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# Morphometric study of the apical anatomy of C-shaped root canal systems in mandibular second molars

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## Abstract

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**Aim** To investigate the apical anatomy of C-shaped canal systems in mandibular second molars by micro-computerized tomography (μCT) and stereomicroscopy.

**Methodology** Forty-four permanent mandibular second molars with a C-shaped root canal systems from a native Chinese population were scanned at 100 μm intervals by μCT at a resolution of 30 × 30 μm. The apical 5 mm of each tooth was reconstructed three-dimensionally for visualization and classification of the canal configuration using Vertucci's criteria. The main and auxiliary (accessory) foramina were examined under a stereomicroscope.

**Results** Type IV and VIII canal configurations were most often found in the apical 5 mm of these canal systems. The prevalence of accessory canals, lateral canals, inter-canal communications and apical delta were 41%, 25%, 27% and 11%, respectively. Approximately 80% of C-shaped canals had 1–3 apical foramina; the prevalence of accessory foramina was about 48%. The mean distance between the main foramen and the anatomic root apex was 0.84 mm, and that between the accessory foramen and the apex was 1.61 mm. The mean (shortest and longest) diameters of major and accessory foramina were 0.19∼0.32 mm and 0.07∼0.10 mm, with a mean form factor of 0.73 and 0.82, respectively.

**Conclusion** The apical anatomy of C-shaped root canal systems in mandibular second molars is extremely complex with many anatomical variations.

**Keywords:** C-shaped canal, dental anatomy, micro-computerized tomography, stereomicroscopy, tooth morphology.

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## Introduction

Knowledge of root morphology and the configuration of the pulpal space, especially in the apical third, plays an important role in ensuring thorough debridement, and the outcome of root canal treatment (Hsu & Kim 1997, Jung *et al.* 2005). Several studies have reported that the prevalence of accessory canals and isthmuses is high in the apical 2∼5 mm of the root (Jung *et al.* 2005). Complete debridement of these regions through mechanical instrumentation is impossible, and necrotic tissue remnants and microorganisms in the apical portion of the canal are commonplace in cases of post-treatment outcome (Nair *et al.* 1990).

The C-shaped root canal system is an anatomical variation found mostly in mandibular second molars, especially in the Asian population (Yang *et al.* 1988). The main anatomic feature of the C-shaped canal system is the presence of a fin or web connecting the individual root canals. Melton *et al.* (1991) classified

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C-shaped canals based on their cross-sectional configuration into three types, and reported differences between the coronal, middle and apical parts of the same root. Fan *et al.* (2004) also reported the complex nature of the apical anatomy of C-shaped canals revealed by micro-computerized tomography (μCT); their analysis was based on individual cross-sectional images of the tooth. A three-dimensional (3D) visualization and examination of the apical region of such canals is lacking; such information would be valuable for clinicians when treating such cases.

Micro-computerized tomography has been introduced for endodontic research and proved to be an invaluable, nondestructive means for examining the shape and morphology of root canal systems (Bergmans *et al.* 2001, Peters *et al.* 2003). With the advances in hardware and imaging software, the resolution of μCT has been improved; a 3D model of a root canal can now be reconstructed allowing qualitative and quantitative examination of the anatomy of the pulpal space (Peters *et al.* 2000, Oi *et al.* 2004). Stereomicroscope, on the other hand, is a proven means to examine the external morphology of teeth, and has been used to evaluate the morphology of apical foramen/foramina of the root (Marroquin *et al.* 2004). Combining the information from stereomicroscopy with information of the 'internal' anatomy from μCT would provide a thorough understanding of the complex anatomy of the root canal system.

The purpose of this study was to investigate the anatomical features of the apical 5 mm of C-shaped root canal systems in mandibular second molars by stereomicroscopy and μCT.

## Materials and methods

Extracted human mandibular second molars with fused roots and a longitudinal groove on the lingual root surface were collected from native Chinese adults. All teeth had a mature root apex and were stored in 10% neutral-buffered formalin solution. Prior to examination, they were washed under tap water and immersed in a 5% sodium hypochlorite solution for 2 h to remove any adherent soft tissue. Deposits of calculus and extrinsic stain were removed using an ultrasonic scaler. Each tooth was examined for the presence of a C-shaped canal system according to the criteria established by Fan *et al.* (2004); only those with a C-shaped canal system ($n = 44$) were included. Tomographs of the apical 5 mm of the selected teeth were obtained, with the long axis of the root aligned normal to the scanning plane, at 100 μm intervals in a μCT scanner (μCT-20; Scanco Medical AG, Bassersdorf, Switzerland) at a standard resolution ($30 \times 30$ μm) to produce a stack of images for each root. The stacks were imported into a geometrical analysis software (VGStudio MAX 1.1; Volume Graphics GmbH, Heidelberg, Germany). After calibration, each image stack was subjected to grey-value segmentation and a Gaussian filtration for noise reduction. A 3D model of the apical part of the roots was created by volume rendering (Fig. 1a); the internal configuration of the canal was visualized through changing the grey value and opacity of the (overlying) dentine and cementum (Fig. 1b).

The 'main' foramen was defined in this study as the exit of the main canal, and an 'auxillary' (or 'accessory') foramen as the exit of any accessory and lateral canal, or of apical delta. An 'accessory canal' was defined as a fine branch of the pulp canal that diverged at an oblique angle from the main canal to exit into the periodontal ligament space; a 'lateral canal' was a branch diverging at almost right angle from a main canal. An 'apical delta' was defined as a complex ramification of branches of the pulp canal located near the anatomical apex with a main canal not being discernible. Inter-canal communication was a branch of the pulpal space that ran between (more than one) main canals but did not communicate with the root surface. An example of each of these anatomical features is illustrated in Fig. 2. All 3D-reconstructed canals were subjected to the following qualitative and quantitative examinations.

**1.** The type of canal configuration in this apical root portion was categorized according to Vertucci's classification (Vertucci 1984).

**2.** The presence of accessory and lateral canals, inter-canal communication and apical delta was noted.

**3.** Number and location of the main and accessory foramina were recorded.

**4.** The distance between the most coronal point of each main, or accessory foramen and the anatomical root apex was measured in software (VGStudio MAX 1.1, with a resampled resolution of $30 \times 30 \times 30$ μm) (Fig. 3).

Then, the dimension of the apical foramen (main or accessory) was measured using the method described by Marroquin *et al.* (2004). Briefly, a foramen was identified at ×20 magnification, guided by information from the 3D-reconstructed model of the canal. The orientation of the root was adjusted until the foramen was located in the middle of the field and parallel to the objective lens. At ×50 magnification and through

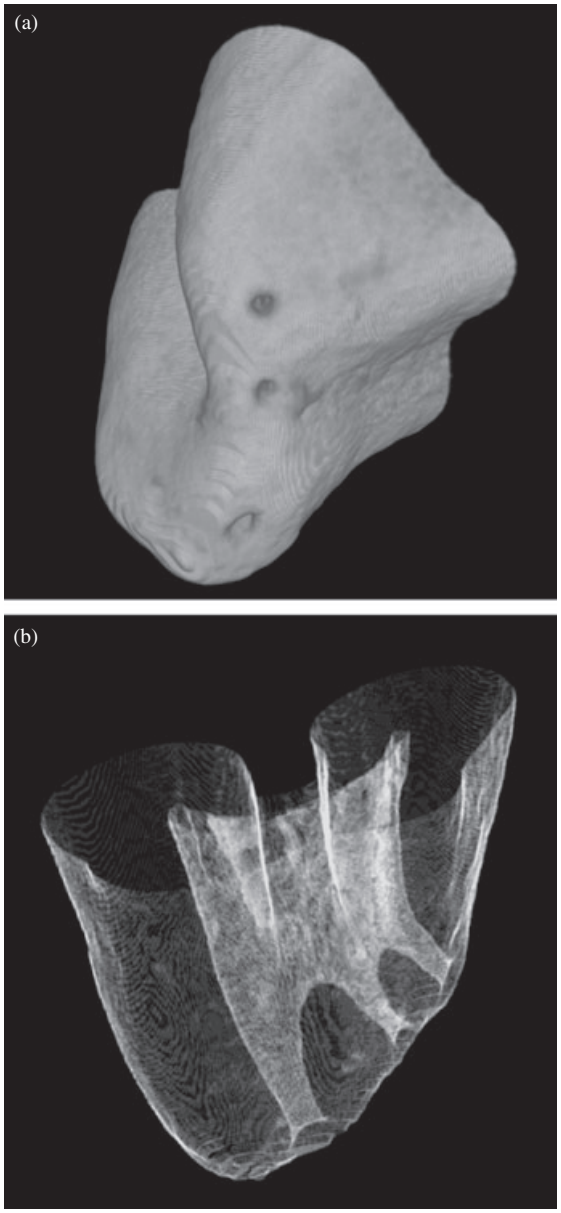


**Figure 1** The apical 5 mm of the C-shaped canal system was reconstructed in 3D for visualization of: (a) the external root surface; and (b) the internal anatomy made visible by changing the grey values and opacity of the dentin and cementum. Note: image in (b) was rotated with respect to (a).

regulating the focus, the image of the 'physiological foramen' was captured (Fig. 4). Here, a 'physiological' foramen was that part of the apical foramen with the smallest planar dimension by focusing below the major apical diameter (Fig. 4b); this may be regarded as equivalent to the apical constriction of the pulp canal (Marroquin *et al.* 2004). All photomicrographs were captured with an image software (Image-Pro Plus 4.5; Media Cybernetics, Silver Spring, MD, USA). The boundary of each foramen was 'auto-segmented' and its longest and shortest diameters were 'auto-calculated' against a 1 mm standard (with each pixel representing a distance of 2.07 μm). The form factor (FF) was calculated to describe the shape of the foramen; a round object would have a FF value equal to one.

All data were subjected to statistical analysis using SPSS for Windows 11.5 software (SPSS, Chicago, IL, USA). The distance between the foramen and the apex, the diameter of the foramen, and the FF of the main and accessory foramina were compared using the Mann–Whitney *U*-test at $P = 0.05$.

## Results

Of the 44 C-shaped canals included for analysis, 22 were mandibular right and 22 mandibular left second molars. The apical 5 mm of the root was reconstructed three-dimensionally (Fig. 1).

### Canal configuration of the apical portion

Most of these C-shaped canals possessed two (i.e. type II, IV, V or VI), or three (i.e. type VIII) main root canals (Table 1). About one-fifth of specimens showed four or more main canals.

Accessory and lateral canals, inter-canal communication and apical delta were noted on the 3D-reconstructed models (Fig. 2). The prevalence of these anatomical features ranged from 11% to 41% (Table 2).

### Examination of the apical foramina

From the 44 reconstructed root canal models, a total of 115 main and 41 accessory foramina were noted (Table 3); the distance between these foramina and the anatomic apex was summarized in Table 4. The difference between the mean distance of the main foramen to the anatomic apex and that of accessory foramina was statistically significant ($P < 0.001$, Table 4). In contrast, whilst all 115 main foramina were observed, only 21 accessory foramina (in 15 teeth) could be identified under the stereomicroscope (Fig. 4). As only the apical constriction would be of clinical significance, the dimension and FF value of the 'physiological' foramina were shown in Tables 5 and 6, respectively (results for the anatomical foramen are on file and available on request [Table S1 and Table S2]).


**Figure 2** Example (arrow) of various anatomical features revealed by micro-computerized tomography: (a) an accessory canal that branched at an oblique angle from a main canal; (b) a lateral canal that branched at almost right angle from a main canal; (c) an apical delta that had a complex, fine ramifications near the apex; and (d) inter-canal communication running between main canals but did not communicate with the root surface.

## Discussion

The apical 3–5 mm of a root canal system is generally regarded as a critical zone, complete debridement of which has been considered as an important element for a good prognosis of root canal treatment (Simon 1994). The C-shaped root canal system, undoubtedly, is a challenge to even the most experienced clinicians. A detailed morphological description of the apical 5 mm of such root canals has been achieved in the root study using 3D-reconstructed models in tandem with examination under the stereomicroscope.

Approximately 36% of the mandibular second molars with a C-shaped canal system had two main apical foramina, one in each albeit fused root; some 16% of these teeth possessed one single canal and a single main foramen. Marroquin *et al.* (2004), using stereomicroscope measurements, reported a 69% incidence of single foramen and 31% of two foramina in the mesial root, and 87% and 13%, respectively, in

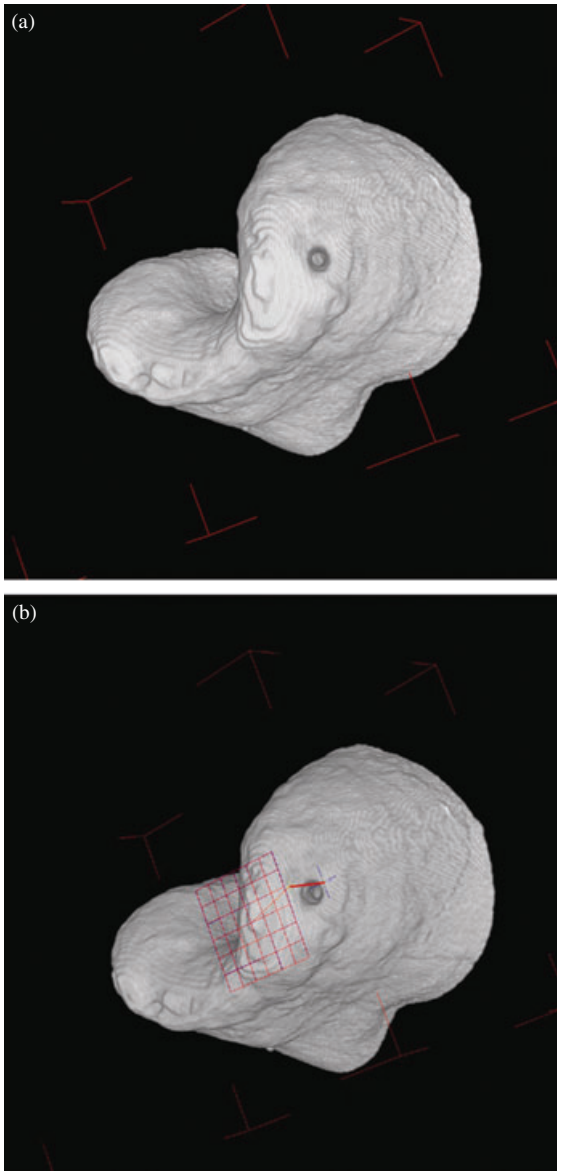


**Figure 3** (a) An apical foramen as observed in software; and (b) a red line representing the distance between the most coronal point of the anatomical foramen and anatomical root apex (being the most apical plane of the root which was indicated by a grid).

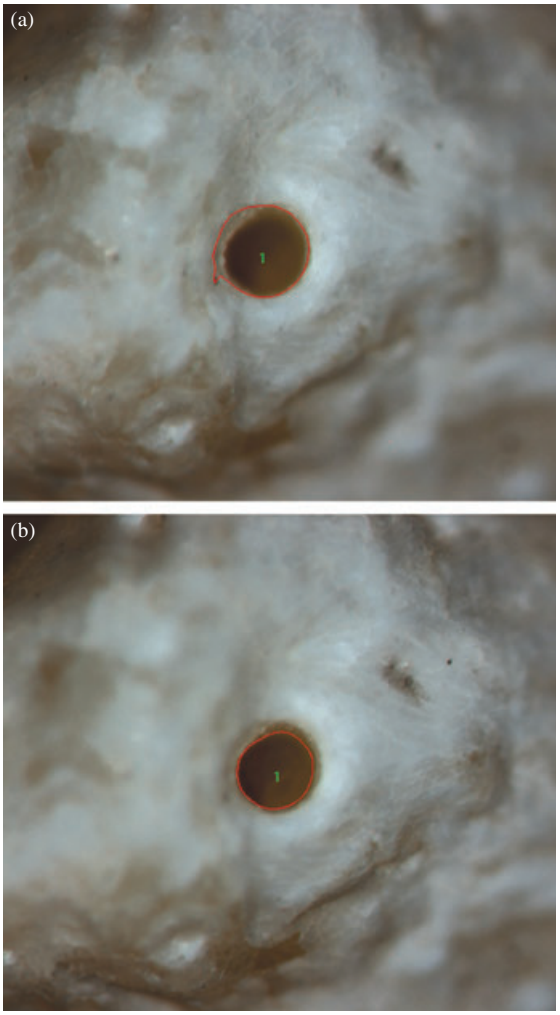


**Figure 4** Photomicrograph of an apical foramen (same tooth as in Fig. 3) captured under ×50 magnification: (a) with the perimeter outlined in red by auto-segmentation in software; and (b) the 'physiological' foramen, outlined in red, identified through regulating the focus.

the distal root of mandibular second molars in general. In the study of Green (1955), 100 mandibular molars (not limited to C-shaped canals) were examined under a stereo-binocular microscope, revealing an approximate incidence of 41% for one foramen and 30% for two foramina in the mesial root, and 65% and 23%, respectively, for the distal root. Morfis *et al.* (1994) studied the apices of human permanent teeth under the scanning electron microscope and found that 50% of the mesial roots of mandibular molars had one apical foramen whilst the rest had two or more foramina; however, all distal roots possessed one main foramen only. Rocha *et al.* (1996) reported an incidence of 61% with one and 38.8% with two foramina in the mesial root, and 97.4% and 2.6%, respectively, for the distal root of mandibular second molars. The difference in the

**Table 1** The types of canal configurations in apical 5 mm of each root

| Vertucci's | Type I | Type II | Type III | Type IV | Type V | Type VI | Type VII | Type VIII | Additional canal types | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Classification | (1) | (2–1) | (1–2–1) | (2) | (1–2) | (2–1–2) | (2–3) | (3) | (≥4) | |
| Count | 4 (9%) | 3 (7%) | 0 | 13 (29%) | 2 (5%) | 1 (2%) | 0 | 12 (28%) | 9 (20%) | 44 (100%) |

Figures in parentheses are percentages of total.

**Table 2** Prevalence of accessory canals, lateral canals, inter-canal communications and apical deltas on 3D-reconstructed instrumented models

| | Accessory canal | Lateral canal | Inter-canal communication | Apical delta |
|---|---|---|---|---|
| Present | 18 (41%) | 11 (25%) | 12 (27%) | 5 (11%) |
| Not found | 26 (59%) | 33 (75%) | 32 (73%) | 39 (89%) |
| Total | 44 | 44 | 44 | 44 |

**Table 3** Identification of main and accessory foramina on 3D-reconstructed models of C-shaped canals: (A) number; and (B) distribution of teeth with various number of foramen noted

| No. of foramina identified | Main foramen | | | | Accessory foramen | | |
|---|---|---|---|---|---|---|---|
| | No. (%) | M | D | S | No. (%) | M | D |
| (A) | | | | | | | |
| 0 | – | – | – | – | 23 (52) | – | – |
| 1 | 7 (16) | – | – | 7 | 7 (16) | 5 | 2 |
| 2 | 16 (36) | 16 | 16 | – | 9 (20) | 11 | 7 |
| 3 | 12 (28) | 22 | 14 | – | 4 (10) | 8 | 4 |
| 4 | 7 (16) | 14 | 14 | – | 1 (2) | 4 | 0 |
| 5 | 1 (2) | 4 | 1 | – | – | – | – |
| 6 | – | – | – | – | – | – | – |
| 7 | 1 (2) | 4 | 3 | – | – | – | – |
| Total | 44 (100) | 60 | 48 | 7 | 44 (100) | 28 | 13 |
| | | 115 | | | | 41 | |

| No. of foramina identified | No. of teeth (%) | Locations |
|---|---|---|
| (B) | | |
| 1 | 7 (16) | Single canal: 7 |
| 2 | 16 (36) | One mesial, one distal: 16 |
| 3 | 12 (28) | Two mesial, one distal: 10<br>One mesial, two distal: 2 |
| 4 | 7 (16) | Two mesial, two distal: 3<br>One mesial, three distal: 2<br>Three mesial, one distal: 2 |
| 5 | 1 (2) | Four mesial, one distal:1 |
| 7 | 1 (2) | Four mesial, three distal: 1 |
| Total | 44 (100) | |

D, the number of the main and accessory foramina being from distal root canal.
M, the number of the main and accessory foramina being from mesial root canal.
S, the number of the main and accessory foramina being from single root canal.

**Table 4** Distance between the main or accessory foramina and the anatomic apex (in millimeters) measured on 3D-reconstructed canal models

| | Main foramen | | | Accessory foramen | | |
|---|---|---|---|---|---|---|
| | Subtotal | Mesial canal | Distal canal | Subtotal | Mesial canal | Distal canal |
| Minimum | 0.01 | 0.01 | 0.07 | 0.13 | 0.13 | 0.27 |
| Maximum | 3.15 | 2.66 | 3.15 | 4.32 | 4.32 | 4.16 |
| Mean | 0.84[a] | 0.89 | 0.79 | 1.61[a] | 1.47 | 1.86 |
| SD | 0.58 | 0.64 | 0.52 | 1.15 | 1.08 | 1.27 |
| Subtotal | 115 | 60 | 48 | 41 | 27 | 14 |

[a]Mann–Whitney *U*-test for the difference between the mean distance of main foramen to the anatomic apex and that of accessory foramen, $P < 0.001$.
SD, standard deviation.

number of foramen between this and those previous studies may be related to the different samples (only C-shaped canals examined here) and the method of identifying the foramina. There was a high percentage of one foramen at the mesial (20/44) or the distal (29/44) aspect in the cases of two canals within a C-shaped root in this present study. The high percentage of multiple foramina is related to the high incidence of types IV and VIII and of the additional (with 4–7 foramina) canal configurations revealed in these teeth (see Table 1). This indicated the complexity of the anatomy of C-shaped canals near the apical region, calling for special attention to ensure complete cleaning and shaping during root canal preparation.

The prevalence of teeth with an accessory canal was 41% from the 3D-restructed images in this study, which was similar to that of Vertucci (1984) and Morfis *et al.* (1994) but was considerably higher than that of Marroquin *et al.* (2004) and Green (1955). On the other hand, only a small number of teeth with accessory foramen could be found, a figure similar to Marroquin *et al.* (2004) and Green (1955) who used a similar method of examination. There was a high percentage of canal irregularities, such as accessory or lateral canals, and apical delta, suggesting that the cleaning, shaping and filling of the C-shaped canal system would be a challenge.

**Table 5** The longest and shortest diameters (in millimeters) of the main (in 44 teeth) and accessory foramina (in 15 teeth) as were observed under stereomicroscope

| | Main 'physiological' foramen | | | | | | Accessory 'physiological' foramen | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Subtotal | | Mesial canal | | Distal canal | | Subtotal | | Mesial canal | | Distal canal | |
| | L | S | L | S | L | S | L | S | L | S | L | S |
| Minimum | 0.06 | 0.06 | 0.06 | 0.06 | 0.08 | 0.06 | 0.04 | 0.02 | 0.04 | 0.02 | 0.06 | 0.04 |
| Maximum | 1.34 | 0.45 | 1.34 | 0.36 | 1.22 | 0.45 | 0.15 | 0.12 | 0.15 | 0.12 | 0.14 | 0.11 |
| Mean | 0.32 | 0.19 | 0.26* | 0.15** | 0.36* | 0.22** | 0.10 | 0.07 | 0.10 | 0.07 | 0.10 | 0.07 |
| SD | 0.21 | 0.09 | 0.19 | 0.06 | 0.21 | 0.09 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| Total no. | 115 | | 60 | | 48 | | 21 | | 15 | | 6 | |

Mann–Whitney *U*-test: *$P = 0.01$; **$P = 0.000$.
L, the longest diameter.
S, the shortest diameter.
SD, standard deviation.

**Table 6** Form factor (FF) of main and accessory foramina

| | Main foramen | Accessory foramen |
|---|---|---|
| Minimum | 0.15 | 0.42 |
| Maximum | 0.92 | 0.95 |
| Mean | 0.73[a] | 0.82[a] |
| SD | 0.16 | 0.12 |
| Total no. | 115 | 21 |

[a]Mann–Whitney *U*-test, $P = 0.006$.
SD, standard deviation.

The dimension of the 'physiological' foramen, or apical constriction, has been a focus of debate. The measurement here should provide clues for the size of master apical file during root canal preparation (Ricucci 1998, Jou *et al.* 2004). The mean value for the longest and the shortest diameter of the apical constriction were found to be 0.26 and 0.15 mm at the mesial; those measurements for the distal canal were 0.36 and 0.22 mm, respectively. Marroquin *et al.* reported a similar mean diameter of 0.16 (shortest) to 0.33 mm (longest) for both the mesial and distal root (Marroquin *et al.* 2004), whereas Morfis *et al.* (1994) found a mean diameter of 0.26 mm and 0.39 mm for the mesial and distal canals, respectively (without defining the exact site of measurement). A number of reports have described the shape of the apical foramen (Simon 1994, Marroquin *et al.* 2004). In this study, the shape of the foramen was quantified by a FF value that has been commonly used to evaluate the shape of an object in the medical field (Crocker *et al.* 1983, Tosi *et al.* 1984). The present results indicated that the shape of the accessory foramen was usually more regular, i.e. close to round (FF≈1), than that of the main foramen. The FF, as well as the dimension of the apical constriction, can have an impact on the selection of instrumentation technique.

## Conclusion

The apical anatomy of C-shaped root canal systems (found in mandibular second molars) is extremely complex with many anatomical varieties.

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## Supplementary Material

The following supplementary material is available for this article:

**Table S1** The longest and shortest diameters (in millimeters) of the anatomical main (in 44 teeth) and accessory foramina (in 15 teeth) as were observed under stereomicroscope.

**Table S2** Form factor (FF) of anatomical main and accessory foramina.

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