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The anatomy of two-rooted mandibular canines determined using micro-computed tomography

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Abstract

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Aim To investigate the internal and external anatomy of extracted human mandibular canines with two roots and two distinct canals using micro-computed tomography (μCT).

Methodology Fourteen two-rooted human mandibular canines were scanned using a high-resolution μCT system (SkyScan 1174v2; SkyScan N.V., Kontich, Belgium). The images were processed to evaluate the size of the roots, the furcation regions, the presence of accessory canals, the mean distances between several anatomical landmarks, the position of the apical foramina, the direction of root curvatures, the cross-sectional appearances (SMI index), the volume and surface areas of the root canals.

Results Root bifurcation was located in both apical (44%, $n = 6$) and middle (58%, $n = 8$) thirds of the root. The size of the buccal and lingual roots was similar in 29% of the sample. From a buccal view, no curvature towards the lingual or buccal direction occurred in either roots. From a proximal view, no straight lingual root occurred. In both views, S-shaped roots were found in 21% of the specimens. Location of the apical foramen varied considerably, tending to the mesio-buccal aspect of both roots. Lateral and furcation canals were observed mostly in the cervical third in 29% and 65% of the sample, respectively. The structure model index (SMI) index ranged from 1.87 to 3.86, with a mean value of 2.93 ± 0.46. Mean volume and area of the root canals were 11.52 ± 3.44 mm^3 and 71.16 ± 11.83 mm^2, respectively.

Conclusions The evaluation of two-rooted mandibular canines revealed that bifurcations occurred in the apical and middle third. S-shaped roots were found in 21% of the specimens. Mean volume, surface area and SMI index of the root canals were 11.52 mm^3, 71.16 mm^2 and 2.93, respectively.

Keywords: mandibular canine, micro-computed tomography, root canal anatomy.

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Introduction

A comprehensive understanding of the complexity of the internal anatomy of teeth is imperative to ensure successful root canal treatment (Vier-Pelisser *et al.* 2010, Setzer *et al.* 2011). *Ex vivo* studies have analysed root canal morphology using clearing techniques (Pécora *et al.* 1993, Sharma *et al.* 1998, Omer *et al.* 2004), longitudinal and transverse cross-sectioning (Garala *et al.* 2003, Yoshioka *et al.* 2005), radiographic examination (Omer *et al.* 2004), operative microscopy, and scanning electron microscopy (Schwarze *et al.* 2002).

In recent years, significant technological advances for imaging teeth have been introduced, including digital radiography, densitometry, magnetic resonance imaging, ultrasound and computed tomography (Versiani *et al.* 2008, Patel *et al.* 2009, Neelakantan *et al.* 2010, D'Addazio *et al.* 2011, Liang *et al.* 2011, Peters & Paqué 2011, Verma & Love 2011). Their non-invasive nature allows the use of teeth for other purposes or to use as

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controls for further treatment procedures (Versiani *et al.* 2008, Vier-Pelisser *et al.* 2010, Peters & Paqué 2011). The development of X-ray micro-computed tomography (μCT) has gained increasing significance in the study of hard tissues in endodontics (Jung *et al.* 2005, Paqué *et al.* 2011, Peters & Paqué 2011) as it offers a reproducible technique that can be applied quantitatively as well as qualitatively for the three-dimensional assessment of the root canal system (Peters *et al.* 2000, Ikram *et al.* 2009, Moore *et al.* 2009, Somma *et al.* 2009, Paqué *et al.* 2011, Peters & Paqué 2011, Verma & Love 2011).

Although mandibular canine usually have one root canal, the occurrence of two roots and two distinct canals has often been reported (Ouellet 1995, Sharma *et al.* 1998, D'Arcangelo *et al.* 2001, Victorino *et al.* 2009). Most reports refer to two-rooted mandibular canines in case reports (D'Arcangelo *et al.* 2001, Victorino *et al.* 2009), whilst data from *ex vivo* studies report this anatomic variation to occur in 1.7% (Pécora *et al.* 1993) to 5% (Ouellet 1995) of cases. The aim of this *ex vivo* study was to investigate the internal and external anatomy of extracted human mandibular canine teeth with two roots and two distinct canals using micro-computed tomography.

Materials and methods

Fourteen unrestored human mandibular canine teeth with fully formed apices with two roots and two distinct canals were selected from a pool of 793 extracted canines and stored in labelled individual plastic vials containing 0.1% thymol solution until use. After being washed in running water for 24 h, each tooth was dried, mounted on a custom attachment and scanned in a desktop X-ray microfocus CT scanner (SkyScan 1174v2; SkyScan N.V., Kontich, Belgium) at an isotropic resolution of 16.7 μm. The system consisted of a sealed air-cooled X-ray tube, 20–50 kV/40W/800 μA, with a precision object manipulator with two translations and one rotation direction. The system also included a 14-bit CCD camera based on a 1.3 Megapixel (1304 × 1024 pixels) CCD sensor.

Images of each specimen were reconstructed from the apex to the coronal level with dedicated software (NRecon v1.6.1.5; SkyScan), which provided axial cross sections of the inner structure of the samples in approximately 450 slices. Then, DataViewer v.1.4.3 software (SkyScan) was used to evaluate the size of the roots, the furcation region, the presence of accessory canals and the mean distances between several anatomical landmarks. CTVox v.0.9.0r366 software (Skyscan) was used for three-dimensional visualization and qualitative evaluation of the position of the apical foramina and the direction of root curvature, from proximal and buccal views. Volume (mm^3), surface area (mm^2) and cross-sectional appearance, expressed as the structure model index (SMI), were measured using CTAn v1.10.1.0 software (Skyscan).

Results

Mean distances (± SD) between reference landmarks on the buccal and lingual roots of the teeth are shown in Fig. 1.

The furcation was located in both apical (44%, $n = 6$) and middle (58%, $n = 8$) thirds of the root (Fig. 2). The size of the buccal and lingual roots of each tooth was equal in 28% of the sample ($n = 4$). Lingual roots were larger than buccal in 36% of the sample ($n = 5$) and the reverse was true with larger buccal roots being found in 36% of specimens (Fig. 3).

Table 1 shows the percentage distribution of the direction of curvature of the roots. From a buccal perspective, no curvature towards the lingual or buccal direction was found in any of the roots. Straight lingual and buccal roots were observed in 28% ($n = 4$) and 44% ($n = 6$) of the sample, respectively. Most of the lingual roots curved mesially ($n = 6$; 44%). From a proximal perspective, lingual roots curved buccally in 79% of the sample ($n = 11$; 79%). Straight buccal roots were observed in 58% ($n = 8$) of the sample. In both views, S-shaped roots were found in 21% ($n = 3$) of the specimens. In all specimens, only one single apical foramina with no apical delta was observed. Table 2 reveals that the location of the apical foramina varied considerably, tending to the mesio-buccal aspect of both roots.

Three-dimensional reconstruction of the internal anatomy revealed that all teeth had two main root canals. Lateral and furcation canals were observed mostly in the cervical third in 28% ($n = 4$) and 65% ($n = 9$) of the sample, respectively (Table 3, Fig. 4). The SMI index ranged from 1.87 to 3.86, with a mean value of 2.93 ± 0.46. The mean volume and area of the root canals were 11.52 ± 3.44 mm^3 and 71.16 ± 11.83 mm^2, respectively.

Discussion

Although the existence of mandibular canine teeth with two roots was described more than a century ago

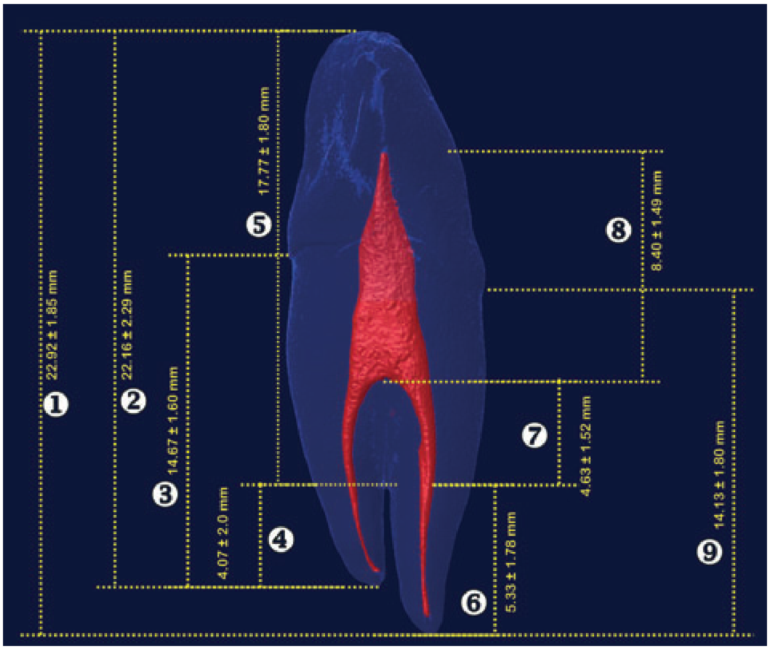

Figure 1 Mean distance (±SD), in millimetres, between reference landmarks in the buccal and lingual roots of the teeth (n = 14). (1) Distance between cusp tip and apex of buccal root; (2) Distance between cusp tip and apex of lingual root; (3) Distance between cemento-enamel junction and apex of lingual root; (4) Distance between furcation and apex of lingual root; (5) Distance between cusp tip and furcation; (6) Distance between furcation and apex of buccal root; (7) Distance between pulp chamber floor and furcation; (8) Distance between pulp chamber floor and pulp horn; (9) Distance between cementoenamel junction and apex of buccal root.

(Koskins 1886) and a detailed analysis of its internal anatomy has been published (Sharma *et al.* 1998), no study has been undertaken to evaluate its anatomy using high-resolution computed tomography.

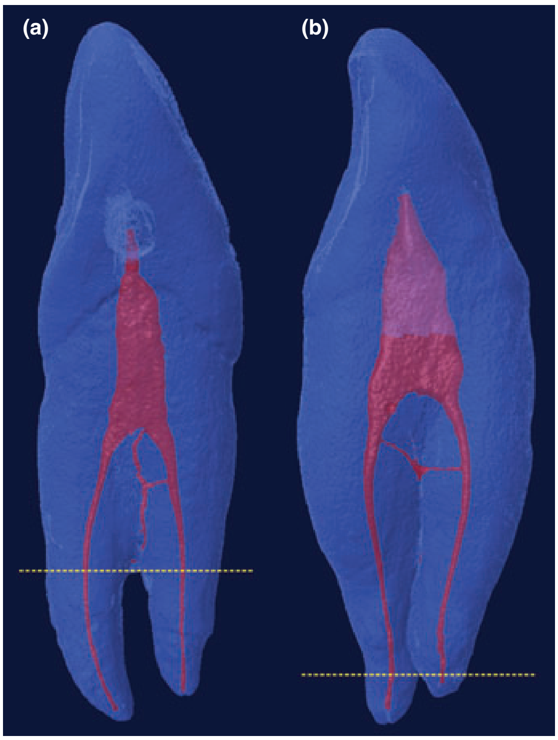

Figure 2 Two-rooted mandibular canines with furcation located at the middle (a) and apical (b) thirds.

The most extensive study on this subject was conducted to investigate sixty-five two-rooted mandibular canines using a clearing and staining technique (Sharma *et al.* 1998). This technique has been considered valuable in studying the internal anatomy of teeth as it is inexpensive, does not require complex laboratory equipment and allows a thorough examination of the root canal system (Pécora *et al.* 1993, Omer *et al.* 2004, Neelakantan *et al.* 2010). Conversely, its major disadvantage is that the tooth is irreversibly altered because of its dissolution and the injection of dye (Robertson *et al.* 1980, Neelakantan *et al.* 2010). Thus, in the present study, fourteen extracted two-rooted mandibular canines were examined using a device that provides three-dimensional and detailed views of the tooth, without the need of sectioning, preparation or destruction of the specimens (Bjørndal *et al.* 1999, Peters *et al.* 2000, Neelakantan *et al.* 2010, Vier-Pelisser *et al.* 2010, Paqué *et al.* 2011, Peters & Paqué 2011, Verma & Love 2011).

Most of the sample had roots with approximately equal lengths and, on average, shorter than single-rooted canines (Pécora *et al.* 1993, Sharma *et al.* 1998). Despite Sharma *et al.* (1998) have observed root bifurcation in the cervical third in 3.1% of their sample, in the present investigation this was only observed at the middle and apical thirds. In this

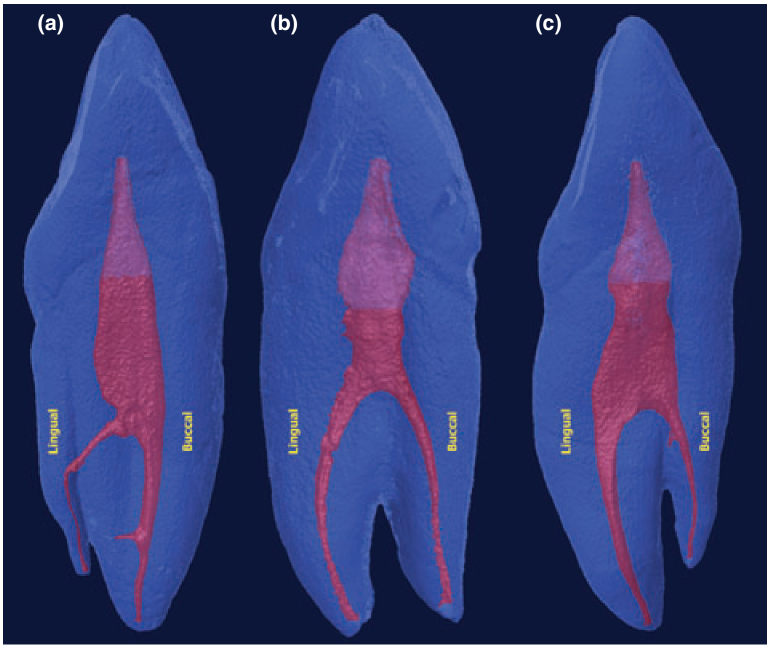

Figure 3 Two-rooted mandibular canines with a buccal root larger than lingual root (a), buccal and lingual roots of the same size (b) and lingual root larger than buccal root (c).

context, the risk of accidental bifurcation perforation is minimal as the distance from the pulp chamber floor to the roof varied from 5.98 to 10.6 mm and to the furcation from 3.42 to 9.05 mm. On the other hand, it would be more difficult to find the canal entrances because the canals in this cases would be invariably located more apically (Vier-Pelisser *et al.* 2010).

Although theoretically it is desirable to prepare the canal to the apical constriction (Ricucci & Langeland 1998), displacement of the apical foramina labially or lingually may result in over instrumentation. In the present study, eccentric placement of the apical foramina was recognized in all specimens and, as observed in other teeth, its location varied considerably (Vier-Pelisser *et al.* 2010, Verma & Love 2011). In term of the direction of curvature, the main finding was the high incidence of curvature towards a buccal direction in the lingual roots (79%). If the apical foramina deviates in the lingual/buccal plane, it is difficult to locate its position using radiographs alone, even with multiplane angles (Nekoofar *et al.* 2006). Thus, special attention should be given during working length determination and root canal preparation of these root canals. In contrast to accessory canals, which are most frequently found in the apical third of

Table 1 Percentage distribution (*n*) of the direction of root curvature observed in both buccal and proximal views of two-rooted mandibular canines

	Buccal view		Proximal view	
Direction of curvature	Buccal root	Lingual root	Buccal root	Lingual root
None (straight)	44 (6)	28 (4)	58 (8)	–
Towards distal	21 (3)	7 (1)	–	–
Towards mesial	14 (2)	44 (6)	–	–
Towards lingual	–	–	7 (1)	–
Towards buccal	–	–	14 (2)	79 (11)
S-shaped	21 (3)	21 (3)	21 (3)	21 (3)

Table 2 Percentage distribution (*n*) of the apical foramen position in the buccal and lingual roots of mandibular canines

Foramen position	Buccal root	Lingual root
Mesio-buccal	65 (9)	50 (7)
Mesio-lingual	7 (1)	0.0 (0)
Disto-buccal	14 (2)	36 (5)
Disto-lingual	0.0 (0)	7 (1)
Buccal	0.0 (0)	7 (1)
Lingual	7 (1)	0.0 (0)
Mesial	7 (1)	0.0 (0)

Table 3 Percentage distribution (*n*) of the sample presenting lateral and furcation canals observed after three-dimensional reconstruction

	Lateral canal		
Root third	Lingual root	Buccal root	Furcation canal
Cervical	14 (2)	14 (2)	65 (9)
Middle	0 (0)	7 (1)	0 (0)
Apical	0 (0)	0 (0)	0 (0)

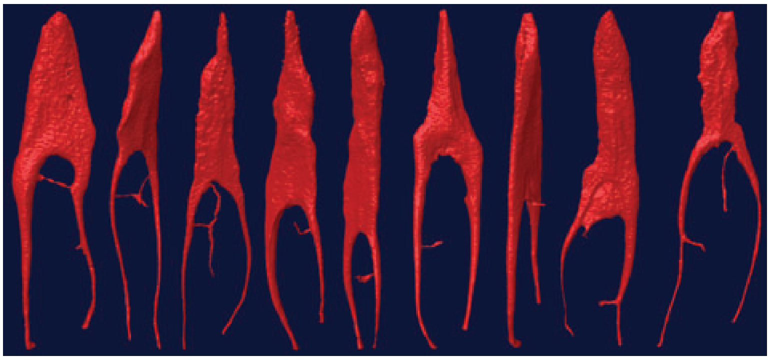

Figure 4 Three-dimensional reconstruction of the pulp cavity of two-rooted mandibular canines showing the position of the lateral and furcation canals.

teeth (Vier-Pelisser *et al.* 2010, Verma & Love 2011), in the present study, they mostly occurred at the cervical third, close to the furcation, favouring a more effective cleaning, shaping and filling of the root canal system.

It is interesting to note that the results of this study were no different from those obtained with a conventional method used for studying root canal anatomy (Sharma *et al.* 1998). Nonetheless, algorithms used in μCT evaluation allows further measurement of basic geometrical parameters such as volume and surface area as well as additional descriptors of canal shape such as SMI (Bjørndal *et al.* 1999, Peters *et al.* 2000, 2001, Paqué *et al.* 2011, Peters & Paqué 2011, Verma & Love 2011). These three-dimensional data are impossible to achieve using clearing techniques (Neelakantan *et al.* 2010).

The SMI describes the plate- or cylinder-like geometry of an object (Peters *et al.* 2000). This variable has been used to detail changes in trabecular microstructure in osteoporosis or other bone diseases (Hildebrand & Rüegsegger 1997), but may also be used to assess root canal geometry. The SMI is determined by an infinitesimal enlargement of the surface, whilst the change in volume is related to changes of surface area, i.e. to the convexity of the structure. If a perfect plate is enlarged, the surface area does not change, yielding an SMI of zero. However, if a rod is expanded, the surface area increases with the volume and the SMI is normed, so that perfect rods are assigned an SMI score of 3 (Peters *et al.* 2000). In the present study, the mean SMI result indicates that the root canal system has a cylinder-like geometry.

Conclusions

Root bifurcation in mandibular canines with two roots were observed only at the apical and middle thirds of the root. The size of the buccal and lingual roots was equal in approximately one-third of the sample. No straight lingual root was observed in the proximal view. The location of the apical foramina varied considerably, tending to the mesio-buccal aspect of both buccal and lingual roots. Lateral and furcation canals were observed mostly at the cervical third. Mean volume, surface area and SMI index were 11.52 mm^3, 71.16 mm^2 and 2.93, respectively.

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