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3D computer-aided reconstruction of six teeth with morphological abnormalities

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Summary

Anatomical peculiarities of teeth are a complicating factor in root canal treatment because of the difficulties they can cause. The purpose of this study was the 3D reconstruction of six teeth with morphological peculiarities using serial cross sections and a personal computer. All the teeth were put in 3% NaOCl solution after extraction, washed under running water and air-dried. They were then embedded in a two-phase polyester resin, and serial cross sections were produced from each specimen using a special microtome. The thickness of each section was 0.75 mm. Each section was photographed under a stereoscopic microscope. The photographs of the cross sections were digitized and the external contours of the teeth and the root canal outline were annotated for each section. Semiautomatic alignment of the sections was achieved with the use of image processing techniques. Three dimensional surface representation was used in this project to reconstruct the inner and outer surface of the teeth. The results showed in detail the internal morphology of the teeth under investigation. The fact that it was possible to observe and study these teeth from different angles is one of the main advantages of this method, as the three dimensional anatomy of these teeth was apparent. In conclusion, the 3D reconstructing method is a useful tool for the study of the morphology of the teeth.

***Keywords*: computer, dental anatomy, morphological abnormalities, 3-D reconstruction.**

Introduction

Before root canal treatment is performed, the dentist ideally should know the morphology of the pulp chamber of the teeth he will treat. All root canals should be accessed, cleaned and shaped to receive an hermetic filling of the entire root canal space. Incomplete cleaning, shaping and obturation of any root canal will lead to almost certain root canal treatment failure. Anatomical variability of the teeth is often a complicating factor in root canal treatment and many different methods have been used to investigate tooth morphology. These methods include sectioning of extracted teeth (Black 1897, Green 1955), casts of the root canals with Wood's metal (Preiswerk 1909), celluloid (Fischer 1907) or resin (Skidmore & Bjorndal 1971), decalcification of the teeth and dye injection (Vertucci *et al.* 1974), and radiographic studies *in vitro* (Mueller 1933). All these methods have unavoidable pitfalls, and many difficulties have been encountered. In general the above mentioned methods are complicated and time consuming. Furthermore they do not provide the ability to study the external and internal anatomy of teeth three-dimensionally at the same time. The presence of artifacts in the models produced of the internal morphology of teeth is frequent in these methods. Also there is a danger of distortion of the internal anatomy of the tooth after using different chemicals. This paper presents a new method for the study of the morphology of the teeth, based on three-dimensional computer-aided reconstruction. Six teeth with morphological peculiarities were reconstructed using this method and the external and internal morphology of each was studied. The teeth were:

- a maxillary first premolar with three roots
- a maxillary molar with one root, which had an enamel pearl at the cervical third of its distal surface
- a mandibular lateral incisor with two roots
- a mandibular canine with two roots
- a mandibular second premolar with two root canals
- a mandibular molar, the mesial root of which was severely sickle-shaped, curved toward the distal

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Materials and method

After extraction all the teeth were cleaned in 3% NaOCl solution for 24 h, washed under running water and left to air dry. They were then embedded in a two-component polyester resin, and from each specimen serial cross sections were taken 48 h later using a special microtome (Isomet, Buehler, IL, USA). The thickness of each section was 0.75 mm. Each cross section was photographed under a stereoscopic microscope (Stemy SV8; Zeiss, Wetzlar, Germany). Because of the high magnifications available from this stereomicroscope, no single photograph could cover an entire section. Therefore, between two and six photographs were taken from each section, and a montage obtained showing the entire microscopic image of each section.

The first step toward three-dimensional reconstruction was the digitization of the photographs with a resolution

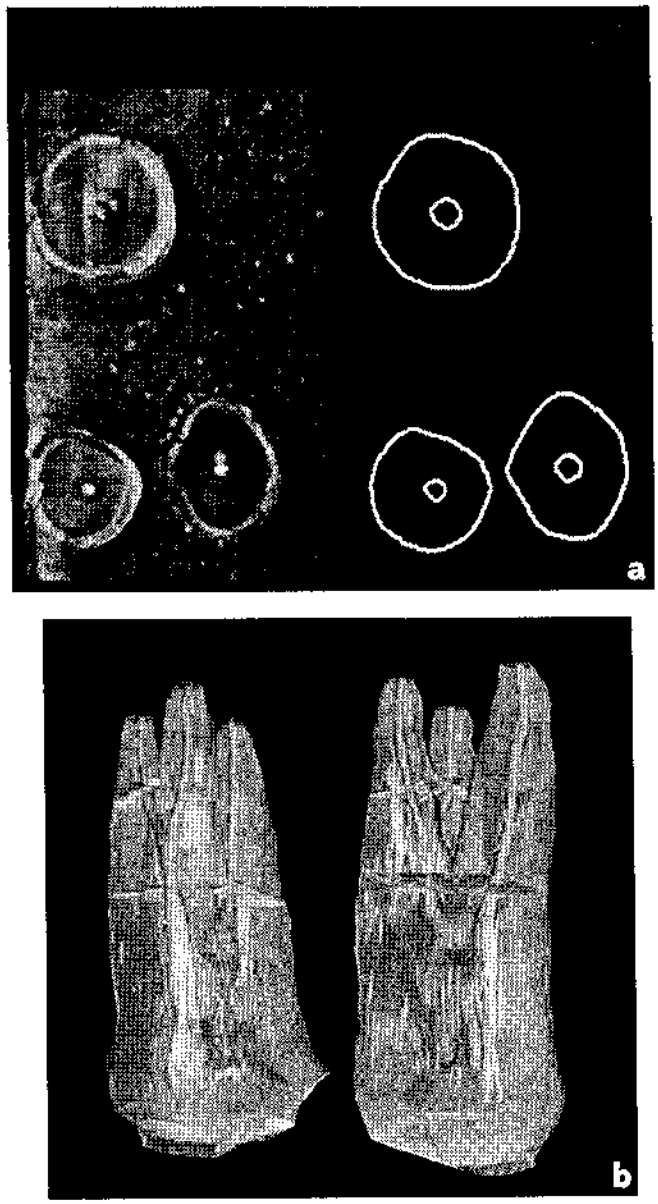


Fig. 1 (a, b) Digitized stereomicroscopic image of a cross section of the maxillary first premolar with three roots and three root canals (left). Extracted contours of the external surfaces of the roots and the root canals from the same section (right). 3D reconstructions of the tooth from two different view angles. It is clearly seen that both buccal root and buccal root canal were divided into two separate and distinct roots and root canals, mesially and distally, in the middle third of the root. The external surface of the tooth is shown as purple and the pulp chamber as yellow.

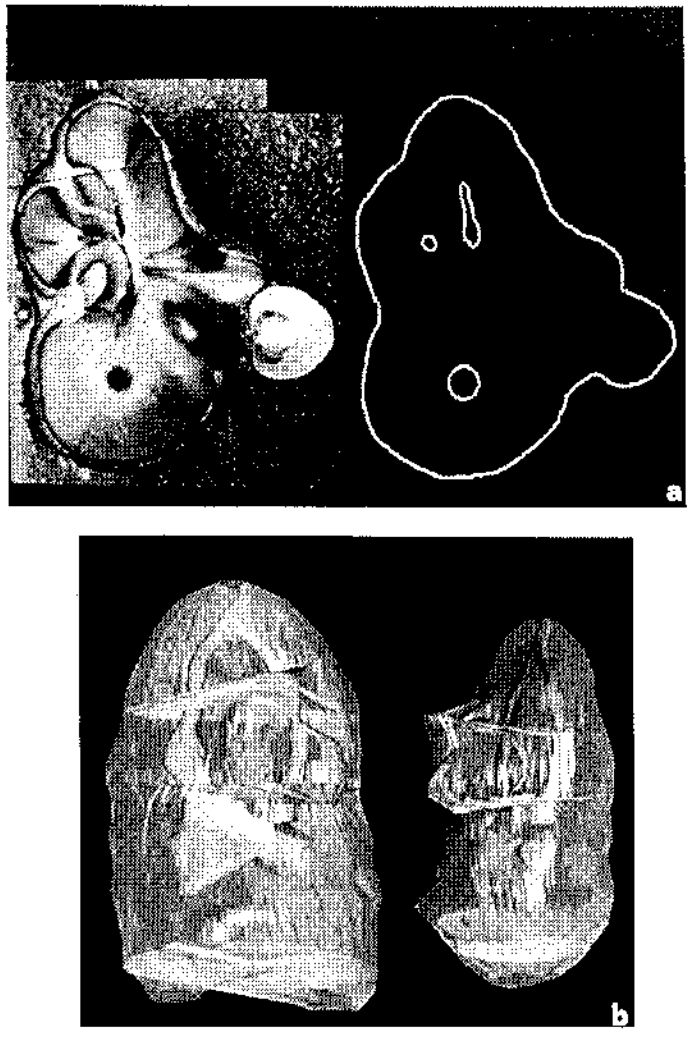
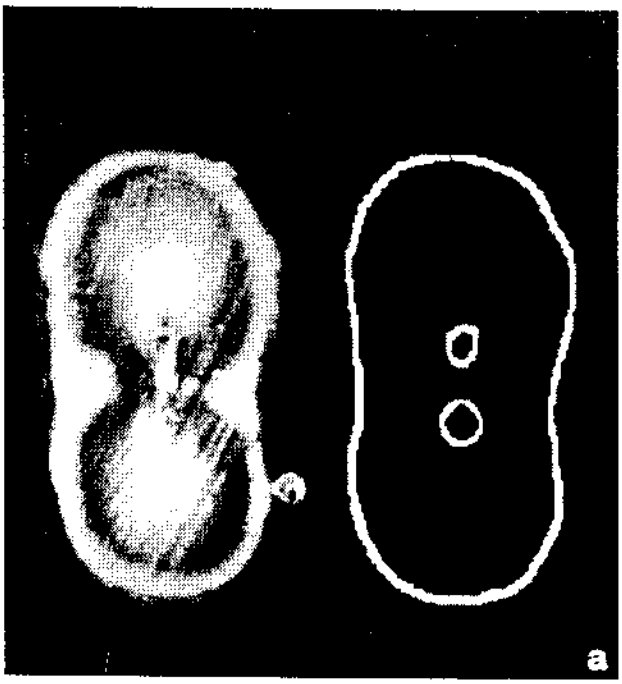


Fig. 2 (a, b) Digitized microscopic image of a cross section from the cervical third of the maxillary molar, where the enamel pearl at the distal surface of its root is clearly seen (left). Extracted contours of the external and internal surfaces of the same section (right). 3D reconstructions from two different viewpoints. It is clearly seen that mainly there were two root canals, which were connected at the apex. The palatal root canal had a lateral branch in its cervical third, which was further reconnected with the main canal.

of 72 dots per inch, using an image scanner (Epson 6000; Seiko Epson Corporation, Nagano, Japan). The grayscale images obtained were further processed by using contrast enhancement methods in order to make different dental tissues more distinguishable and increase the visual image quality (Pitas 1993). The external boundaries of the teeth and the outline of the root canal were identified for each section (Figs 1a, 2a, 3a, 4a, 5a, 6a). Subsequently, semi-automatic alignment of the sections was achieved using image processing techniques. The aligned object contours were finally represented as lists of points for easier contour manipulation (Russ 1990). The next step was the three-dimensional representation of the outer surface of the teeth, as well as their internal structure (root canals system), using the triangulation method. The triangulation algorithm requires interaction with the user in order to decide which contours to connect between successive sections in order to produce the 3D wireframe model.

All the above procedures, boundary extraction, alignment and three-dimensional representation, were implemented by using EIKONA 3D, a digital image processing package for 3D image processing under Microsoft Windows (EIKONA 3D, 1997).

Finally, the visualization of the 3D reconstructed model of each tooth was performed by using surface rendering from different angles around the 3D model, combined with photorealistic effects such as colour and texture addition, lighting and shading. The colours used for the surface rendering were transparent purple for the outer surface of the teeth and opaque yellow matte



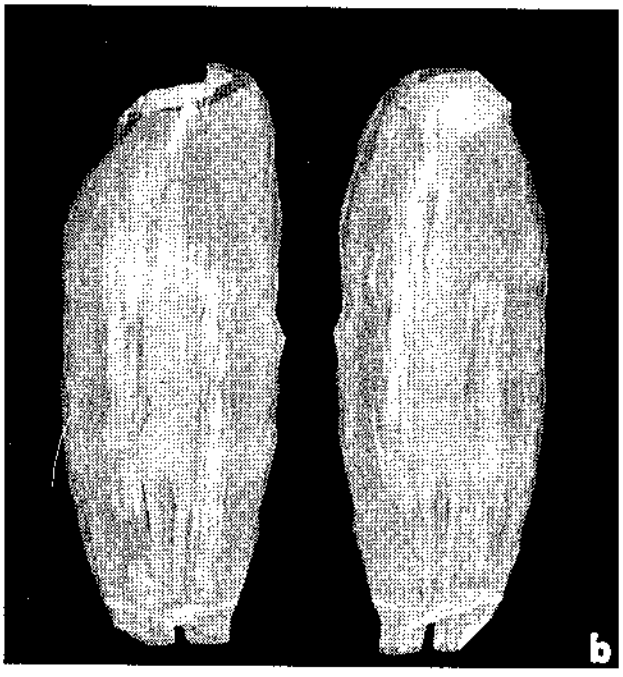
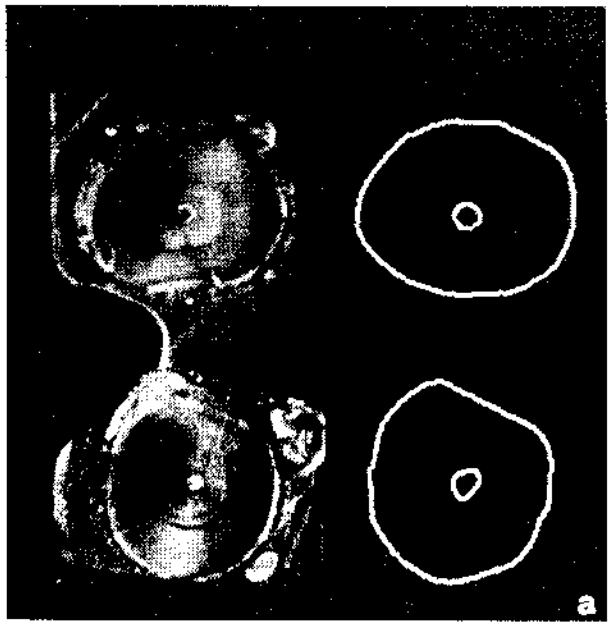


Fig. 3 (a, b) Digitized stereomicroscopic image of the 7th cross section of the mandibular lateral incisor (left). Extracted contours of the external and internal boundary of the root canals from the same section (right). 3D reconstructions from two different view angles. The apical division of the root is clearly seen, as well as the two separate and distinct root canals, buccally and lingually, of the tooth.

for the pulp chamber, so that the best visual result was achieved (Figs 1b, 2b, 3b, 4b, 5b, 6b). The visualization was made using Autodesk 3D Studio Release 4 (Autodesk, Inc., Sin Rafael, USA)



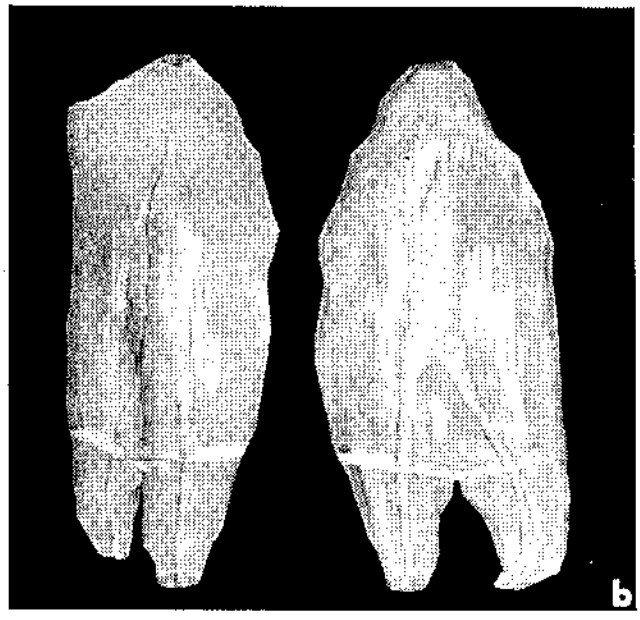


Fig. 4 (a, b) Digitized microscopic image of a cross section from the apical third of the mandibular canine, where the two roots with two root canals are clearly seen (left). Extracted contours of the external surfaces of the roots and the root canals from the same section (right). Two 3D reconstructions from different viewpoints of the tooth, where the two roots with two root canals, buccally and lingually, are obvious.

Results

The microscopic images of the cross sections of the teeth under investigation and their resultant three-dimensional models from different angles, showed their morphology in detail.

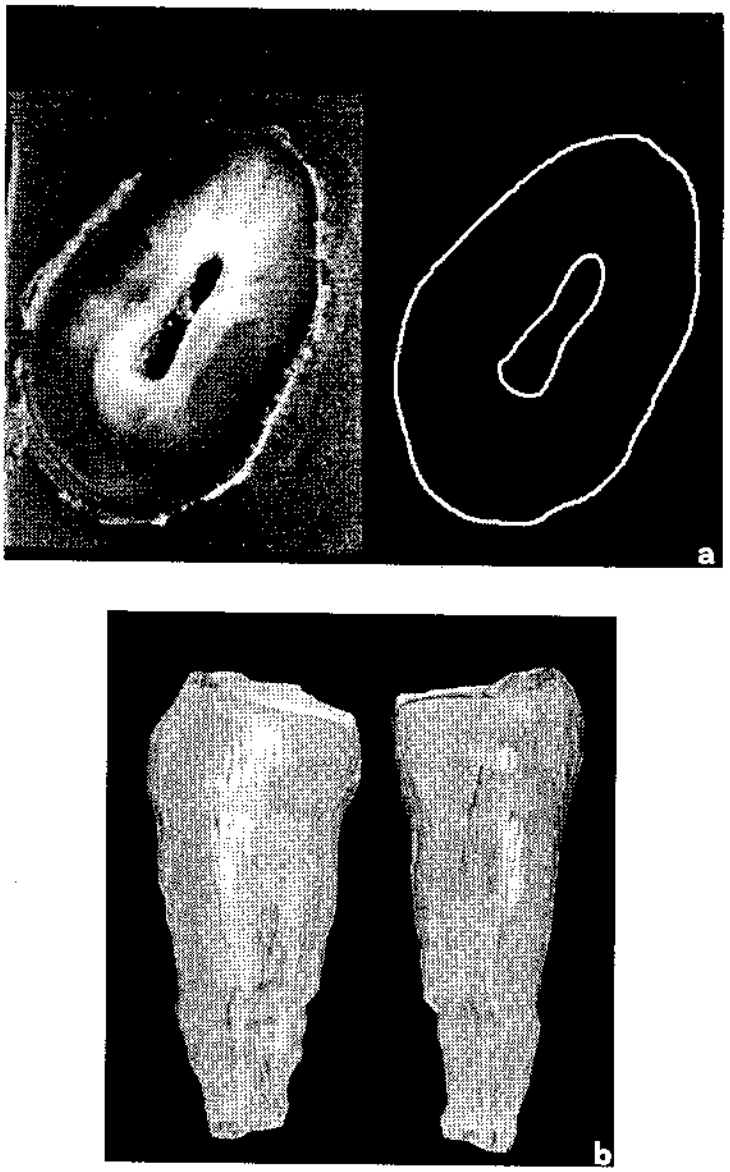


Fig. 5 (a, b) Digitized stereomicroscopic image of a cross section from the cervical third of the mandibular second premolar (left). Extracted contours of the external and internal surfaces of the same cross section (right). 3D reconstructions of the tooth from two different view angles, where it is clearly seen that it was single rooted with two root canals.

The maxillary first premolar had three roots with three root canals. Buccally the separation of the roots as well as the separation of the root canals appeared in the middle third of the root (Fig. 1 a, b).

The maxillary molar had only one root, with an enamel pearl at the cervical third of its distal surface. This tooth had two root canals, one buccal and one palatal, which were connected close to the apex. The lingual root canal had a lateral loop in its cervical third (Fig. 2 a, b).

The mandibular lateral incisor had one root, which divided close to the apex into two separate and distinct roots, one buccal and one lingual. The pulp chamber was divided into two separate and distinct root canals, buccally and lingually, in the middle third of the root (Fig. 3 a, b).

The mandibular canine had two roots with two root canals, buccally and lingually. The bifurcation of the pulp chamber was observed in the cervical third, whilst the root was bifurcated in the middle third of the root (Fig. 4 a, b).

The mandibular second premolar was single rooted with two root canals, one buccally and one lingually (Fig. 5 a, b).

The mandibular second molar had two roots with two root canals, mesially and distally. The mesial root and its

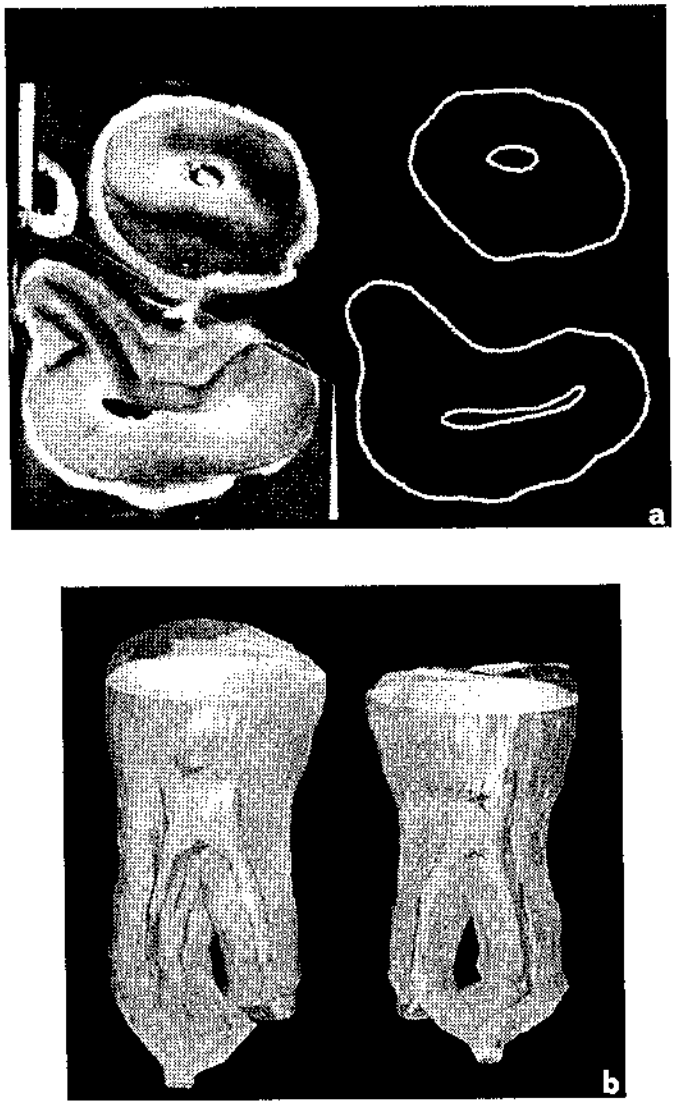


Fig. 6 (a, b) Digitized microscopic image of a cross section of the mandibular second molar, where the two roots with two root canals, mesial and distal, are clearly seen (left). Extracted contours of the external surfaces of the roots and the root canals from the same section (right). Two 3D reconstructions of the tooth from different viewpoints, where the extreme apical curvature of both its mesial root and root canal toward the distal is obvious.

root canal were severely ribbon-shaped, curved toward the distal (Fig. 6 a, b).

Discussion

The method used in this work appears to be a useful and interesting tool for the study of the external and internal anatomy of teeth. The three-dimensional knowledge of root canal morphology of teeth is of great interest because of the ability to transfer this information from the laboratory to the clinic.

One of the advantages of the method is that one can observe the internal anatomy of the teeth from different angles. The rendering which was used is very important for the clinicians because through proper lighting, colour and texture, a better understanding of the dental structures under investigation can be achieved. All these factors make the method an interesting educational tool. Also, it is possible to obtain an animation showing movement of each tooth around its vertical axis. This was implemented and, as expected, proved to be an even more helpful way of visualizing the tooth morphology.

In conclusion, this is a very interesting method, showing the possibilities of the application of informatics technology in dentistry.

Acknowledgement

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