JOURNAL OF ENDODONTICS
Printed in U.S.A.
VOL. 30, NO. 12, DECEMBER 2004

CASE REPORT/CLINICAL TECHNIQUES

C-shaped Canal System in Mandibular Second Molars: Part I—Anatomical Features

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The purpose of this study was to investigate the anatomical features of C-shaped root canal system in mandibular second molars using micro-computed tomography (μCT). Fifty-eight extracted mandibular second molars with fused roots were collected from a native Chinese population. The teeth were scanned into layers of 0.5-mm thickness by μCT and measurements were made at eleven levels. The ratio of the depth of the deepest part of the groove to the buccal-lingual thickness of the cross-section of the root was calculated for each tooth. The canal shapes of the scanned cross-sections were assessed and classified according to a modified Melton's method. Results were subject to the Kruskal-Wallis test. Of the 58 molars, 54 had a C-shaped canal system with a mean groove-to-thickness ratio of 47.96%; the four teeth without a C-shaped canal had a mean ratio of 14.82%. Most orifices (98.1%) were found within 3 mm below the cementoenamel junction. Of teeth with a C-shape canal system, a majority demonstrated an orifice with an uninterrupted "C" configuration. Seventeen canals divided in the apical portion, most of which did so within 2 mm from the apex. The cross-sectional shape varied drastically along the length of the canal. Teeth with a high groove-to-thickness ratio had at least one section with C1, C2, or C3 configuration. The canal shape in middle and apical thirds of C-shaped canal systems could not be predicted on the basis of the shape at the orifice level. Section 2 of this paper addressed the correlation between the radiographic appearance and these μCT images.

The C-shaped canal system is an anatomical variation mostly seen in mandibular second molars, although it can also occur in maxillary and other mandibular molars (1, 2). The main anatomical feature of C-shaped canals is the presence of a fin or web connecting the individual root canals—the orifice may appear as a single ribbon-shaped opening with a 180° arc linking the two main canals (3). Typically, this canal configuration is found in teeth with fusion of roots either on its buccal or lingual aspect. In such teeth, the floor of the pulp chamber is usually situated deeply and may assume an unusual anatomical appearance. A number of reports have described different trends in the shape and number of roots and root canals among different human races (3, 4). The variation appears to be genetically determined and may be used in tracing the ethnic origin of the subjects (3). The prevalence of C-shaped canal system in second mandibular molars has been reported to be 31.5% for the Chinese population (5), which is much higher than that reported for other populations (1, 4). When present on one side, a C-shaped canal may be found in the contralateral tooth in over 70% of individuals (6).

Roots containing a C-shaped canal often have a conical or square configuration (7, 8). The description regarding these roots was identified initially in comparative anthropology. Manning (7) speculated that the failure of the Hertwig's epithelial root sheath to fuse on the lingual or buccal root surface was the main cause of a C-shaped root, which always contains a C-shaped canal. The C-shaped root may also be formed by coalescence because of deposition of cementum with time (7).

The C-shaped canal system can assume many variations in its configuration. Melton and co-workers (9) proposed a classification of C-shaped canals based on their cross-sectional shape. However, it has been pointed out that this shape can vary along the length of the root so that the clinical crown morphology or the appearance of the canal orifice may not be good predictors of the actual canal anatomy (10). In Melton's classification, there has been no clear description of the difference between categories II and III (i.e. C2 and C3, respectively, in Fig. 1), as well as the clinical significance. Furthermore, they examined three arbitrary levels of the root and hence little information is present describing how the canal shape may change over its length. Cooke and Cox (1) were first to describe the clinical significance of C-shaped canals, which present a challenge with respect to their debridement and obturation. This is especially true when it is uncertain whether a C-shaped orifice found on the floor of the pulp chamber may continue to the apical third of the root. Irregular areas in a C-shaped root canal

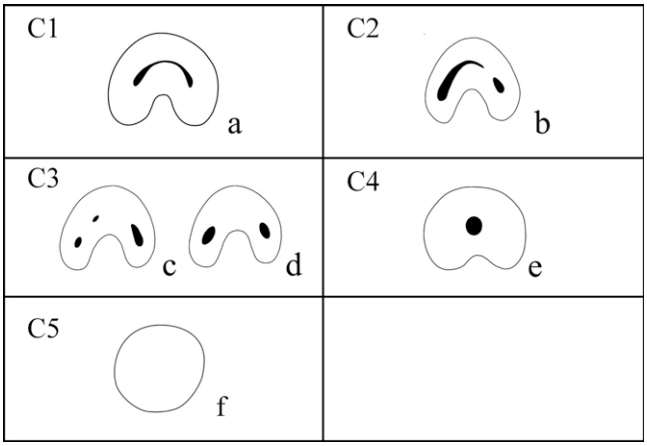

FIG 1. Classification of C-shaped canal configuration.

system that may house soft tissue remnants or infected debris may escape thorough cleaning or filling—this has provoked the many modified techniques to manage such cases endodontically (11, 12).

In recent years, micro-computed tomography (μCT) has been applied not only to evaluate cross-sections of teeth, but also to diagnose or evaluate the location and size of periradicular lesions (13, 14). The morphological changes in the root canal shape before and after instrumentation may also be determined in details by μCT nondestructively (15, 16). The same apparatus is obviously suitable for an in-depth study of root canal anatomy (16, 17). The purpose of this study was to investigate the anatomical features of C-shaped canal system through analyzing the serial cross-sectional shapes of human mandibular second molars obtained by μCT scanning. Further correlation of this data will be presented in a subsequent paper.

MATERIALS AND METHODS

Fifty-eight extracted mandibular second molars with fused roots were collected from a native Chinese population. They were stored in 10% neutral buffered formalin and any attached soft tissue were removed before the experiment. Each tooth was scanned from the anatomical apex to the crown at 0.5-mm interval using μCT (μCT-20, Scanco Medical AG, Switzerland) at high resolution and following the manufacturer's instruction. The canal shape at each selected level was classified into the following categories that were a modification of Melton's method:

Category I (C1): the shape was an uninterrupted "C" with no separation or division (Fig. 1A).

Category II (C2): the canal shape resembled a semicolumn resulting from a discontinuation of the "C" outline (Fig. 1B), but either angle α or β (Fig. 2) should be no less than 60°. These angles were measured using the VixWin2000 software (Dentsply, York, PA; now Gendex Dental Systems, Des Plaines, IL) by three independent operators and the mean was taken.

Category III (C3): two or three separate canals (Figs. 1C, D) and both angles, α and β, were less than 60° (Fig. 3). The measuring method was the same as above.

Category IV (C4): only one round or oval canal in that cross-section (Fig. 1E).

Category V (C5): no canal lumen could be observed (which was usually seen near the apex only) (Fig. 1F).

For purpose of this study, the level of cementoenamel junction (CEJ) was taken at the level where the enamel occupied 1/2 of the perimeter of that cross-section. The orifice of root canal was taken at the level where the floor of pulp chamber became discernible. The tooth was defined as having a C-shaped canal system when one or more cross-sections assumed a C1, C2, or C3 configuration.

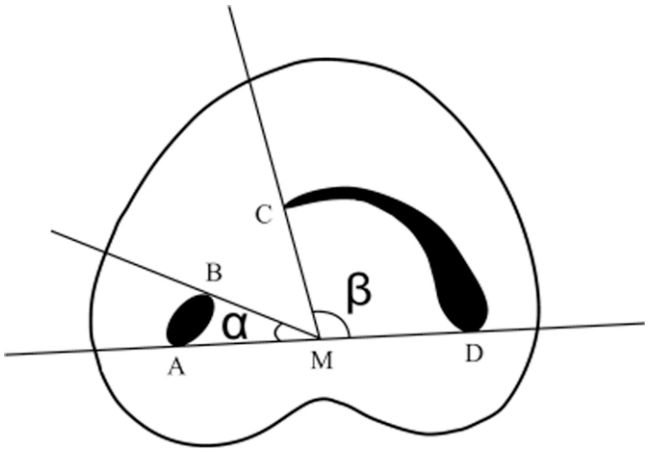

FIG 2. Measurement of angles for the C2 canal. Angle β is more than 60°. (A and B) Ends of one canal cross-section; (C and D) ends of the other canal cross-section; M, middle point of line AD; α, angle between line AM and line BM; β, angle between line CM and line DM.

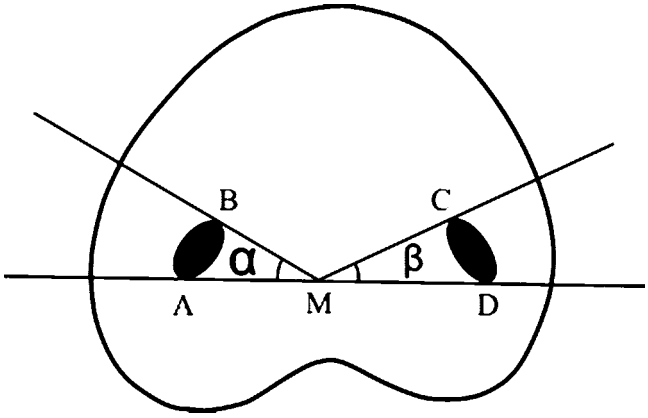

FIG 3. Measurement of angles for the C3 canal. Both angle α and angle β are less than 60°. (A and B) Ends of one canal cross-section; (C and D) ends of another canal cross-section; M, middle point of line AD; α, angle between line AM and line BM; β, angle between line CM and line DM.

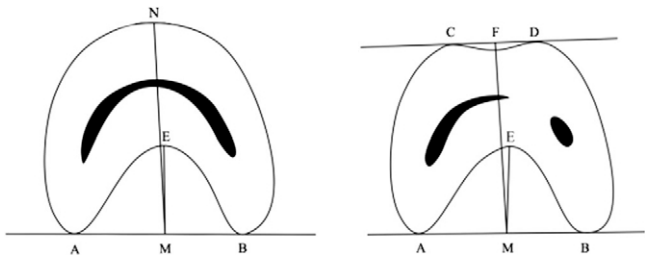

FIG 4. Measurement of depth of groove and thickness of root. AB, tangent line on the side of measured groove; CD, tangent line on the opposite side of measured groove; M, middle point of AB; E, vertex of the measured groove; EM, the depth of groove; N, vertex of the root surface opposite to AB; F, middle point of CD; MN or MF, the thickness of root cross-section.

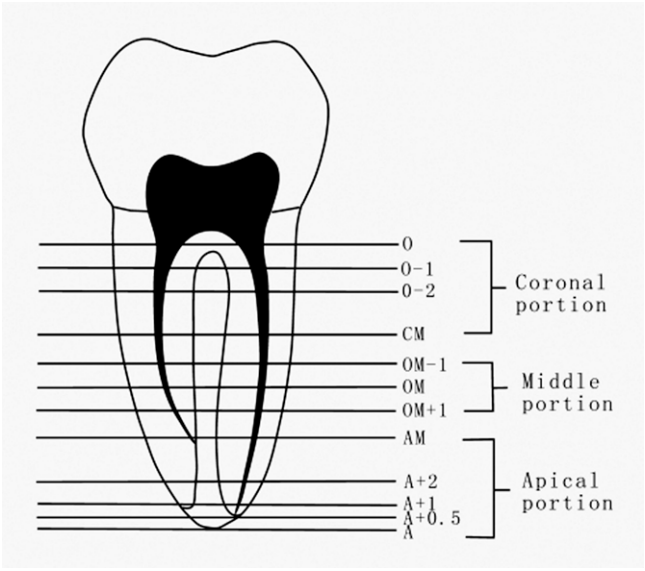

FIG 5. Levels over the length of root.

Teeth containing only one single round or oval canal (i.e. C4 type) from crown to apex was not classified as having a C-shaped canal.

For all 58 teeth, the cross-section with the deepest groove was chosen for distance measurement (Fig. 4). Of the roots with two grooves (buccal and lingual grooves), the deeper groove was chosen to measure. The distance EM was recorded as the depth of this groove, and NM (root with only one groove) or FM (root with two grooves) as the buccal-lingual thickness of that cross-section (Fig. 4). The ratio of EM to NM (or FM) was then calculated. This measurement was repeated three times and the mean value was reported as the "groove-to-thickness" ratio (R). The groove was classified into three levels according to the ratio value: no groove ($0 \leq R < 5\%$); shallow groove ($5\% \leq R < 20\%$), deep groove ($R \geq 20\%$).

The cross-sectional configurations were analyzed at the following 11 levels: O, the orifice of canal; O + 1, 1 mm below the canal orifice of canal; O + 2, 2 mm below the canal orifice; CM, the coronal-third point (1/3 the distance between the orifice and the anatomical apex); OM-1, 1 mm coronal to the middle of the root; OM, middle of the root (mid-point from orifice to apex distance-wise); OM + 1, 1 mm apical to the middle of the root; AM, the apical-third point (junction between the middle and apical thirds of the root distance-wise); A + 2, 2 mm from the anatomical apex (A); A + 1, 1 mm from the apex; A + 0.5, 0.5 mm from the apex (Fig. 5). The level at which the main canal began to branch or divide was also noted.

The distribution of various canal configurations along the root length was subject to the Kruskal-Wallis statistical test at a significance level of 0.05.

RESULTS

Specimen Demographics

In all of the 58 teeth, 23 had only one longitudinal groove on lingual root surface, whereas the other 35 had one buccal and one lingual groove. In those teeth with two grooves, 33 had a deeper groove on the lingual root surface, and only two teeth had **a** deeper groove on the buccal. Fifty-four teeth had a C-shaped canal system somewhere along its length (Fig. 6), whereas four had a single

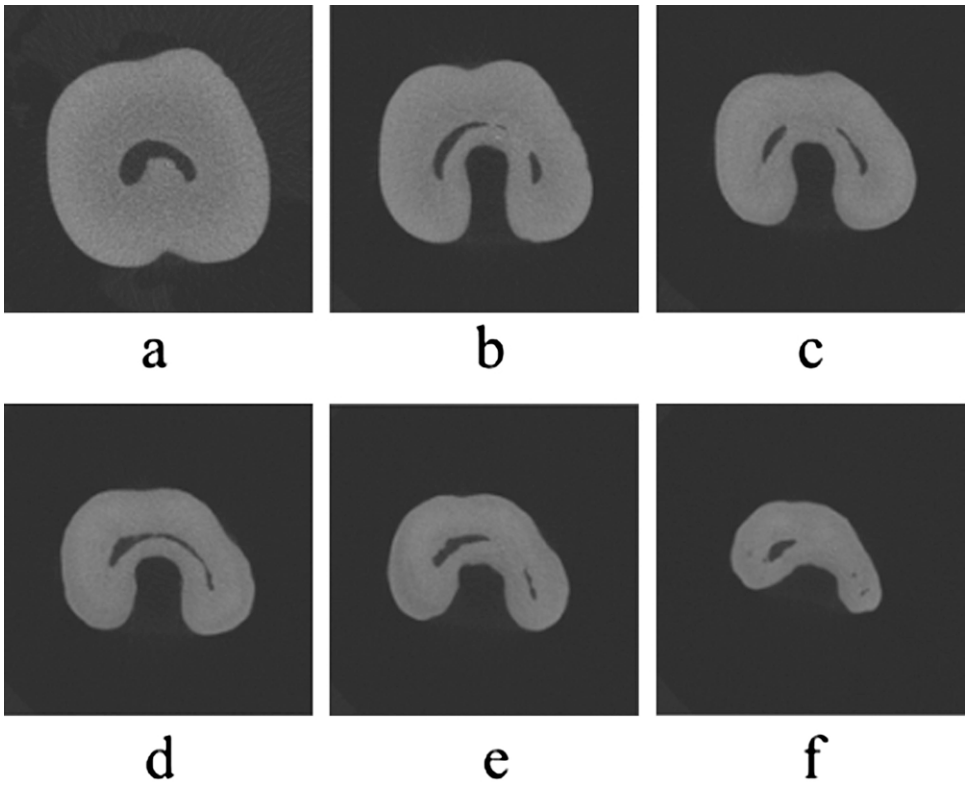

FIG 6. Examples of some μCT images of a tooth with C-shaped canal system. (*a*) Canal orifice; (*b*) coronal—third point; (*c*) mid-root; (*d*) apical—third point; (*e*) 2 mm above apex; (*f*) 1 mm above apex.

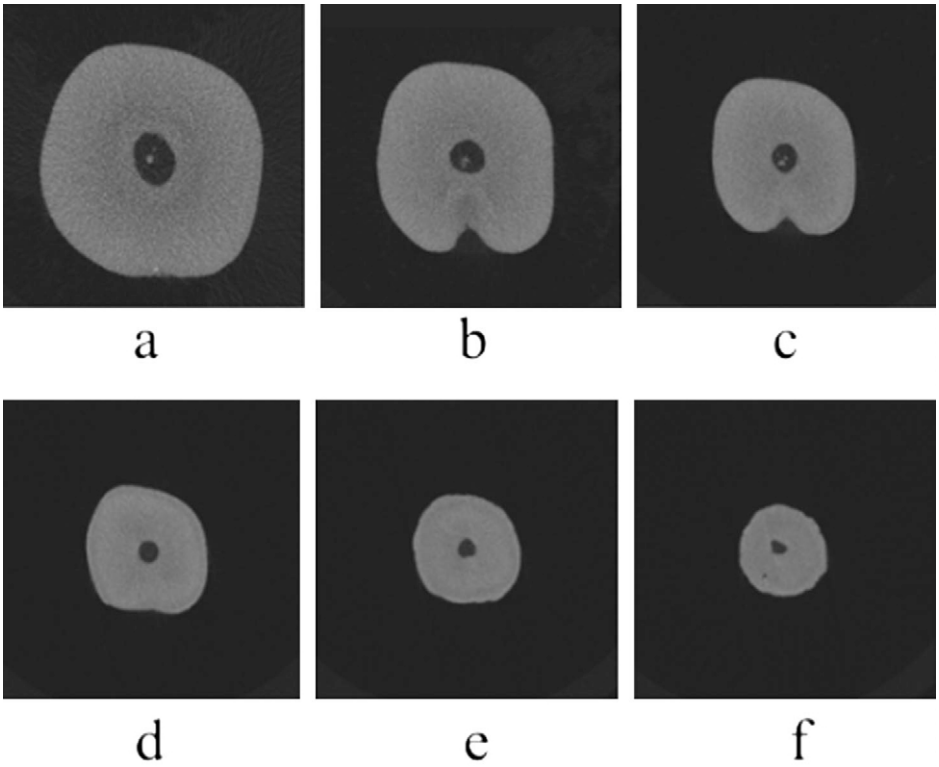

FIG 7. Scanned images of a tooth without C-shaped canal system (C4 category). (a) Canal orifice (2 mm below the CEJ); (*b*) coronal—third point; (*c*) mid-root; (*d*) apical—third point; (e) 2 mm above apex; (*f*) 1 mm above apex.

TABLE 1. Ratio of the groove depth to the buccal-lingual thickness of the root examined

	Groove-to-thickness ratio (R)					Mean ratio (%)	Total no.
	$0 \le R < 0.05$	$0.05 \le R < 0.20$	$0.20 \le R < 0.40$	$0.40 \le R \le 0.60$	$R > 0.60$		
Teeth with a C-shaped canal	0	2	8	37	7	47.96	54
Teeth without a C-shaped canal	0	4	0	0	0	14.82	4

TABLE 2. Level at which the canal orifices were found (those with C-shaped canals only, *n* = 54)

Location	No.	(%)	Cumulative no.	Cumulative %
CEJ	0	(0.00)	0	0.00
CEJ + 1	13	(24.10)	13	24.10
CEJ + 2	32	(59.26)	45	83.30
CEJ + 3	8	(14.81)	53	98.10
CEJ + 4	1	(1.85)	54	100.00

CEJ + 1: 1 mm below the CEJ; CEJ + 2: 2 mm below the CEJ; CEJ + 3: 3 mm below the CEJ; CEJ + 4: 4 mm below the CEJ.

TABLE 3. Appearance of the orifices (C-shaped canals only, *n* = 54)

Shape	No.	%
C1	48	88.89
C2	4	7.41
C3	2	3.70
Total	54	100.00

round or oval canal throughout (Fig. 7). The mean ratio of groove-to-thickness in these 54 teeth with a C-shaped canal was 47.96%; that for the four teeth without was 14.82% (Table 1). The average length of the roots (from CEJ to root apex) for all specimens was 12.1 mm, ranging from 9.5 mm to 16.5 mm.

TABLE 4. Distribution of various canal shapes over the length of the root

Location	C1	C2	C3	C4	C5
O	48	4	2	0	0
O-1	32	13	9	0	0
O-2	18	27	9	0	0
CM	4	32	18	0	0
OM-1	5	31	18	0	0
OM	8	22	24	0	0
OM + 1	12	15	27	0	0
AM	14	12	27	1	0
A + 2	10	3	32	9	0
A + 1	2	1	29	22	0
A + 0.5	2	0	12	34	6

$T = 275.19$, $p < 0.005$ (Kruskal-Wallis test).

Orifice: Location and Appearance

None of the orifice was found at the level of the CEJ; only about 1/4 were found at a level 1 mm below. Nearly all (98.1%) could be found within 3 mm below the CEJ (Table 2). The majority of canal orifices demonstrated an uninterrupted "C" shape, i.e. C1 configuration (e.g. Fig. 6*a*). Four teeth had a C2-type orifice, and another two assumed the C3 shape (Table 3). Those four teeth without a C-shaped canal all had oval or round orifices (Fig. 7*a*).

TABLE 5. Level at which the canal divided (C-shape canals only, N = 54)

Location	No.	Cumulative	(Cumulative % of subtotal)	% of total
A + 1	3	3	(17.65)	5.56
A + 1.5	5	8	(47.06)	9.26
A + 2	6	14	(82.35)	11.11
A + 2.5	1	15	(88.24)	1.85
A + 3	1	16	(94.12)	1.85
A + 4	1	17	(100.00)	1.85
Subtotal	17	—	—	31.48
Total	54	—	—	100.00

A + 1: 1 mm from the apex; A + 1.5: 1.5mm from the apex; A + 2: 2mm from the apex; A + 2.5: 2.5mm from from the apex; A + 3: 3mm from the apex; A + 4: 4mm from the apex.

Cross-Sectional Canal Shape

Only those 54 teeth with a C-shaped canal system were reported here (Table 4). There were significant differences in the distribution of various canal configurations at different levels of the root (Kruskal-Wallis test, $p < 0.005$), that is, the canal shape varied along the length of the root (e.g. see Fig. 6).

Canal Bifurcation

The level at which the C-shaped canal began to divide was summarized in Table 5. Canal bifurcation was observed in the apical 4 mm of 17 teeth, with the great majority of them occurring within 2 mm from the apex.

DISCUSSION

Al-Fouzan (18) considered C-shaped canals as all those with a general outline of a "C" and present in a C-shaped root, i.e. one with a longitudinal groove on the root surface, regardless of whether a separate canal or orifice was observed. In the present study, all mandibular second molars qualified as having a C-shaped canal system had to exhibit all the following three features:

(a) fused roots;
(b) a longitudinal groove on lingual or buccal surface of the root;
(c) at least one cross-section of the canal belongs to the C1, C2, or C3 configuration.

There were six teeth with relatively shallow grooves, of which four did not contain a C-shaped canal system; only two teeth with a shallow groove on the root had such. When a deep groove (as given by a high groove-to-thickness ratio) is present, a C-shaped canal is to be expected. Although the C3-type orifice may look like two or three separate orifices, an isthmus linking them is often discernible. The single, round, or oval canal (C4 in our classification), which may be found near the apex, should be considered as a variation since other parts of the canal have demonstrated the "C" configuration.

The original classification by Melton and co-workers (9) stated that C2 and C3 canals have separated canals, but there was no description of how to differentiate the two. In our modified classification, one of the canals in the C2 category would appear as an arc (with $\beta \geq 60^{o}$, see Fig. 2). That is, the C2 canal would be more likely to extend into the "fused" area of the root where the dentin wall may be quite thin. They are probably more difficult to clean and shape than the C3-type canals.

In this study, the μCT has provided serial cross-sections over the entire length of the root canal system at a high resolution. Based on these images, the C-shaped canal could be seen to vary in shape at different levels considerably (Table 4). Clinically, when a C-shaped canal orifice is observed, say, under the operating microscope, one cannot assume that such a shape continues throughout its length. New methods should be developed to diagnose not only the existence, but the configuration of the entire C-shaped canal system in mandibular second molars.

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References

1. Cooke HG, Cox FL. C-shaped canal configurations in mandibular molars. J Am Dent Assoc 1979;99:836–9.
2. Sidow SJ, West LA, Liewehr FR, Loushine RJ. Root canal morphology of human maxillary and mandibular third molars. J Endod 2000;26:675–8.
3. Gulabivala K, Opasanon A, Ng Y-L, Alavi A. Root and canal morphology of Thai mandibular molars. Int Endod J 2002;35:56–62.
4. Haddad GY, Nehme WB, Ounsi HF. Diagnosis, classification, and frequency of C-shaped canals in mandibular second molars in the Lebanese population. J Endod 1999;25:268–71.
5. Yang ZP, Yang SF, Lin YL. C-shaped root canals in mandibular second molars in Chinese population. Endod Dent Traumatol 1988;4:160–3.
6. Sabala CL, Benenati FW, Neas BR. Bilateral root or root canal aberrations in a dental school patient population. J Endod 1994;20:38–42.
7. Manning SA. Root canal anatomy of mandibular second molars. Part II. C-shaped canals. Int Endod J 1990;23:40–5.
8. Jerome CE. C-shaped root canal system: diagnosis, treatment, and restoration. Gen Dent 1994;42:424–7.
9. Melton DC. Krell KV, Fuller MW. Anatomical and histological features of C-shaped canals in mandibular second molars. J Endod 1991;17:384–8.
10. Fan B, Chen WX, Fan MW. Configuration of C-shaped canals in mandibular molars in Chinese population. J Dent Res 2001;80:704
11. Walid N. The use of two pluggers for the obturation of an uncommon C-shaped canal. J Endod 2000;26:422–4.
12. Liewehr FR, Kulild JC, Primack PD. Obturation of a C-shaped canal using an improved method of warm lateral condensation. J Endod 1993;19:474–7.
13. Kim E, Kim KD, Roh BD, Cho YS, Lee SJ. Computed tomography as a diagnostic aid for extracanal invasive resorption. J Endod 2003;29:463–5.
14. Stechow DV, Balto K, Stashenko P, Mller R. Three-dimensional quantitation of periradicular bone destruction by micro-computed tomography. J Endod 2003;29:252–6.
15. Peters OA, Laib A, Göhring TN, Barbakow F. Changes in root canal geometry after preparation assessed by high-resolution computed tomography. J Endod 2001;27:1–6.
16. Peters OA, Laib A, Ruegsegger P, Barbakow F. Three-dimensional analysis of root canal geometry using high-resolution computed tomography. J Dent Res 2000;79:1405–9.
17. Nielsen RB, Alyassin AM, Peters DD, Carnes DL, Lancaster J. Micro-computed tomography: an advanced system for detailed endodontic research. J Endod 1995;21:561–8.
18. Al-Fouzan KS. C-shaped root canals in mandibular second molars in a Saudi Arabian population. Int Endod J 2002;35:499–504.