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Clinical aspects of C-shaped canals in maxillary and mandibular second molars: a case report series and literature review*

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ABSTRACT

Introduction: The success of root canal treatment depends on the proper cleaning, shaping, and obturation of the root canal system, along with an adequate understanding of root canal morphology. One of the most important anatomical variations in maxillary and mandibular second molars is the C-shaped root canal system. The purpose of this study was to describe cases of upper and lower second molars with C-shaped canals, their treatment course, and their configurations according to a new classification using cone-beam computed tomography (CBCT) scans.

Materials and methods: Ten teeth with C-shaped canals in 4 female patients were analyzed using CBCT scans. After instrumentation with an ultrasonic tip BUC #1 and ProTaper Next rotary files using the circumferential brushing technique, 5.25% NaOCl was agitated with passive ultrasonic irrigation. The C-shaped canals were filled using thermoplastic techniques with gutta-percha and AH Plus sealer.

Results: All reported cases with C-shaped canals were bilateral. In mandibular second molars, the C1 configuration was more common at the coronal level, C1 and C2 were more frequent in the middle, and C3 and C4 were equally prevalent at the apical level. In maxillary second molars, C1 and C3 configurations were equally prevalent in the coronal and middle regions, with C4 more common in the apical section. Types I and VI root fusion were observed in upper second molars. Clinical and radiographic follow-up examinations revealed asymptomatic teeth with no pathological signs or symptoms. All presented cases were successfully treated.

Conclusions: In the endodontic treatment of C-shaped canals, dental practitioners should utilize CBCT examination, an operating microscope, and ultrasonic tips to effectively clean and agitate the irrigants.

Keywords: C-shaped canal; cone-beam computed tomography; mandibular second molar; maxillary second molar; root and canal morphology.

INTRODUCTION

The success of root canal treatment (RCT) depends on proper preparation, disinfection, and obturation of the root canal system, along with adequate knowledge of root canal morphology. Clinicians must be familiar with potential anatomical variations in the pulp cavity to prevent complications during cleaning and shaping in RCT [1, 2, 3, 4]. One of the most important anatomical variations in maxillary and mandibular second molars (ManSMs) is the C-shaped root canal system. Cooke and Cox were the first to document clinical cases of this anatomical variation [5]. A C-shaped canal was defined by the American Association of Endodontists in the "Glossary of Endodontic Terms" as a pulp canal anatomy with a cross-sectional shape resembling the letter "C". This configuration is commonly found in ManSM teeth, where mesiobuccal (MB) and distal canals communicate due to the fusion of mesial and distal roots [6].

Several theories have been proposed to explain the formation of the C-shaped canal configuration. The literature offers various explanations, such as: incomplete fusion of the Hertwig epithelial sheath, deposition of cementum over time, genetic variations (especially among individuals of Asian descent), and root fusion as an adaptation to a smaller jaw [7, 8, 9]. A recently published study also confirmed a correlation between taurodontism and complex C-shaped canal configurations [10].

According to a systematic review with meta-analysis of anatomical studies using cone-beam computed tomography (CBCT), the prevalence of C-shaped canal morphology in mandibular first and second molars was 0.3% and 12%, respectively [7]. Different frequencies were observed in maxillary first and second molars, with prevalence rates of 1.1% and 3.4%, respectively. C-shaped canal morphology has a low prevalence in mandibular first and second premolars or third molars of the upper and lower arches [9, 11].

To better understand C-shaped canal anatomy, numerous classifications of these configurations have been proposed [12, 13, 14, 15, 16, 17, 18, 19, 20, 21]. Melton et al. developed the first classification of C-shaped canals [16]. Using a light microscope and stereomicroscope, they examined 3 levels of the root to observe changes in shape. Their classification divides C-shaped canals into 3 categories: I – a continuous C-shaped canal running from the pulp chamber to the apex; II – a semicolon-shaped orifice where dentin separates the main C-shaped canal from a buccal or lingual canal; III – 2 or more separate canals. Fan et al. later modified this classification [13, 14, 19]. Based on their investigation of the anatomical and radiographic features of C-shaped

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canal systems in ManSMs, they described 3 radiographic types and 5 anatomical categories. These anatomical categories were defined as: C1 – a continuous "C" with no separation; C2 – a semicolon shape due to a discontinuity in the "C"; C3 – 2 or 3 separate round, oval, or flat canals; C4 – 1 round, oval, or flat canal in cross-section; and C5 – no canal lumen. Radiographically, the canal images were classified into 3 types: I – merging type; II – symmetrical type; and III – asymmetrical type.

In 2016, Martins et al. proposed the upper-C (UC) configuration system as a modification for upper molars based on Fan et al.'s research on mandibular molars [21]. They classified UC into 5 types: A – fusion of the MB and palatal (P) roots, forming a semilunar mesiopalatal root canal; B – fusion of the MB and distobuccal (DB) root canals, forming a semilunar buccal root canal system, with subtype B1 (the semilunar shape turned toward the P root) and subtype B2 (the semilunar shape turned toward the buccal root); C – fusion of the DB and P roots, forming a large semilunar distopalatal root canal; D – a large P root canal in a semilunar shape (formerly described as a fusion between 2 P roots); E – fusion of all 3 roots, with subtype E1 (a large semilunar mesiopalatal canal merging with an independent DB canal with a single apical foramen) and subtype E2 (a large semilunar distopalatal canal connecting with the MB canal at a single apical foramen).

Anatomic variations in root fusion in teeth with C-shaped canals have been previously reported in the literature [15, 17]. According to Zhang et al., the shape of the root fusion was classified into 6 types: I – MB and DB root fusion; II – MB and P root fusion; III – DB and P root fusion; IV – MB and DB root fusion with P fused to either MB or DB; V – fusion of all 3 roots; and VI – MB, DB, and P roots fused into a single cone-shaped root [15]. A recent study by Ahmed and Dummer introduced a new coding system for classifying tooth, root, and canal anomalies, which can be used in research, clinical practice, and training [8]. This system also includes descriptions of C-shaped canal configurations.

Many of the studies mentioned above [8, 15, 17, 21] used CBCT, a popular diagnostic tool in endodontics. Cone-beam computed tomography, along with a dental operating microscope, provides 3-dimensional images of teeth, offering better visualization. Ultrasonic tips and thermoplastic obturation techniques are essential tools for treating C-shaped canals.

The purpose of this study was to describe cases of maxillary and mandibular teeth with C-shaped root canal systems, their treatment, and their configurations according to a new classification for upper and lower second molars based on CBCT scans.

MATERIALS AND METHODS

Case report series

Patients diagnosed with C-shaped canal system configurations were referred to an endodontic office. All patients arrived with a previously completed CBCT examination. At the first appointment, written consent for RCT was obtained, and endodontic treatment was initiated. The patients' medical histories were not relevant to the treatment. During the radiological examination, the diagnosis of C-shaped second molar anatomy was confirmed. In ManSMs, CBCT axial images revealed a C-shaped root canal as a fusion of the mesial and distal roots. Additionally, a radicular lingual groove (Fig. 1) was observed in the cervical third of the root in cases 3 and 4, and in all ManSMs in the middle third section. Interestingly, in case 4, all second maxillary and mandibular molars showed similar root configurations, with mesial and distal root fusion in the lower jaw and P and buccal root fusion in the upper jaw. In case 1, the CBCT axial image of previously endodontically treated maxillary second molars (MaxSMs) revealed a C-shaped canal morphology with MB and DB root fusion. All examined cases showed bilateral C-shaped canals.

Teeth diagnosed with irreversible pulpitis (cases 2–4) were symptomatic. Clinical examination revealed pathological reactions to electrical and thermal stimuli, physiological mobility, and no pain on percussion. In case 1, the patient, who was referred for retreatment due to apical periodontitis (AP), was asymptomatic, showing no response to electrical or thermal stimuli, no pain on percussion, physiological mobility, and improper obturation with periapical radiolucency. During the radiological examination, cross-sectional C-shaped second molars at various root levels were observed.

In all second upper and lower molars, C-shaped canal configurations were classified according to Fan et al.'s [13, 14] criteria, evaluating the cervical, middle, and apical thirds. For maxillary molars, Zhang et al.'s [15] classification was also used. Additionally, all evaluated teeth were classified according to Ahmed and Dummer's new classification [8].

Following anesthesia with 4% articaine hydrochloride with adrenaline 1 : 100,000 (Citocartin 100, Molteni Stoma, Italy), proper isolation and endodontic access were prepared. The pulp cavity and canal orifices were prepared using an ultrasonic tip BUC #1 (Obtura Spartan, USA) and MUNCE Discovery Burs (CJM Engineering Technologies, USA). The pulp chamber was irrigated with 5.25% sodium hypochlorite (NaOCl), dried with cotton pellets, and inspected under a dental operating microscope.

In retreatment cases, gutta-percha was softened with Orange Guttane solvent (Cerkamed, Poland), and an ultrasonic tip Endo-Chuc with a U-file was used to remove the obturation material. After determining the working length with an apex locator and measuring the length on CBCT scans, canals were scouted with hand stainless-steel C+ Files (Dentsply Sirona, Switzerland). In all cases, canals were prepared with ProTaper Next rotary files (Dentsply Sirona, Switzerland) using a circumferential brushing technique. During treatment, 5.25% NaOCl agitation with passive ultrasonic irrigation (PUI) was applied. Calcium hydroxide was used as a disinfectant dressing for 1 week.

At the next visit, patients were sign- and symptom-free. To remove the calcium hydroxide, the ultrasonic tip EDDY (VDW, Germany) was activated. Final irrigation was performed with 17% EDTA Endo-solution (Cerkamed, Poland) and 5.25% NaOCl with ultrasonic activation. For obturation, gutta-percha points were fitted, and C-shaped canals were filled using the continuous wave of condensation (CWC) method with AH Plus as a sealer (Dentsply Sirona, Switzerland). The canal orifices and pulp chamber floor were sealed with a flow composite material, and the cavity was closed with a temporary filling. A control X-ray was taken, and the patients were referred for final restoration.

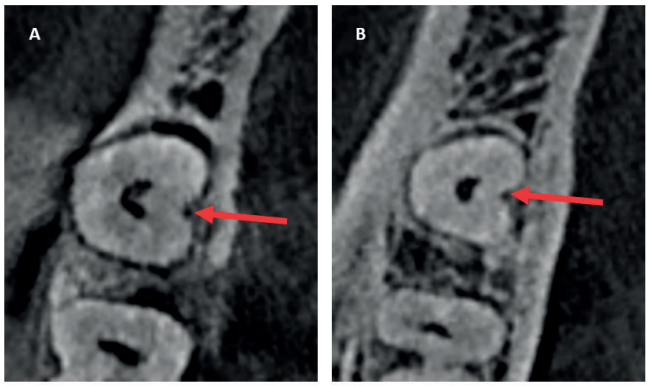

FIGURE 1. Lingual radicular groove (red arrow)

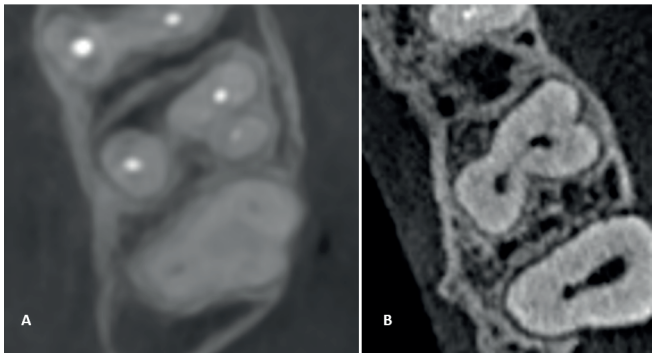

FIGURE 3. Examples of the shape of the root fusion according to Zhang et al. [15]: A – type I; B – type IV

RESULTS

The evaluation of patients and their C-shaped MaxSMs is shown in Table 1 and Figures 2 and 3. The evaluation of patients and their C-shaped ManSMs is presented in Table 2 and Figures 1 and 4. Postoperative radiographs demonstrated properly obturated C-shaped canal systems and isthmuses. During clinical and radiographic follow-up examinations, all patients presented with asymptomatic teeth and no pathological signs or symptoms. The cases presented were successfully treated.

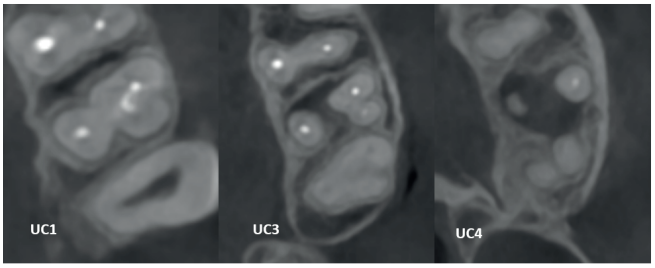

FIGURE 2. According to Martins et al.'s [21] configuration, an example of subtype B2 involves fusion between the mesiobuccal and distobuccal root canals, with the semilunar shape turned towards the buccal roots (UC1, UC2). Examples of different types of maxillary C-shaped configurations include: UC1 – continuous C-shaped canal system; UC3 – 2 separated root canals; and UC4 – single round root canal

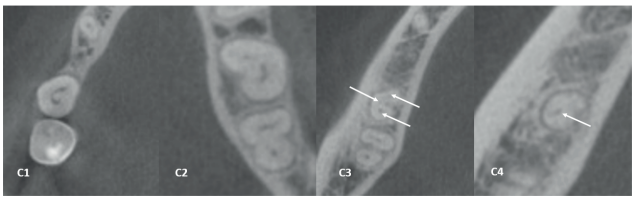

FIGURE 4. Examples of different types of mandibular C-shaped configurations: C1 – continuous C-shaped canal system; C2 – the canal shape resembled a semicolon; C3 – 3 separated root canals (root canal – white arrow); and C4 – single round root canal (white arrow)

DISCUSSION

This case report series presents the unusual anatomy and treatment of ManSMs and the retreatment of MaxSMs with C-shaped canal configurations. Understanding and recognizing morphological variations in roots and root canal systems enhances the success rate of RCT and retreatment. Furthermore, the use of magnification and CBCT simplifies the location, scouting, and shaping of root canals in both upper and lower molars. Cone-beam computed tomography is critical for the success of RCT and retreatment; therefore, when a clinician suspects C-shaped canal morphology, 3D examination is recommended. Considering the limitations of periapical X-rays in endodontic diagnosis due to their low accuracy [22], CBCT

TABLE 1. Evaluation of patients and C-shaped maxillary second molars teeth

Patient	Age	Tooth number	Fan et al.'s [13, 14] classification			Zhang et al.'s [15] classification	Ahmed and Dummer's [8] classification	Diagnosis	Final obturation
			axial root level						
			C	M	A				
1	39	17	UC3	UC3	UC4	type I	$(CsC^{II})^2$ 17 MB/DB*	AP	CWC
1	39	27	UC1	UC1	UC3	type I	$(CsC^{II})^2$ 27 MB/DB	AP	CWC
4	48	17	UC3	UC3	UC4	type VI	$(CsC^{II})^2$ 17 B/P**	healthy	–
4	48	27	UC1	UC1	UC3	type VI	$(CsC^{II})^2$ 27 B/P	healthy	–

C – coronal; M – middle; A – apical; MB – mesiobuccal; DB – distobuccal; B – buccal; P – palatal; AP – apical periodontitis; CWC – continuous wave of condensation
* tooth 17 with 2 fused roots (mesiobuccal/distobuccal), C-shaped canal types II (symmetrical); ** tooth 17 with 2 fused roots (buccal/palatal), C-shaped canal types II (symmetrical)

TABLE 2. Evaluation of patients and C-shaped mandibular second molars teeth

Patient	Age	Tooth number	Fan et al.'s [13, 14] classification			Ahmed and Dummer's [8] classification	Diagnosis	Final obturation
			axial root level					
			C	M	A			
2	37	47	C1	C2	C3	$(CsC^{III})^2$ 47 M/D*	pulpitis	CWC
2	37	37	C2	C3	C3	$(CsC^{III})^2$ 37 M/D	healthy	–
3	35	37	C1	C1	C4	$(CsC^{II})^2$ 37 M/D	pulpitis	CWC
3	35	47	C3	C3	C4	$(CsC^{II})^2$ 47 M/D	AP	–
4	48	47	C1	C1	C4	$(CsC^{I})^2$ 47 M/D**	pulpitis	CWC
4	48	37	C4	C4	C3	$(CsC^{I})^2$ 37 M/D	healthy after RCT	–

C – coronal; M – middle; A – apical; M/D – mesial/distal; AP – apical periodontitis; RCT – root canal treatment; CWC – continuous wave of condensation
* tooth 47 with 2 fused roots (mesial/distal), C-shaped canal types III (unsymmetrical); ** tooth 47 with 2 fused roots (mesial/distal), C-shaped canal types I (merging)

images were used in this and other case reports to detect and analyze the configuration of C-shaped root canals [23, 24, 25, 26, 27, 28, 29, 30, 31, 32].

The correlation between the type of C-shaped canal in ManSMs and gender has also been assessed by researchers. In this study, all the patients were female. Similarly, other studies have shown that the prevalence of C-shaped roots in ManSMs is higher in females than in males [7, 33, 34, 35, 36, 37, 38, 39]. This is consistent with a recent systematic review evaluating the prevalence of C-shaped ManSMs in different regions worldwide based on CBCT scans [40]. However, other studies have reported no significant correlation between gender and the prevalence of C-shaped canals in ManSMs [41, 42, 43, 44, 45, 46, 47]. Interestingly, no significant correlation has been found between gender and C-shaped canal configurations in MaxSMs [7, 17, 47, 48].

The C-shaped canal configuration is more common in mandibular than maxillary molars. In this study, 2 cases of MaxSMs and 3 cases of ManSMs were described. Various studies using CBCT scans have investigated the prevalence of C-shaped root canal systems in ManSMs, with findings depending on ethnic groups and study models [7, 40]. According to cross-sectional studies, the worldwide prevalence of C-shaped canal morphology in ManSMs on CBCT scans ranges 2–44.5%. The highest prevalence has been associated with Asian populations, including: Thailand (42.4%) [34], Korea (40%) [35, 36], China (35.8–44.5%) [33, 45, 49], and Myanmar (22.4%) [50]. Lower prevalence rates have been reported in: Venezuela (19.5%) [51], Iran (2–15.6%) [41, 43, 44], Egypt (12.8%) [46], Saudi Arabia (4.3–9.1%) [38, 42], Brazil (8.5%) [37], Yemen (9%) [52], black South Africans (5.7%) [53], and white populations (5.2%) [54]. In MaxSMs, C-shaped canal anatomy is rare, with the highest prevalence in Argentina (11%) [55], Iraq (7.9%) [47], and Saudi Arabia (5.1%) [56]. The lowest prevalence in MaxSMs has been found in Asia (0.9–5.24%) [17, 57, 58] and Europe (1.9–3.4%) [21, 59]. No C-shaped canals were observed in MaxSMs in Brazilian, Thai, or Burmese subpopulations [50, 60, 61].

In this study, all cases of C-shaped canals in upper and lower teeth were bilateral, as previously reported [17, 29, 33, 35, 36, 38, 45, 47, 54, 55]. The prevalence of symmetrical C-shaped configurations in ManSMs was 80.4–81% in Chinese populations [33, 45], 77–82% in Koreans [35, 36], 64.1% in Iraq [47], 46.2% in Saudi Arabia [38], and 15.6% in a selected Iranian population [43]. In contrast, bilateral C-shaped canal configurations in MaxSMs were less common, with 46.7% in Iraq [47], 24% in Argentina [55], 13% in Saudi Arabia [56], and 1.27% in China [17].

According to Fan et al.'s classification [13, 14, 19], in this study, the C1 configuration was most prevalent at the coronal level in ManSMs, while C1 and C2 were common in the middle level, and C3 and C4 were equally prevalent apically. The predominance of the C1 configuration at the coronal level and the C3 configuration apically aligns with previous studies [13, 35, 43, 44, 45, 62]. However, other studies reported C1 and C4 as the most common configurations apically [63], or C3 in the coronal and middle sections and C4 apically [38]. In contrast, some research showed C2 dominance in the coronal and middle regions, with C3 being most common apically [44]. Brazilian [37] and Turkish [64] populations predominantly showed C1, while Koreans [36] and Iraqis [47] had more C2 configurations in the coronal region. In Saudi populations, C2 and C3 configurations were the most common [42].

Studies investigating radicular grooves in ManSMs with C-shaped configurations have found that the lingual surface is most frequently involved, consistent with this study [38, 45, 49, 64, 65].

In MaxSMs, UC1 and UC3 configurations were equally prevalent in the coronal and middle sections, while UC3 and UC4 were noticed apically. In contrast, UC1 and UC2 were most common at all levels except the apical section in an Argentine subpopulation [55]. Additionally, in a recently published paper, only 10% of MaxSMs had a single root [66]. According to Martins et al.'s classification [7, 11, 20, 21], type B (subtype B2) was diagnosed in all MaxSM cases in this study, whereas other studies reported B1 as the most prevalent, with type C being the least frequent [55]. However, contrasting findings indicated types B and C as more common [48]. Pulp chamber anatomy in previous case reports included B (MB and DB root fusion) [30], C (DB and P root fusion) [31], and D (large P root or fusion of 2 P roots) [31, 32].

In this study, root fusion types I and VI according to Zhang et al., were observed in patients with C-shaped MaxSMs [15]. In the Turkish population, type I was seen in 24.24% of MaxSMs [67]. Previous studies in the Chinese population reported fusion frequencies between 30.37–69.14% [15, 17]. The prevalence of type VI fusion has been noted to range 2.47–20.25% [15, 17, 67]. Differences in sample size, imaging techniques (micro-CT vs. CBCT), and ethnic backgrounds may account for discrepancies in findings.

Considering the complex root canal anatomy of mandibular and MaxSMs, case reports are essential to understanding clinical outcomes in treating C-shaped canal variations. Numerous case reports of lower [23, 24, 25, 26, 27, 28] and upper second molars [29, 30, 31, 32] have been documented. Treatment in these studies, as well as this one, was performed using magnification with an operating microscope.

The complex anatomy of C-shaped canals, with their narrow and irregular isthmuses, can harbor infected pulp tissues, microorganisms, and dentinal debris. In all cases presented, ultrasonic agitation of irrigants was used to enhance root canal disinfection, as in previous studies [23, 26, 31, 68]. A recent systematic review and meta-analysis highlighted discrepancies regarding the effectiveness of irrigant activation. Barbosa et al. concluded that PUI was more effective than non-activated irrigation based on micro-CT studies [69]. However, other reviews reported no clear evidence that additional irrigation methods, including ultrasonic activation, improve long-term RCT outcomes beyond what is achieved with syringe irrigation and instrumentation [70].

In this study, working length was established with an apex locator and confirmed by CBCT measurements, consistent with earlier research [71]. Calcium hydroxide was used as an intracanal medicament for additional disinfection of irregular areas, as in previous studies [23, 24, 25, 26, 27, 28, 31, 72, 73].

The causes of failure in C-shaped RCTs have been debated. Common causes include leaky canals, missed isthmuses, missing canals, overfilling, and iatrogenic errors, which were consistent with case 1 in this study (root canal retreatment) [62]. The final obturation of C-shaped root canals is a challenge. In previously published case reports, cold lateral condensation of gutta-percha [26, 28] and thermoplastic techniques [25, 27, 29, 68] were used. A systematic review of micro-CT studies concluded that thermoplasticized gutta-percha resulted in fewer voids than cold lateral condensation and more effectively filled isthmuses and lateral canals [74].

Clinical implications

Assessment of the root canal system configuration is crucial for dental practitioners. A thorough understanding of the morphological variations in the root canal system significantly enhances the success rate of RCT and retreatment. The C-shaped canal configuration is one of the most challenging anatomical variations in endodontics, highlighting the clinical significance of this case report series. The diagnostic and treatment protocols described in this study provide valuable guidance to help dentists optimize treatment quality and achieve successful outcomes.

CONCLUSIONS

It should be emphasized that managing C-shaped canals presents a significant challenge for dental practitioners. Success in RCT of C-shaped configurations in mandibular and MaxSMs depends on a thorough understanding of the complex root canal system morphology, the operator's skill, and the use of modern technologies and endodontic tools. The cases presented in this report may help dentists better understand the variations in C-shaped root canal morphology in second molars. Cone-beam computed tomography allows clinicians to detect and fully assess these variations in 3 dimensions. When C-shaped canals are suspected, a dental practitioner should use CBCT and an operating microscope to identify atypical anatomy. Ultrasonic tips are essential for cleaning the isthmus and grooves, while ultrasonic agitation of irrigants enhances the removal of necrotic tissue and maximizes root canal disinfection. Thermoplastic obturation techniques are recommended, as they result in fewer voids and more effectively fill C-shaped canals.

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