The C-shaped Root Canal Configuration: A Review

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Abstract

Recognition of unusual variations in the canal configuration is critical because it has been established that the root with a single tapering canal and apical foramen is the exception rather than the rule. The early recognition of these configurations facilitates cleaning, shaping, and obturation of the root canal system. "C" configuration, which is an important anatomic variation, presents a thin fin connecting the root canals. Because of the importance of its true diagnosis and treatment, a comprehensive review of published information and investigations about it in addition to approaches for its treatment is necessary. *(J Endod 2007; 33:517–523)*

Key Words

Anatomy, canal configuration, C-shape

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The study of root and canal anatomy has endodontic (1) and anthropologic (2–6) significance. In fact, it is important to be familiar with variations in tooth anatomy and characteristic features in various racial groups because such knowledge can aid location and negotiation of canals as well as their subsequent management (1).

One of the most important anatomic variations is the "C" configuration of the canal system. The C-shaped canal, which was first documented in endodontic literature by Cooke and Cox in 1979 (7), is so named for the cross-sectional morphology of the root and root canal. Instead of having several discrete orifices, the pulp chamber of the C-shaped canal is a single ribbon-shaped orifice with a 180° arc (or more), which, in mandibular molars, starts at the mesiolingual line angle and sweeps around the buccal to the end at the distal aspect of the pulp chamber. Below the orifice level, the root structure can harbor a wide range of anatomic variations. These can be classified into two basic groups: (1) those with a single, ribbon-like, C-shaped canal from orifice to apex and (2) those with three or more distinct canals below the C-shaped orifice. Fortunately, C-shaped canals with a single swath of canal are the exception rather than the rule (8).

Once recognized, the C-shaped canal provides a challenge with respect to debridement and obturation, especially because it is unclear whether the C-shaped orifice found on the floor of the pulp chamber actually continues to the apical third of the root (7, 9).

Typically, this canal configuration is found in the teeth with fusion of the 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 anatomic appearance (10). The main anatomic feature of C-shaped canals is the presence of a fin or web connecting the individual root canals. Roots containing a C-shaped canal often have a conical or square configuration (2, 3, 11).

Because of the great challenges in the diagnosis and treatment of "C" configuration and critical need for its proper management, this review will address its etiology, classification, diagnosis, and treatment.

Etiology

The shape and the number of roots are determined by Hertwig's epithelial sheath, which bends in a horizontal plane below the cementoenamel junction and fuses in the center leaving openings for roots (12). Failure of the Hertwig's epithelial root sheath to fuse on the lingual or buccal root surface is the main cause of C-shaped roots, which always contain a C-shaped canal. The C-shaped root may also be formed by coalescence because of deposition of the cementum with time (3).

C-shaped canals appear when fusion of either the buccal or lingual aspect of the mesial and distal roots occurs. This fusion remains irregular, and the two roots stay connected by an interradicular ribbon. The floor of the pulp chamber is deep and has an unusual anatomic appearance. Two or three canals may be found in the C-shaped groove, or the C-shape may be continuous throughout the root length (9, 13).

Classification

The C-shaped canal system can assume many variations in its configuration so a comprehensive classification can help in true diagnosis and management (10).

Melton's Classification

Melton et al. (14) in 1991 proposed the following classification of C-shaped canals based on their cross-sectional shape:

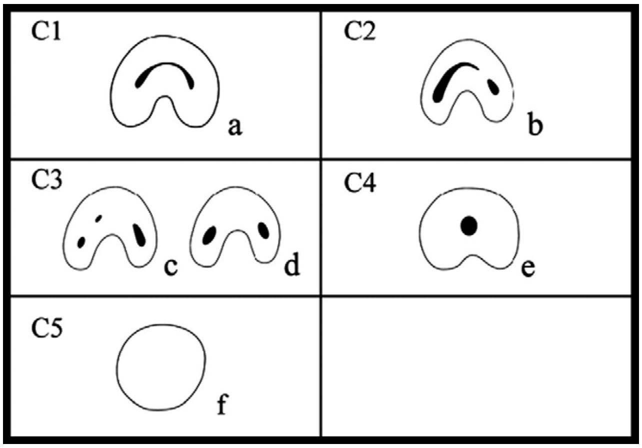

Figure 1. Classification of C-shaped canal configuration

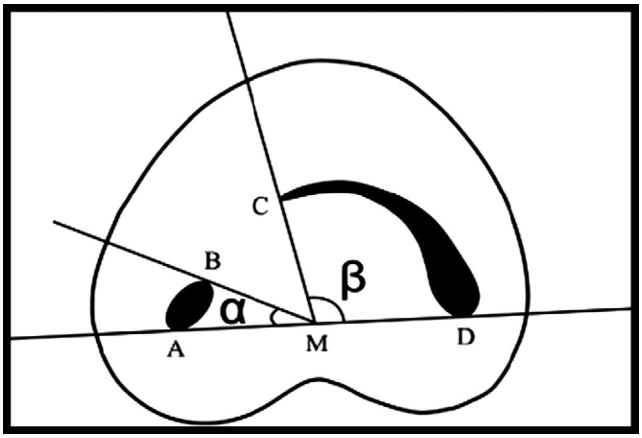

Figure 2. Measurement of angles for the C2 canal. Angle β is more than 60°. (*A* and *B*) Ends of one canal cross-section, (*C* and *D*) ends of the other canal cross-section; M, middle point of line AD; α, angle between line AM and line BM; β, angle between line CM and line DM

1. Category I: continuous C-shaped canal running from the pulp chamber to the apex defines a C-shaped outline without any separation (i.e., C1 in Fig. 1).
2. Category II: the semicolon-shaped (;) orifice in which dentine separates a main C-shaped canal from one mesial distinct canal (i.e., C2 in Fig. 1).
3. Category III: refers to those with two or more discrete and separate canals: subdivision I, C-shaped orifice in the coronal third that divides into two or more discrete and separate canals that join apically; subdivision II, C-shaped orifice in the coronal third that divides into two or more discrete and separate canals in the midroot to the apex; and subdivision III, C-shaped orifice that divides into two or more discrete and separate canals in the coronal third to the apex (i.e., C3 in Fig. 1).

In this classification, there has been no clear description of the difference between categories II and III 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. Also, they noted that the second type of C-shaped canal is the most common.

Fan's Classification (Anatomic Classification)

Fan et al. (10) in 2004 modified Melton's method into the following categories:

1. Category I (C1): the shape was an interrupted "C" with no separation or division (Fig. 1*A*).
2. Category II (C2): the canal shape resembled a semicolon resulting from a discontinuation of the "C" outline (Fig. 1*B*), but either angle α or β (Fig. 2) should be no less than 60°.
3. Category III (C3): 2 or 3 separate canals (Fig. 1*C* and *D*) and both angles, α and β, were less than 60° (Fig. 3).
4. Category IV (C4): only one round or oval canal in that cross-section (Fig. 1*E*).
5. Category V (C5): no canal lumen could be observed (which is usually seen near the apex only) (Fig. 1*F*).

They considered that although the C-type orifice may look like 2 or 3 separate orifices, an isthmus linking them is often discernible. The single, round, or oval canal (C4 in their classification), which may be found near the apex, should be considered as a variation because other parts of the canal have shown the "C" configuration. They noted that "C" shape can vary along the root length so the clinical crown morphology or the appearance of the orifice may not be good predictors of the actual canal anatomy. In this classification, one of the canals in the C2 category would appear as an arc (with $\beta \geq 60°$, Fig. 2) (i.e., 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 more difficult to clean and shape than C3 canals.

Fan's Classification (Radiographic Classification)

Fan et al. (11) classified C-shaped roots according to their radiographic appearance into three types:

1. Type I: conical or square root with a vague, radiolucent longitudinal line separating the root into distal and mesial parts. There was a mesial and a distal canal that merged into one before exiting at the apical foramen (foramina) (Fig. 4*A*).

2. Type II: conical or square root with a vague, radiolucent longitudinal line separating the root into distal and mesial parts. There was a mesial and a distal canal, and the two canals appeared to continue on their own pathway to the apex (Fig. 4*B*).

3. Type III: conical or square root with a vague, radiolucent longitudinal line separating the root into distal and mesial parts. There was a mesial and a distal canal, one canal curved to and superimposed on

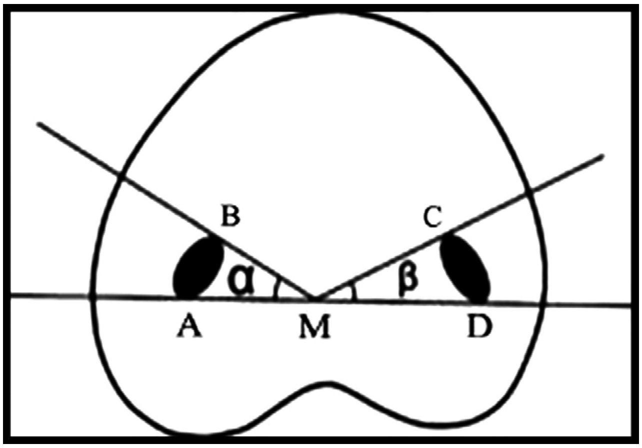

Figure 3. Measurement of angles for the C3 canal. Both angle α and angle β are less than 60°. (*A* and *B*) Ends of one canal cross-section; (*C* and *D*) ends of another canal cross-section; M, middle point of line AD; α, angle between line AM and line BM; β, angle between line CM and line DM

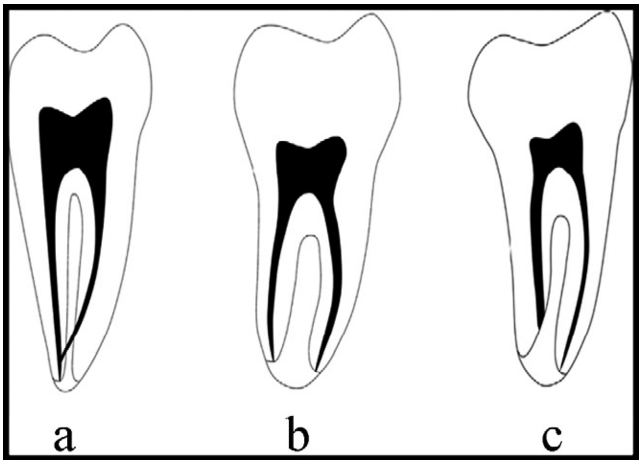

Figure 4. Radiographic types. (*A*) Type I, (*B*) type II, and (*C*) type III

this radiolucent line when running toward the apex, and the other canal appeared to continue on its own pathway to the apex (Fig. 4*C*).

Epidemiology

Endodontic textbooks state that the C-shaped canal is not uncommon (15), and this is confirmed by studies in which frequencies ranging from 2.7% (16) to 8% (7) have been reported (Table 1).

This configuration is a significant ethnic variation in the incidence of C-shaped molars. It is seldom found in white people; they have a relatively high prevalence in mandibular second molars of Chinese and Lebanese populations (3, 6, 16–18). This anatomy is much more common in Asians than in whites (8).

This variation may occur in mandibular first molars (19), maxillary molars (20, 21), mandibular first premolars (22), and even in maxillary lateral incisors (23), but it is most commonly found in mandibular second molars (2, 19, 21). When present on one side, a C-shaped canal may be found in the contralateral tooth in over 70% of individuals (24).

Various studies on the morphology of the root canal system have shown the complexity in the number and distribution of canals and that these differences may be caused by dissimilarities of examination methods, classification systems, sample size, and ethnic background of tooth sources (25).

Mandibular First Premolar

In 1992, using stereomicroscope and photography, Baisden et al. (26) reported the existence of C-shaped canals in 14% of mandibular first premolars. An interesting finding in this study was the number of C-shaped canals that were associated predominantly with type IV canal systems.

Sikri and Sikri (27) in 1994, using radiography from two directions (buccolingual and mesiodistal) and sectioning at three sites, indicated the incidence of 10% in mandibular first premolars, whereas this shape was not observed in mandibular second premolars.

In a recent study (2006) in a Chinese population performed by using a clearing technique, Lu et al. (22) reported the incidence of 18%. The C-shaped root canal occurred predominantly in the 3- and 6-mm sections with one or two canals coronally.

Mandibular First Molar

Barnett (13), in 1986, reported a case of a mandibular first molar with a normal mesiolingual orifice and a C-shaped groove that ran continuously from the mesiobuccal orifice along the buccal wall to the distal canal orifice. The groove ran continuously down the root to the apical third, where it is divided into two canals. Also, Bolger and Schindler (19) in 1988 reported the existence of a C-shaped groove in a mandibular first molar of a white male that extended from the distolingual to the distobuccal orifice and across the buccal surface to the mesiobuccal orifice, whereas the mesiolingual orifice remained separate. Four separate apical foramina were evident after extraction of the tooth.

Mandibular Second Molar

Studies on mandibular second molars have shown a high incidence of C-shaped roots and canals (10%-31.5%) in Japanese (28),

TABLE 1. Prevalence of "C" configuration—survey of available studies

Tooth Type	Investigators	Race	Sample Size	Number of C-shaped Roots^R/Canals^C	Total Percentage (%)
Mandibular first premolar	Baisden et al. (1992)	Not stated	106	15^R	14
	Sikri and Sikri (1994)	Not stated	112	11^C	10
	Lu et al. (2006)	Chinese	82	15^C	18
Mandibular second molar	Pineda and Kuttler (1972)	Not stated	300	0^C	0
	Cooke and Cox (1979)	Not stated	Not stated	Not stated	8
	Vertucci (1984)	Not stated	100	0^C	0
	Yang et al. (1988)	Chinese	581	183^R 81^C	31.5 13.9
	Weine et al. (1988)	Not stated	75	2^C	2.7
	Sutalo et al. (1998)	Not stated	112	14^R	12.5
	Weine (1998)	Mixed	811	62^C	7.6
	Haddad et al. (1999)	Lebanese	94	18^C	19.1
	Gulabivala et al. (2001)	Burmese	134	30^R	22.4
	Lambrianidis et al. (2001)	Not stated	480	22^C	5
	Gulabivala et al. (2002)	Thai	60	6^R	10
	Al-Fouzan (2002)	Saudi Arabian	151	16^C	10.6
	Seo and Park (2004)	Korean	272 (In vivo)	89^C	32.7
	Seo and Park (2004)	Korean	96 (In vivo)	30^C	31.3
	Cimilli et al. (2005)	Not stated	491	40^C	8
	Jin et al. (2006)	Korean	220	98^C	44.5
Third molars	Sidow et al. (2000)	Not stated	300	13^C	2.2
	Gulabivala et al. (2002)	Thai	173	19^R	11
Maxillary first molar	De Moor (2002)	Not stated	2175	2^C	0.091
	Cleghorn et al. (2006)	Mixed	2480	3^C	0.12

Chinese (17), Hong Kong Chinese (6), Lebanese (18), and Thai (29) populations. These studies indicate that C-shaped canals are more frequent in Asians, especially from the Far East.

In 1972, in a mesiodistal and buccolingual roentgenographic investigation, Pineda and Kuttler (30) surprisingly reported no C-shapes and, in fact, no single-rooted mandibular second molar.

Cooke and Cox (7) in 1979 claimed that 8% of the mandibular second molars treated endodontically in the late 1970s had the C-shaped, although no total sample size was indicated. In 1984, in a very exhaustive dye-injection study of mandibular second molars, Vertucci (1) failed to describe even one C-shaped root.

Yang et al. (17) in 1988, using a clearing technique, observed that approximately 31.5% of mandibular second molars in Chinese population had C-shaped roots. Less than half of these had true C-shaped canals, and only one fifth of the teeth (7.4%) had C-shaped canal orifices. At the same time, Weine et al. (16), using a clinically oriented in vitro method, reported the incidence of 2.7%.

In 1990, by rendering the roots transparent and allowing the canal system to be observed by black ink infiltration, Manning (3) found that only 10% had true C-shapes, which most frequently had three canals.

Sutalo et al. (31) in 1998, using injection of a contrast liquid (methylene blue) to the prepared teeth, showed the incidence of 12.5%, either total or partial C-configuration. At the same time, Weine (32), by combining the efforts of an endodontic study club, reported that 7.6% of root-filled second molars were C-shaped.

In 1999, Haddad et al. (18) examined 94 mandibular second molars with scheduled endodontic treatment over a 1-year period in the Lebanese population. They used two detection procedures, radiography and clinical examination, and indicated the incidence of 19.1%. They also noted that true C-shaped canals with a single swath of the canal in mandibular second molars were the exception rather than the rule.

Gulabivala et al. (33) in 2001, using a canal staining and tooth clearing technique, reported the incidence of 22.4% in Burmese patients. Intercanal communications were not uncommon in these teeth. At the same time, Lambrianidis et al. (25) evaluated the periapical radiographs of the patients and compared it with the clinical diagnosis stated on the patient's records and noted that 5% of treated teeth were C-shaped.

In 2002, using the injection of Indian ink, Gulabivala et al. (29) noted the prevalence of 10% in Thai population. The configuration of the canals in one third of the roots was type I (one canal), another one third had type IV canals (two canals), and the remainder had 3 to 4 or 2 to 3 configurations. At the same time, Al-Fouzan (34) indicated the incidence of 10.6% in the Saudi Arabian population. They concluded that all patients showing category III configuration were less than 40 years of age. This is in contrast to the observation of Manning (3) that age-related deposition of dentine formed separate canals. (Manning also reported that category III [subdivision III] systems occurred most frequently, which is in agreement with Al-Fouzan).

Seo and Park (35) in 2004, in clinical observation of the Korean population observed that 32.7% of mandibular second molars had C-shaped canals, whereas of the teeth examined in vitro, 31.3% had C configuration. Sixty-six percent of teeth had more than two categories in the five levels, but no consistent change of category in the area between two adjacent levels could be observed. Category II was by far superior in number on clinical observation, which is in accordance with the results of Yang et al. (17). At the apical level, there was no significant difference between the incidences of the three categories. This means that C-shaped canals, which have semicolon and continuous shape at the orifice level, have a high possibility of dividing into 2 or 3 canals in the apical region, which is important in endodontic treatment.

Chai and Thong (36) in 2004, by evaluation of cross-sectional morphology of mandibular molars, showed that the configurations were complete C (27%), incomplete C (64%), and non-C (9%). The mean value for the minimum width of the lingual and buccal walls was 0.58 and 0.96 mm, respectively.

At the same time, by anatomic evaluation, Fan et al. (10) indicated that a majority of teeth with C-shaped canal system showed an orifice with an uninterrupted "C" configuration. Thirty-two percent of the 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. 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. In addition, most orifices were found within 3 mm below the cementoenamel junction. In another study (11), by radiographic evaluation, they indicated that 30% of mandibular second molars showed type I radiographic image, 40% type II, and 30% type III. In the type I category, the C1 and C4 canal configurations were mostly found in the apical area. Categories C2 and C3 were the main configurations in the middle and apical areas in type II and III. The type III had more C2 canals in middle area than type II. These results suggested that it was possible to predict the presence and the configuration of C-shaped canal system by the radiographic appearance.

In 2005, Cimilli et al. (37), using spiral computed tomographic imaging, concluded that the prevalence of C-shaped canals in single-rooted mandibular second molars was 8%. Vertucci type I canals were most frequently seen in these C-shaped molars.

In a recent study (2006) performed by using serial axial computed tomography images, Jin et al. (38) reported the incidence of 44.5%. The continuous C-shaped canal was the most frequently found, and the separated canal was the least. Also, the thinnest remaining tooth structure in the groove area of the C-shaped molar was not different from that of the danger zone of normal ones.

Mandibular and Maxillary Third Molar

In 2000, using the method of transparency, Sidow et al. (39) concluded that 2.2% of third molars in the U.S. population were C-shaped. It should be emphasized that Gulabivala et al. (29) in 2002, using the injection of Indian ink, noted that mandibular third molars had a surprisingly high prevalence of C-shaped roots (11%).

Maxillary First Molar

Newton and McDonald (40) in 1984 reported the first case of "C" configuration in the maxillary molars, which was presented in the distobuccal canal of maxillary first molar. Another case of bilateral C-shaped canals was reported in 1990 (21). Also, using a clearing technique with methyl salicylate, al Shalabi et al. (41) in 2000 reported a fusion of the distobuccal and palatal roots in 1 of 83 extracted maxillary first molars in an Irish population.

In 2002, De Moor (42) concluded that the probability of observing C-shaped canals in maxillary first molars was as low as 0.091%. He noted that C-shaped root canal morphotypes may occur in the distal portion of the pulp chamber. It was observed that the "C" shape results from a fusion of the distobuccal and palatal roots, which may extend to the apical third of the fused roots.

According to literature review of Cleghorn et al. (43) in 2006, C-shaped roots and canals were found only in 0.12% of maxillary first molars. They divided past studies into laboratory studies (in vitro), clinical root canal system anatomy studies (in vivo), and clinical case reports of anomalies.

In another case report in 2006, a C-shaped canal in the buccal root of a maxillary first molar was reported. In the buccal root, what appeared to be the mesial and distal canals joined to form a single C-shaped canal that led to three separate foramina at the apex.

Maxillary Second Molar

Yang et al. (17) in 1988, using a clearing technique, observed that C-shaped canals were encountered in 4.9% of the Chinese maxillary second molars. These canals probably corresponded to both mesial and distal C-shapes.

Diagnosis

Some authors 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) (34), but the others noted that all teeth that qualified as having a C-shaped canal system had to exhibit all the following three features: fused roots, a longitudinal groove on the lingual or buccal surfaces of the root, and at least one cross-section of the canal belongs to the C1, C2, or C3 configuration (10). The C-shaped canal variation of morphology is unusual and can lead to difficulties during treatment (44) so the proper diagnosis of this situation is mandatory before treatment.

Radiographic Diagnosis

The preoperative awareness of a C-shaped canal configuration before treatment can facilitate effective management. A preoperative radiograph and an additional radiograph from 20° mesial or distal projection may be the only noninvasive means clinically to provide clues about the canal morphology (11, 42). Cooke and Cox (7) stated that it was impossible to diagnose C-shaped canals on the preoperative radiograph, but in the study of Haddad et al. (18) almost all preoperative radiographs showed common characteristics. These characteristics formed a typical image that allowed prediction of the existence of this anatomic condition. In fact, most radiographs revealed radicular fusion or proximity, a large distal canal, a narrow mesial canal, and a blurred image of a third canal in between. The canal orifice may present with a "C" shape but not always, and, when it does, it is no guarantee that it continues apically as a single canal (33).

Radiographs taken while negotiating the canals may reveal two characteristics for such canal configuration: instruments tending to converge at the apex and/or may exit at the furcation (2). The latter sometimes may resemble a perforation of the furcation (2, 9, 14, 45). This radiographic appearance is more likely to occur in category I (continuous) (2). The presence of instruments or filling materials in the furcation area in combination with the poorly distinguished floor of the pulp chamber can lead to radiographic recognition of "C" configuration. Differential diagnosis of C-shaped molars from furcation perforation, on the basis of radiographs, can be aided in cases of interpretation of more than one radiograph (25). Also, using a third-generation apex locator with the ability of reading canal lengths in the presence of electrolytes, should help to distinguish between the two (14).

The root configuration of molars having this canal shape may be represented as a single fused root or as two distinct roots with a communication, the latter of which may not be very obvious at first glance (33). Thus, its recognition is improbable until access to the pulp chamber has been achieved. Radiographic recognition may be of particular importance for prosthodontists, especially in cases in which a cast post involving the root canal is planned (25).

Preoperative radiographs show close fused roots or images of two distinct roots. This occurs when the fin is thin and thus, not visible on the radiograph, and makes clinical recognition of the C-shaped canal unlikely until access to the pulp chamber has been achieved (9, 18).

Radiographic interpretation is overall more effective when based on film combinations ("preoperative and working length radiographs" or "preoperative and final radiographs" or "all three radiographs") than on single radiographs. Among the latter, working length radiographs are more helpful than the preoperative and final ones, whereas preoperative radiographs are the least effective in diagnosing the C-shaped cases (25).

It should be noted that using a radiograph showing files set to the canal terminus to diagnose and to determine canal morphology may not give the results expected. In some instances, it may be difficult to distinguish between C-shaped canal or one with single or three canals joining apically. Thus, it is necessary to confirm the diagnosis by exploring the access cavity (16, 34).

Clinical Diagnosis

Clinical recognition of C-shaped canals is based on definite observable criteria (i.e., the anatomy of the floor of the pulp chamber and the persistence of hemorrhage or pain when separate canal orifices were found) (25).

The pulp chamber in teeth with C-shaped canals may be large in the occlusoapical dimension with a low bifurcation. Alternatively, the canal can be calcified, disguising its C-shape. At the outset, several orifices may be probed that link up on further instrumentation (7). In a true C-shaped canal, it is possible to pass an instrument from mesial to distal aspect without obstruction. In other configurations, such passage is impeded by discontinuous dentine bridges (14). If a file could not be passed through the isthmus of the pulpal floor during clinical inspection, the practitioner might consider the root canal as being separated. But in the laboratory analysis, these canals might merge just below the isthmus area (35).

Fused roots and C-shaped roots may present with narrow root grooves that predispose to localized periodontal disease, which may in fact be the first diagnostic indication of such anatomic variance. It is equally probable that the groove will occur on the buccal or lingual surface (14, 18). When a deep groove is present on lingual or buccal surfaces of the root, a C-shaped canal is to be expected (10).

Clinically, when a C-shaped canal orifice is observed 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 (10). It is possible to overlook the fact that the canal may be connected in the coronal portion yet separated in the apical region. When the canal orifice looks continuously connected at the subpulpal level, a separate root canal exiting at the apical level should be suspected (35).

Management

Central to successful endodontics is knowledge, respect, and appreciation for root canal anatomy and careful, thoughtful, meticulously performed cleaning and shaping procedures. "C" configuration is known to present a complex canal anatomy; its irregular areas house soft-tissue remnants or infected debris that may escape thorough cleaning or filling procedures, thus requiring supplementary effort to accomplish a successful root canal treatment. This has provoked many modified techniques to manage such cases endodontically (46, 47). Challenges range from diagnosis to endodontic instrumentation, obturation, and post space preparation (2).

Preoperative Diagnosis

Clues about preoperative canal anatomy cannot be ascertained from the clinical crown morphology, but limited information can be derived from the radiographic examination. Apically tapering roots and roots that appear to be continuous or square at the apex are likely candidates. The dentin isthmus that connects the mesial and distal roots may be too thin to be radiographically evident. Therefore, the radiographic appearance of two distinct roots does not preclude the existence of a C-shaped root (2). It should be noted that bilateral occurrence is possible so the review of dental history is important (17).

Also, Barril et al. (9) emphasized on the importance of preoperative radiographs and noted that some C-shaped canals are difficult to interpret because of the thickness of bone trabeculae. C-shaped canal must be suspected when the roots are fused or very close to each other.

Canal-System Identification and Preparation

The access cavity for teeth with a C-shaped root canal system varies considerably and depends on the pulp morphology of the specific tooth (8). Initial canal-system recognition occurs after achievement of routine endodontic access and removal of tissue from the pulp chamber (2). If a C-shaped root is present, two of Melton's three categories (category I and II) should be evident (in category III, two or three separate canals may appear initially as a typical three-canal orifice mandibular molar) (14).

Some equipment can aid in this procedure. Fiberoptic transillumination can enhance variant canal anatomy identification. Placing the fiberoptic tip under the rubber dam on the buccal surface illuminates the pulp chamber. The canal system appears as a dark line or area in an illuminated field (2). Also, the increased visibility afforded with the use of surgical operating microscopes has made treatment more successful (8, 20).

The necessity for deep-orifice preparation and careful probing with small files characterize the C-shaped category more accurately. In all categories, the mesiobuccal and distal canal spaces usually can be prepared normally. However, the isthmus should not be prepared with larger than no. 25 files; otherwise, strip perforation is likely. Also, Gates-Glidden burs should not be used to prepare the mesiobuccal and buccal isthmus areas. Extravagant use of small files and 5.25% NaOCl is a key to thorough debridement of narrow canal isthmuses (2).

Alternative canal cleaning techniques, such as those that use ultrasonics, would be more effective. An increased volume of irrigant and deeper penetration with small instruments using sonics or ultrasonics may allow for more cleansibility in fan-shaped areas of the C-shaped canal (14). Although ultrasonic preparation may effectively remove tissues from narrow C-shaped canal ramifications, aggressive instrumentation may cause perforation (2).

The orifice portions of the slit must be widened considerably early in treatment but not too deeply toward the apex lest a perforation occur. Because of the large area of canal space, it is doubtful that intracanal instruments can reach and debride the entire portion of the continuum, making the irrigation procedures more significant (32).

The ribbon canal space is frequently eccentric to the lingual side of the C-shaped radicular dentin. An anticurvature filing method in the coronal third of the canal is needed to prevent perforation. If dentin filing is directed buccaly, perforation will likely be avoided (2).

It should be emphasized that in C-shaped mandibular molars, the mesiolingual canal is separate and distinct from the apex, although it may be significantly shorter than the mesiobuccal and distal canals. These canals are easily overinstrumented in C-shaped molars with a single apex. In these molars, the mesiobuccal canal swings back and merges with the distal canal, and these exit onto the root surface through a single foramen. A few of these molars with C-shaped orifices have mesiobuccal and distal canals that do not merge but have separate portals of exit (8).

Canal-System Obturation

Obturation of C-shaped canals may require technique modifications. The mesiolingual and distal canal spaces can be prepared and obturated as standard canals. However, sealing the buccal isthmus is difficult if lateral condensation is the only method used. Because this isthmus may not be prepared with a sufficient flare to permit deep placement of the spreader, application of thermoplasticized gutta-percha is more appropriate. Gutta-percha can be thermoplasticized with spreaders heated in an open flame or electric spreaders or delivered by injectable systems. Single-insertion thermoplasticized gutta-percha condensation devices may not condense gutta-percha adequately into the long narrow isthmuses. In addition, proper placement of sealer with ultrasonic endodontic files is critical, regardless of the choice of obturation technique (2, 8, 48).

Considering the ease and speed of lateral compaction as well as the superior density gained by vertical compaction of warm gutta-percha, Martin (49) developed a device Called EndoTec II (Medidenta, Inc., Woodside, NY) that appears to achieve the best qualities of both techniques. In 1993, an Army group (47) found they could measurably improve compaction while obturating a mandibular molar with a C-shaped canal by using the EndoTec in what they termed a "zap and tap" maneuver: preheating the EndoTec plugger for 4 to 5 seconds before insertion (zap) and then moving the hot instrument in and out in short continuous strokes (taps) 10 to 15 times. The plugger was removed while still hot, followed by a "cold spreader with insertion of additional accessory points."

The compaction of softened gutta-percha and sealer throughout a well-prepared canal space should be predictably move gutta-percha and sealer into root canal aberration. But in C-shaped canals, conditions are different for two reasons: (1) divergent areas that are frequently unshaped and may offer resistance to obturating material flow and (2) communications between the main canals of the C-shape, through which the entrapped filling materials that should be captured between the apical tug-back area and the level of condensation may pass from one canal to another. In 2000, Walid (46) described the use of two pluggers simultaneously to down pack the main canals in a C-shaped canal. In this case, the pulp floor showed a C-shaped orifice from the distal to mesiolingual canals and a separate mesiobuccal orifice. Two fine-medium cones were selected for distal and mesiolingual canals, and no accessory cones were placed in the fin between them, whereas a medium point was fitted in the mesiobuccal canal. Three pluggers were selected for obturation. A Touch'N Heat (Sybron Endo/Analytic, Irvine, CA) was used to sear off gutta-percha at the mesiolingual orifice level where the largest plugger selected was placed while down packing the distal canal with the smallest plugger. Then, the smallest plugger used in the distal canal was held in place while packing the mesiolingual canal. Placing two master points and blocking the canal entrance with a plugger increases the resistance toward the passage of obturating material from one canal to another.

Endodontic Surgery

The clinician must be aware of the impact this anatomy has when surgical endodontics is indicated. The absence of furca contraindicates hemisection or root amputation. The intercanal communications or fins visualized on the serial sections reinforce the difficulty the clinician would encounter after apicoectomy with the retropreparation and eventual retrofilling. If endodontic surgical intervention is indicated for a molar with C-shaped root canal anatomy, strong considerations should be given to extraction, retrofilling, and intentional replantation (7).

Restoration and Prognosis

Technique modification may be required for restoration of C-shaped roots. If post placement for a crown core is desired, use of only the distal canal should be considered. Proper post-canal adaptation and stress distribution is more likely to result in the tubular distal canal. Placement of posts or antirotational pins in the mesiolingual and mesiobuccal areas of C-shaped root invites perforation. Also, post width should be minimized (2). It should be remembered that there is a higher risk of root perforation at the thinner lingual walls of C-shaped canals during shaping and post space preparation procedures. Both buccal and lingual canal walls are frequently narrower at mesial locations (36).

During follow-up radiographic examination, the dentist should look for furcal breakdown because that region is the most difficult to obturate and is associated with the greatest risk of perforation. Restorations with failure in the furca have a poor prognosis. If the failure results from an apical etiology and apical surgery is not possible, viable options include extraction, extraoral retrofilling, and replantation. Because C-shaped roots generally are conical, they are easy to extract without fracture (2).

When sound principles of biomechanical preparation, obturation, and restoration are followed, the long-term prognosis for the C-shaped root retention equals that of other molars, but cautious optimism would seem most appropriate when prognosticating the success of the root canal treatment of a C-shaped canal (2, 14, 40).

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