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British Journal of Oral and Maxillofacial Surgery 52 (2014) 838–844

BRITISH Journal of Oral and Maxillofacial Surgery

www.bjoms.com

Evaluation of the potential of automatic segmentation of the mandibular canal using cone-beam computed tomography

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Accepted 25 July 2014
Available online 22 August 2014

Abstract

We aimed to investigate the effectiveness of software for automatically tracing the mandibular canal on data from cone-beam computed tomography (CT). After the data had been collected from one dentate and one edentate fresh cadaver head, both a trained Active Shape Model (ASM) and an Active Appearance Model (AAM) were used to automatically segment the canals from the mandibular to the mental foramen. Semiautomatic segmentation was also evaluated by providing the models with manual annotations of the foramina. To find out if the tracings were in accordance with the actual anatomy, we compared the position of the automatic mandibular canal segmentations, as displayed on cross-sectional cone-beam CT views, with histological sections of exactly the same region. The significance of differences between results were analysed with the help of **Fisher's exact test and** Pearson's correlation coefficient. When tracings based on AAM and ASM were used, differences between cone-beam CT and histological measurements varied up to 3.45 mm and 4.44 mm, respectively. Manual marking of the mandibular and mental foramina did not improve the results, and there were no significant differences (p = 0.097) among the methods. The accuracy of automatic segmentation of the mandibular canal by the AAM and ASM methods is inadequate for use in clinical practice.

Keywords: Mandibular canal; automatic tracing; cadaver; cone-beam CT; 3-dimensional imaging

Introduction

Accurate preoperative planning is necessary to prevent iatrogenic damage to the neurovascular bundle that passes inside the mandibular canal, the course of which varies within the mandibular body.[1–4]

Three-dimensional,image-based, planning software gives us the opportunity to create a virtual mandibular canal.[5,6] Data from cone-beam computed tomography (CT) can be used. Until now tracing of the mandibular canal has been done manually and was time-consuming.[5] Several automatic methods of segmenting the mandibular canal have been published,[7–12] but only a few have concentrated on segmentation on cone-beam CT views.[11–13] Up to now the canal has been characterised by low contrast between it and the

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http://dx.doi.org/10.1016/j.bjoms.2014.07.253
0266-4356/

surrounding tissues. [13]Areas with the same sort of tissue do not give the same amount of contrast because of the lack of uniformity of radiographic illumination and scattering.[13] As a consequence automatic segmentation of the canal is a challenge.

Obviously to prevent iatrogenic damage it is important that the position of the automatic tracing of the mandibular canal corresponds to its real anatomical position. None of the studies that have described automatic segmentation of the canal based on cone-beam CT data, have mentioned this.[11–13] To validate the results, automatic tracings have always been compared with manual tracings.[11–13] However, these are inaccurate and do not correspond to the real anatomical picture.[5]

The aim of this study was to assess the potential for automatic tracing of the mandibular canal as proposed by Kroon[13] using histological datasets as reference.

Material and Methods

To assess automatic tracings of the mandibular canal made from cone-beam CT data, the position of the canal as displayed on cross-sectional cone-beam CT images was compared with that of histological sections of the corresponding region. In one dentate and one edentate (Cawood and Howell classification V[14]) fresh frozen cadaver head, therefore, the second molar and second premolar region, both on the left and right sides of the mandible, were marked using titanium microscrews (5 mm long and 1.5 mm in diameter, KLS Martin, Gebrüder Martin GmbH&Co, Tuttlingen, Germany). These were positioned perpendicular to the mandibular arch at the free gingival margin in the vestibular fold.

To obtain cone-beam CT data, the skulls were scanned using the i-CAT^{TM} 3-dimensional imaging system (Imaging Sciences International Inc, Hatfield, PA, USA) using the following **variables:** 120 kVp, 1.2 mA, 22 cm field of view, and 0.400 mm voxel size.[15,16]

To collect histological data, the mandibles were cut into small blocks and fixed in 4% neutral buffered formaldehyde. After dehydration in ethanol solutions from 70% to 100%, the samples were embedded in methylmethacrylate and cut into slices 10 μm thick in cross-sectional planes along the markers.[17] Methylene blue and basic fuchsin stains were used.

After the sections had been digitised into JPEG format using a Carl Zeiss light microscope and AxionVision Rel. 4.6 software (Carl Zeiss MicroImaging GmbH, Göttingen, Germany), distances from the middle of the canal to the outer surfaces of the mandibular body were measured (Adobe Photoshop CS4 Version 11.0; San Jose, California, USA). These measurements were used as reference values (A-D; Figure 1).

Different automatic methods of segmentation were investigated on the cone-beam CT data. The first was a modified Active Shape Model (ASM),[13,18] which included previous knowledge of the segmentation algorithm and variations

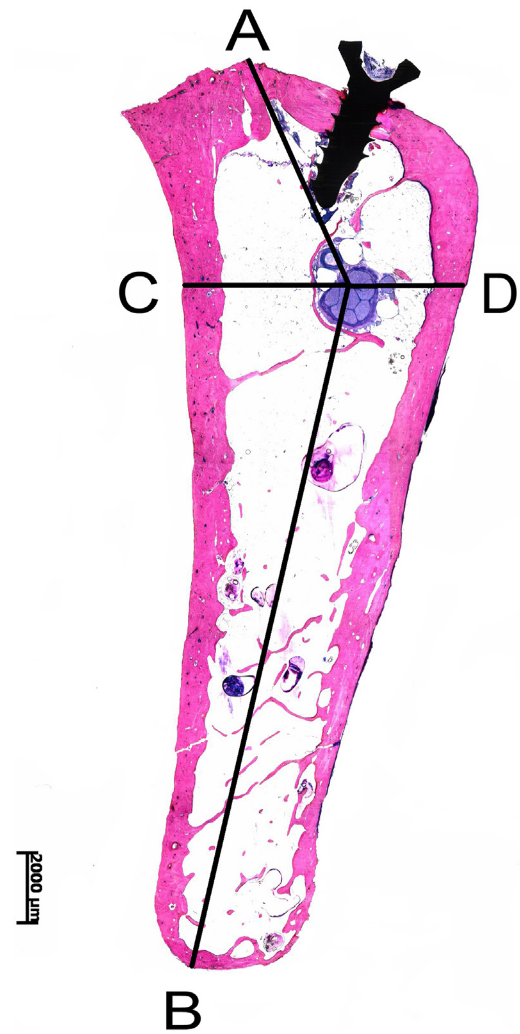

Figure 1. Distances measured on a histological section. The reference screw is clearly visible at the top. A = centre of the mandibular canal to the top of the alveolar ridge; B = centre of the mandibular canal to the base of the mandible; C = centre of the mandibular canal to the lingual surface; and D = centre of the mandibular canal to the buccal surface.

between corresponding points in training datasets, which were used as shape constraints during segmentation.[13,18]

The second method was the Active Appearance Model (AAM) segmentation procedure, which extended the ASM method, and not only included variations in shape but also data about appearance.[13,19] Both methods for tracing the canal automatically generated the mandibular foramen, the mental foramen, and the shape of the canal. They were used on expert segmentations of the mandibular canals and mandibles in 13 cone-beam CT datasets from both dentate and edentate patients.

Both the AAM and ASM based methods were expanded by providing them with manual annotations of the mandibular and mental foramena, which were marked by an experienced oral and maxillofacial surgeon. As a result only the course of the canal needed to be covered by automatic segmentation, and were referred to as AAM-$_{\text{course}}$ and ASM-$_{\text{course}}$.