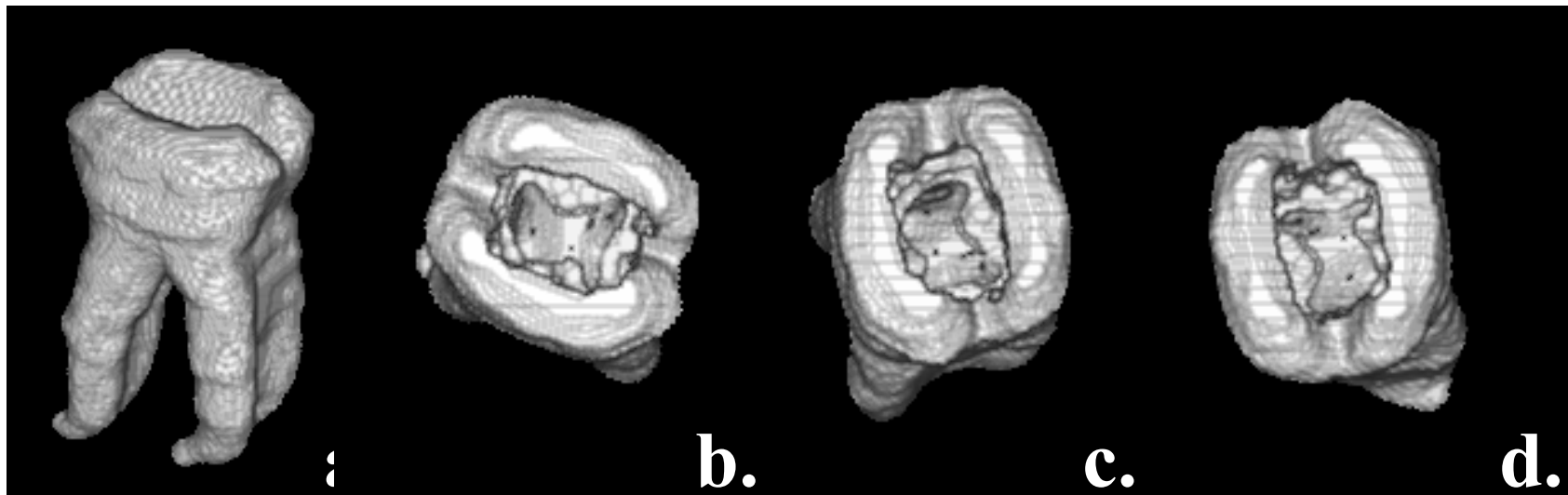


FIGURE 10

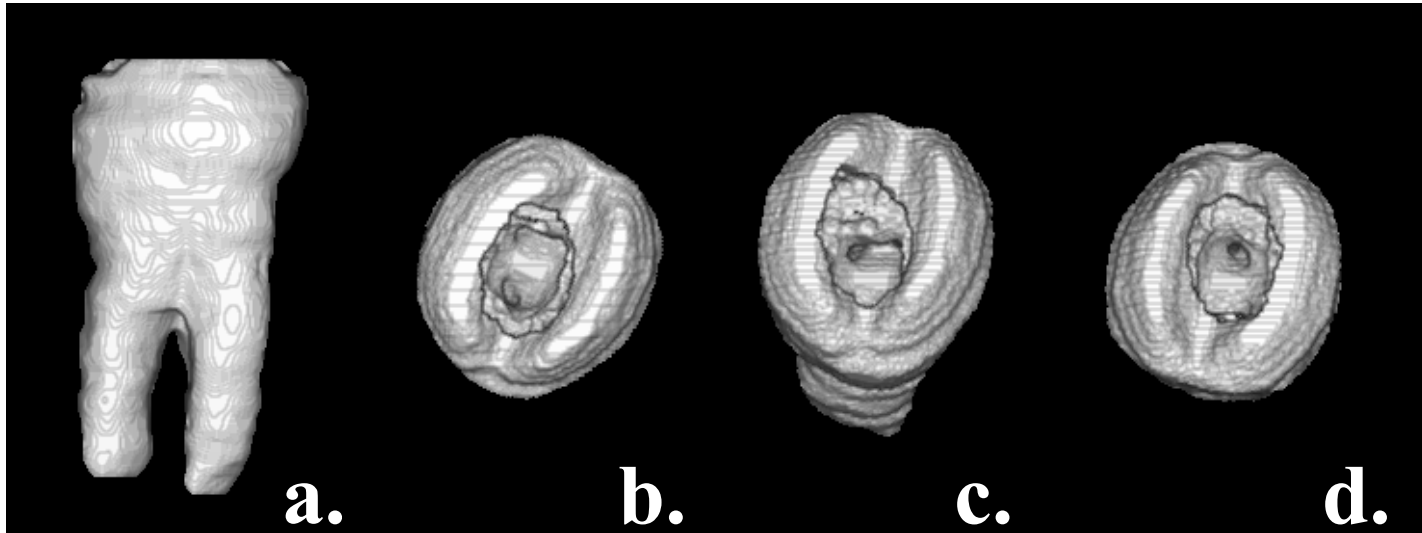


FIGURE 11